THESIS

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by

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MOISTURE EFFECTS ON METABOLISM OF NUTRIENTS IN SOILS

ABSTRACT

Carbon and nitrogen mineralization and phosphorus and potassium status were studied during incubation of soil under constant moisture levels between air-dry and water-logging, and also when low moisture levels were raised to field capacity or water-logging and high moisture levels were lowered to field capacity.

The effect of soil moisture level on carbon and nitrogen mineralization at different soil pH levels and on carbon and nitrogen mineralization and phosphorus and potassium status in the presence of added organic matter was studied in incubation tests.

Total nitrogen balances were studied in incubation tests in a soil of different pH, and moisture levels, and with different organic matter and inorganic nitrogen treatments. Total nitrogen balances were also studied in pot tests under rye-grass and rice plants receiving different inorganic nitrogen treatments during growth at different soil moisture levels.

The performance of the rye-grass and rice tops which had been used for the total nitrogen balance studies above was studied and so was the effect of the moisture and nitrogen treatments on the pH of the soil after cropping.

The effect of the height of water of submergence on the performance of whole rice plants and the effect of the length of period of soil storage under "upland" and

water-logged moisture regimes prior to transplanting on the performance of whole rice seedlings, were studied.

The effect of the period of air-dry storage of soils prior to wetting and incubation or cropping on carbon and nitrogen mineralization or on rye-grass performance was studied.

The effect of alternate wetting to different moisture levels during incubation and air-drying on mineral nitrogen, phosphorus and potassium status of soils and the effect of alternating soil moisture between different levels compared with maintaining constant levels on the performance of rye-grass were studied.

DEDICATION

Dedicated to both my wife and mother.

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CHAPTER I

INTRODUCTION AND REVIEW OF LITERATURE

INTRODUCTION

Water is the most abundant compound on earth and is a vital constituent of all living matter. Although its molecule is one of the simplest known, water plays its most vital role in all biological and most of the physical and chemical processes in nature as a result of the unique properties and characteristics of this molecule.

The molecular structure of water is characterised by high dipole moments and hydrogen bonding which account for its physical properties of existing in gaseous liquid and solid states under natural conditions, viscosity, adhesion, cohesion and surface tension, which determine its retention and movement through porous media such as the soil and plant tissues. They also account for its chemical properties of acting as a solvent for organic and inorganic compounds, both by hydrogen bonding and by acting as a medium for the dissociation of electrolytes and the ability of the water molecule to dissociate into a positively charged hydrogen ion and a negatively charged hydroxyl ion by which it takes part in important chemical reactions in nature.

Taking the soil as one of the media in which water plays these physical and chemical roles, soil water is ultimately derived from rainwater, but, depending on the mineral and organic constituents of the soil and their size and spatial disposition, and on the hydrologic and thermodynamic gradients between the ground water, the soil and the atmosphere, only a relatively small proportion of rain water is retained in the soil, the rest seaping or running off into rivers and lakes. The amount of water retained by the soil when different thermodynamic and hydrologic equilibria have been established can be split into three categories, viz. hygroscopic, capillary and gravitational soil water.

The aim of this work is to study the metabolism and chemical behaviour of four major plant nutrients, carbon, nitrogen, phosphorus and potassium in the soil under these categories of soil moisture regime and how these phenomena are reflected in the uptake of the last three nutrients by plants.

REVIEW OF LITERATURE

A large amount of work has been done on various aspects of plant nutrition in relation to the soil moisture content and this review covers the following aspects:-

(A) General.

(B) Soil moisture and soil micro organisms and respiration.

(C) Soil moisture and soil nitrogen.

(D) Soil moisture and soil phosphorus.

(E) Soil moisture and soil potassium.

(F) Soil moisture and other soil nutrients.

(G) Soil moisture and crop yields.

(H) Soil moisture and nutrient uptake by plants.

(A) General

Davy (1813) cited Virgil in the first book of the Georgics as mentioning the improvement of lands by burning to be known to the Romans. From 1880 to 1920 several workers studied the effects of drying, heating or sterilising soil on the solubility of its constituents and on its productivity. Among those who worked on the effects of air- or oven- drying of soils may be mentioned Warrington (1882), Frank (1888), Tacke (1897), Tacke and Immendorf (1898), Whitney and Cameron (1903), King (1905), Hilgard (1906), Rahn (1907), Ritter (1912),

Fischer (1912), Leather (1912), Buddin (1914), King (1914), Kelley and McGeorge (1913), Ehrenberg (1915), Christensen (1917), Beaumont (1919) and Noyes (1919). Their results were not consistent but agreed broadly that not only was drying and heating of soils for better crop production an ancient farming method but that they could still be used to increase the solubility of soil constituents and crop yields.

After 1920 only very few workers studied the effects of soil drying on soil constituents before the second world war, and among those few were Gustafson (1922) and Lebedjantzev (1924) who studied the effects of drying and heating on the solubility of soil constituents and on soil productivity. Like the earlier workers, they both found increases with drying or heating. So did Steenkamp (1928) who, after dehydrating soils concluded that drying was a natural factor in transforming plant nutrients from an unavailable to an available form.

In an attempt to explain these results, Gustafson (1922) and Comber (1922) were both of the opinion that colloidal changes brought about by drying were responsible. Recently Kanehiro and Sherman (1956) and Kanehiro and Chang (1956) reported that drying reduced the exchange capacity of Hawaiian soils.

Puustjarvi (1957) found that soil exchange capacity on drying was increased with some soils and decreased with others. Huddleson (1957) on the other hand found no significant difference in the cation exchange capacity between moist and dry soil samples.

With regard to cycles of wetting and drying soils, Beaumont (1919) found that a single drying of the soil produced as much effect on colloids as did repeated dryings and wettings. Lebedjantzev (1924) found similar results with regard to increasing crop yields while Birch (1958) found them for the magnitude of organic matter decomposition.

(B) Soil moisture and soil micro-organisms and respiration.

As the greater part of the bodies of micro-organisms is made of water, they are more or less dependent on water for reproduction and vital activities, but the amount of water they require in their environments to carry out these processes may vary.

Gorbunov and Tokarev (1946), Bartholomew and Norman (1946), Bartholomew (1947), Fehér (1949), Bartholomew and Norman (1953), Feher and Manninger (1953), Weissenberg (1954) showed that the rate of decomposition of organic matter and the numbers of micro-organisms in the soil

increased with increasing moisture level up to or near the saturation point. Manninger (1957) confirmed this and correlated the R values of Feher (R = water content of soil x temperature) with the microbial numbers, while Douglas and Tedrow (1959) found the rates of decomposition of the organic matter of saturated field soils of the Arctic region to depend entirely on temperature. In incubation, however, like Manninger (1957) they found the rate of decomposition to depend on both temperature and moisture content of the soil.

Although Tchan and Whitehouse (1953) confirmed the increase in the numbers of micro-organisms with increasing moisture levels, they, as did Rovira (1953), found about 65% of the total population of micro-organisms survived the air-drying of soils.

On the other hand, Bhaumik (1948) and Clark (1947) had reported depressed carbon dioxide production by bacteria and actinomycetes with rise in soil moisture and greater microbial populations in drier soils. This was confirmed by Stover (1953) who found the optimum soil moisture to be 15% of the water holding capacity for species of Fusarium and actinomycetes, but he found the optimum for bacteria to be 75% of the water holding capacity.

Frercks and Puffe (1957) and Hesse (1961) reported increased respiration and organic matter decomposition on draining or drying and rewetting saturated or water logged soils, while Rakhno (1960) found the greatest increase in bacterial numbers under sub-zero temperatures to occur at about 30% soil moisture. He however found no increase at 7% soil moisture.

Katznelson and Stevenson (1956) observed no effect on microbial activity as measured by nitrogen uptake by variations of soil moisture content above field capacity. Frercks and Puffe (1957) confirmed this for moor soils of high water retention which expanded on wetting and thus were not as compacted as wetted sandy soils, for which they found microbial activity to decrease with rapid drying. Greenwood (1961), however, found that the respiration in water-saturated soil crumbs was not inhibited except by very low concentrations of oxygen.

Rovira (1953), like Birch (1958), (1959), and (1960), reported increased respiration rates and production of carbon dioxide when dried soils were re-wetted and incubated. He also found that this respiration rate declined with time of incubation as also did Birch (1958) and Koepf (1954). Birch (1958) also found that the amount of carbon dioxide produced on wetting and incubating dry soils increased with the time during which the dried soils were stored before wetting.

Birch (1958) found that a single drying and wetting produced as much carbon dioxide as did several cycles. Although Birch and Friend (1961) reported little carbon dioxide production when they subjected an organic soil to 204 cycles of alternate wetting and drying, Birch (1959) found that alternate wetting and drying, compared with continuously wetted soils, produced more total carbon dioxide. Koepf (1954) obtained similar results.

(C) Soil moisture and soil nitrogen.

From the above review, it is obvious that soil moisture variations exert considerable control on microbial population and activities. It is also known that the transformations of nitrogen which occur in the nitrogen cycle depend to a large extent on the activities of soil micro-organisms. Thus in this way the soil moisture more or less indirectly affects the transformations of nitrogen. Moisture, also, by affecting the configuration of the colloidal minerals may, in its varying content in the soil, promote or inhibit the trapping of ammonium ions between the lattices of the clay mineral crystals.

Burt and Leather (1909) and Leather (1911), working on nitrogen balances under tropical conditions, observed that nitrogen mineralisation increased with high temperatures but decreased during the dry season due to lack of soil moisture. Jewitt (1945) and (1950) and Griffith and Manning (1950) confirmed the depressive effects of desiccation of the soil during the dry season on the mineralisation of nitrogen and observed complete interruption of mineralisation in dry bare soils. Prescott (1920) had earlier stated that since drought brought about an accumulation of electrolytes and a rise in the soil pH to unfavourable levels, pronounced wet and dry seasons produced the same effects as seasonal irrigation in Egyptian soils.

Utagawa and Kuraishi (1935), reported a 20% decrease in available soil nitrogen in air-dried fields while Aderikhin (1938), stating that drying reduced the mobility of soil ions, concluded that air-dried soil samples did not represent the true condition of the soil in the field because he obtained the maximum nitrate content in chernozem and podzol soils at 60% of their water holding capacity.

Chu and Hance (1939) showed that air- or oven-drying even for short periods, changed the available nitrogen of many soils. Mathews (1942) concluded that

prolonged dry weather might cause nitrates to accumulate near the surface of the soil, whence it might be lost through erosion by the wind or runoff. High concentration of nitrates in the top layers of arid soils had been observed by Hilgard (1906), Headden (1910) and (1911), who thought this accumulation of nitrates to be due to higher rates of mineralisation in arid soils than in humid soils. They had not taken into account the leaching which normally occurred in humid soils and so their conclusions were soon disproved by Stewart (1913a) and (1913b), Stewart and Peterson (1915), and (1916) and Lipman et al. (1916) who showed that nitrogen mineralisation was in fact, higher under humid conditions, but because of leaching under humid conditions the nitrate contents of arid soils were relatively higher.

This was followed by numerous studies which showed that nitrogen mineralisation occurred under both arid and humid regions, but the rate was lower under arid conditions. Among those who did these studies were Swanson and Latshaw (1919), Sievers and Holtz (1922), (1923) and (1924), Gainey et al. (1929), Jenny (1930), (1933) and (1941), Miller et al. (1932), Prescott (1934), Salter and Green (1933), Caldwell et al. (1939), Newton et al. (1939a), (1939b) and (1945), Kardos (1948), Ching-Kwei-Lee and Bray (1949) and Cornish (1949).

More recently Calder (1954), Simpson (1960) and Robinson (1960) also observed the accumulation of nitrates in top soils during dry periods.

On the other hand Shiori and Aomine (1940) found that air-dried soils were enriched with ammonia-nitrogen and Robinson (1960) reported rapid build up of ammonia during long dry spells.

Makfalvi (1938) calcaluting nitrogen values from the results obtained from the invertase content of plants grown by the Mitscherlich's technique found no regular relationship between soil drying and the nitrogen content.

The differences in the apparent accumulation of mineral nitrogen under dry and moist conditions have been shown above, but other workers have studied relationships between soil moisture content and the rate of nitrogen mineralisation.

Reitemeier (1946) found that ammonium-nitrogen, among many other ions, increased with increasing soil moisture, while Hardy (1946) reported fluctuations in soil mineral nitrogen with fluctuations in soil moisture content., Baumann and Schendel (1952), stated that medium soil moisture and high soil temperatures favoured nitrate production and observed maximum soil nitrate content in spring and autumn. Rape (1952-53), from Sweden, reported

however, maximum nitrifying power of the soil to occur in mid-winter and mid-summer and found that soil nitrate content was negatively correlated with soil moisture and rainfall during the months preceding August.

Calder (1957) found that nitrate accumulation was fairly similar over the moisture range from the permanent wilting point to just under water logging but was optimum at about field capacity. Hagenzieker (1957) in Tanganyika, observed a rapid increase in mineral nitrogen on bare soils after the first rains; this nitrogen was maintained at a high level till the field capacity was attained and then decreased to the original dry season levels.

Wahhab et al.(1960), on the other hand, found the optimum moisture level for nitrification of urea nitrogen to be 33% of the soil water holding capacity while Metwally and Pollard (1959) and Synghal (1959) found that the total soil nitrate increased with increasing soil moisture, as did Novogrudsky (1947), Rotini and Lotti (1960) and Justice (1961).

Wahhab et al (1957a) had found the same relationship between nitrification of added ammonia and soil moisture and obtained 76% nitrification even at 4% moisture cohtent, but Selim et al.(1957) reporting increases in mineral nitrogen with irrigation in Egypt

showed that nitrates predominated over ammonia above soil moisture content of about 11%.

Jones, (1957) and (1958) on the other hand, found nitrification and accumulation of nitrate to increase during both dry and wet periods, but he later reported the organic nitrogen to decrease in dry and increase in the wet season. Doneen (1942) had observed that the nitrate content under sugar beet was independent of frequent soil moisture additions.

The study of nitrogen transformations in water logged soils has attracted much attention. Cyplenkin and Schilin (1936), Michniewicz (1951), reported slower nitrification in water logged soils than in well-drained soils. This had already been established by Schloesing and Muntz (1877-1878), Deherain (1902), Traaen (1916), Stevens and Withers (1910), who reported uninterrupted ammonification and in some cases even nitrification in soils at or near water logging. Pikovs'kaya (1940), and Amer and Bartholomew (1951), in supporting this finding stressed the strictly aerobic conditions required for nitrification. Jones (1932), was of the opinion that the mineralisation of nitrogen, be it ammonification or nitrification, depended entirely on the oxygen pressure, as opposed to Utagawa and Kuraishi (1935) who used Neubauer seedlings to show that available nitrogen

increased by 20% in water-logged soils. Under rice, Bamji (1938) found the rate of ammonia production higher than that of crop uptake but Reed and Sturgis (1937) and (1939) found complete exhaustion of all forms of mineral nitrogen and a marked response of the rice to nitrogen fertilization.

Several workers, including Gerretsen (1921), Kapp (1933) Sreenivasan and Subrahmaryan (1934) and (1935), Bamji (1938) and Bhuijan (1949), while observing continued ammonification with flooding, reported that nitrifying organisms were not destroyed, since nitrification in rice soils started again on draining the soil. This has been supported by Wallihan (1938), Chuen and Shiao (1948), Adachi (1942), and Hesse (1961). Harmsen (1932) and (1955), in the reclamation of Zuiderzee, reported increases in rates of ammonification after the enclosure and drainage of the original sea bed in which microflora had been few and ammonification rate very slow.

It has been shown by many workers that nitrogen added to soils may be lost under various moisture levels and through various mechanisms. The loss of added or native nitrogen by volatilisation of NH_3 has been studied by several workers. In rice fields under water-logged conditions, Sreenivasan and Subrahmanyan (1934) and (1935) found nitrogen losses by volatilisation as ammonia

and Wagner and Smith (1960), McGarity (1961), Wahhab et al. (1960) Vanstallen (1960), and Volk (1959) and (1961) found the amount of ammonia volatilised from added ammonium compounds and urea to increase with increasing soil moisture.

Volatilisation of added ammonium nitrogen has, however, been obtained with decreasing soil moisture by Trickey and Smith (1955), Stojanovic and Broadbent (1960), Ernst and Massey (1960) and Meyer et al. (1961). Wahhab et al. (1957) found the volatilisation of ammonia to increase with the soil moisture content up to 25% of the water holding capacity and then to decrease with further increases in moisture. They found the losses of ammonia during air-drying to increase directly with the soil moisture level to which the soil was raised after the addition of the ammonium compound. Wahhab and Uddin (1955) and Mitra and Singh (1958) observed volatilisation in dry soils in the presence of light.

Denitrification, or loss of gaseous nitrogen or its oxides when nitrates are added to water-logged soils, has been reported by several workers, Kapp (1933) Aoki (1939) and (1940), Arnold (1954), Wijler and Delwiche (1954), Kluyver and Verhoeven (1954), Verhoeven et al. (1954) Hauck and Melsted (1956), Nommik (1956), Yamane (1957), Abichandani and Patnaik (1958), Schwartzbeck (1959),

Schwartzbeck and MacGregor (1961), Carter and Allison (1960), and Bremner and Shaw (1958).

De and Sarkar (1936), observed losses of added nitrates from water-logged soils but attributed them to assimilation by micro-organisms.

McGarity et al. (1958), showed that denitrification occurred even in well-aerated soils where, due to textural conditions local anaerobiosis might occur, while Madhok and Fasal-Uddin (1945), had observed nitrous fumes evolved on drying soils with pH greater than 7 containing added nitrite and they ascribed this to some catalytic action of the soil.

On the other hand, Nommik (1956), and Allison et al. (1960), Bremner and Shaw (1958), and Kresge and Satchell (1961) found negligible or no losses of nitrogen when the soil moisture was about or below field capacity.

Loewenstein et al (1957), obtained heavy losses of added ammonia nitrogen in bare soils but only little losses in oat cropped soils held at about field capacity. This had been forecast for rice soils by Dennett (1936), confirmed by Davis and Owen (1954), and contradicted by Greenland (1958), in Ghana fields and Gerretsen and de Hoop (1957), in lysimeters and pot cultures.

In a number of nitrogen balance sheets prepared by several workers for well-drained and aerated lysimeters, Bizzell (1943) and (1944), Collison et al. (1933), Jacobson et al, (1948), Morgan and Jacobson (1942), Morgan et al. (1942a) and (1942b) Chapman et al. (1949), Broadbent and Chapman (1950) obtained significant negative balances and ascribed them to nitrogen volatilization. This showed the possibility of nitrogen losses even in normal well aerated soils under crops.

Similar results have been obtained in the field where estimates of nitrogen losses have been done on soils with very little leaching, by Prince et al. (1941), Lipman et al. (1928), Salter and Green (1933), Allison and Sterling (1949), Sievers and Holtz (1922), Wheeting (1937), and Greaves (1941). In green house experiments negative balances were reported by Mann and Barnes (1951), Pinck et al. (1948a) and (1948b), while Roschach (1957) obtained negative balances only with heavy applications of nitrogen.

Several workers have contended that in spite of possible losses of nitrogen in water-logged rice fields due to volatilisation, denitrification and crop uptake, there was a tendency for the soil total nitrogen to be maintained at about the same value even after prolonged cropping. Rao and Dhar (1931a), (1931b) and (1934) postulated an active photochemical fixation of atmospheric

nitrogen in Indian rice fields, while others like, Allison and Morris (1930), Singh (1939) and (1942) Bhaskaran and Pillai (1942), Kamen and Gest (1949), and Nishigaki and Shiroiri (1959), considered various algae responsible for fixing the atmospheric nitrogen in flooded soils. The latter view has been rejected by Stokes (1940), Fogg(1942), and Willis and Green (1949).

Among those who have considered nitrogen-fixing bacteria as the agents of nitrogen fixation in rice soils are Sen (1929), De and Pain (1936), Uppal et al. (1939), and Chaudhuri (1940), confirmed and clarified by Starkey and De (1939), Starkey (1939), Deix (1950a) and (1950b) and (1951). Voinova-Raikova (1954), and McKnight (1947), who isolated Azotobacter from soils of tropical and temperatre regions which actively fix nitrogen.

It has been only recently that the ability of soils to absorb ammonium against extraction by various reagents or crops has received any attention. Harada and Kutsuna (1954) reported fixation of ammonium by dry and moist soils, the ammonium fixed by moist soils being more easily extracted by normal salt solutions or acids. They further observed that the capacity of the soil to fix ammonium, while increasing with drying, was lost at a drying temperature of 200°C.

This was confirmed by Chiba and Kamei (1955) and had been earlier observed by Aomine (1951), Allison et al. (1951), (1953a) and (1953b), who, however, did not notice any loss of fixing ability at high temperatures. They stated that only a fraction of the fixed ammonium was available for nitrification or plant uptake contrary to the results of Welch and Scott (1960) working with vermiculite, and Stojanovic and Broadbent (1960), who showed that air-dry or oven-dry fixed ammonium was more easily released than moist fixed ammonium.

Ammonium fixation has also been reported by Walsh and Murdock (1960) and Stojanovic (1956). Allison et al. (1953a), found that the extent of ammonium fixation was related to type of clay mineral according to whether dry or moist fixation was used. Mortland (1955), explained the absorption of ammonium by absorbents by the Van der Waal's type of bondage in association with oxygen atoms in a hydrogen-bond similar to that of adsorbed water. He stated that the initial process of ammonium adsorption was an irreversible chemisorption, but Axley and Legg (1960) reported the combination of organic compounds with ammonium at 110°C. They observed that the ammonium fixing capacity of soil did not affect the plant uptake from applied ammonium sulphate or urea except in the presence of large amount of potassium which blocked the release of fixed ammonium.

Kapp (1934) advocated drying of the soil and the addition of carbonaceous material to keep up the supply of available nitrogen which was insufficient in rice soils. Acharya and Jain (1955) found no difference in the ammonifying or nitrogen-fixing power of dry soils stored anaerobically or aerobically, but the nitrification of added ammonia was slower whilst that of native organic nitrogen was quicker on wetting the soil after anaerobic than after aerobic storage.

Cooke and Cunningham (1958), Birch (1958), (1959) (1960), and Gasser (1961) found that air-drying markedly increased the rate of mineralisation of nitrogen on subsequent wetting and incubation of soils, while Harpstead and Brage (1958) reported the same results only when the soils had been stored dry for more than three weeks.

Birch (1958), (1959) and (1960) and Gasser (1961) reported increases in the mineral nitrogen during incubation of soils with increase in the length of the period the soils were stored dry before wetting and incubation.

Birch (1958) found no difference in the mineral nitrogen produced by soils subjected to a single drying and wetting as compared with those subjected to a number of cycles, while Birch and Friend (1961) reported little mineralisation of the organic nitrogen of an organic soil which was subjected to 204 cycles of alternate wetting and drying.

(D) Soil moisture and soil phosphorus.

Nearly all the studies done on native and added phosphorus in relation to soil moisture indicate that phosphate transformations under various soil moisture regimes are mainly by chemical and physico-chemical processes, soil microbial activity being of little importance.

Dunnewald (1935) and Trumble (1947) reported the fixation of phosphorus to increase with the drying of the soils. Earlier, Rydkey (1938), using red-earths and podzols, suggested that the degradation of the soil colloidal surfaces during drying enabled the phosphate ions to penetrate the soil particles.

Contrary to these observations, Shioiri and Aomine (1940), Grava et al (1961), Aderikhin (1960) and Thermlitz (1953) found increases in native available phosphorus or decreases in the fixation of added phosphorus on drying soils or hydrated iron oxides. Smolik (1943), found this increase only at high soil drying temperatures and Ryzhov and Machigin (1939) attributed the increase to the reduction in the activity of soil sesquioxides and increase in the mobility of the soil organic matter as well as changes in the physico-chemical properties of the soil.

On the other hand, Köttgen (1943) suggested periodic fluctuations in the mobile ions, including phosphates, in both dry and moist soils, while Yuan et al. (1960) reported increases in the aluminium-fixed and decreases in the iron-fixed phosphorus with increase in the soil drying temperature.

Reitemeier (1946), observed increases in the solubility of several ions including phosphate, with increase in soil moisture content, and has been supported by Mack (1959), only at high temperatures, while Muller (1954) reporting fairly rapid migration of phosphate through agar, silica gel and sand, observed the restriction of phosphate ions to the vicinity of the phosphate fertilizer granule in a medium loam soil. He found all migrations to increase with the moisture content of the material.

Under water-logged conditions, phosphates have been reported to be greatly mobilised by Aoki (1941), Dennet (1936), Kereszteny (1953), Shapiro and Armiger (1958) Davide (1960), Kaurichev et al. (1958), some of whom also stated that this mobilized phosphate was not all available to plants. This was supported by Mack and Barber (1960).

Gasser and Bloomfield (1955), noticed no release of aluminium or phosphorus from aluminium phosphate but reported releases in iron and phosphorus from iron phosphate under anaerobic conditions. They also reported the fixation of added phosphates by natural clays and release of phosphorus by phosphated clays under the same conditions. The same phenomenon has been observed by Shapiro and Armiger (1958), who noticed no increase in available phosphorus from phosphate rocks of low phosphate availability but a great increase from phosphate rocks of high phosphate availability, under water-logged conditions.

On the other hand, Egawa et al (1951), and Popovic (1958), found that under anaerobic conditions produced either by water-logging or reducing the oxygen pressure, added phosphates were fixed and the lactate-soluble phosphates reduced, especially in soils originally high in phosphates.

Moore (1959), however, found no difference in the acid-extractable phosphorus from phosphate responsive and non-responsive meadow soils incubated under partially anaerobic conditions but found that the non-responsive soil showed a greater increase in acid-extractable phosphorus than the responsive soil when both were incubated under aerobic conditions.

Barber (1960), suggested that moisture levels during the incubation of soils prior to cropping had no effect on the availability of phosphorus to crops. Kawaguchi (1944) had shown that water-logging increased the availability of phosphates to a greater extent than air-drying the soil. He showed a predominance of iron phosphate when the solubility of phosphate was higher under water-logged than under dry field conditions; of tricalcium phosphate when the solubility was higher under dry than water-logged conditions; of soluble phosphate iron phosphates and tricalcium-phosphates when solubility was high under both water-logged and dry conditions; and of aluminium phosphate, when solubility was low under both conditions.

Chang and Chu (1961), reported that when dry soil was wetted to field capacity the proportion of aluminium phosphate was high initially but later iron phosphate was higher. Under water-logging they found iron phosphate dominant after 100 days, contending that the relative amounts and kinds of phosphates formed initially, depended on the specific areas of the solid phase associated with aluminium, iron, or calcium. As time went on, aluminium and calcium phosphates gradually changed to the less soluble iron phosphate, the rate of transformation increasing with the moisture content of the soil.

The only occasion when microbial reduction of phosphates has been studied was when Tsubota (1959) reported the reduction of phosphates to phosphites and hypophosphites in flooded rice soils. He suggested that high humus content of the soil and high temperatures favoured the reduction. He also showed that in culture media Clostridium butyricum and Bacterium coli were concerned with the process.

Several workers have reported increases in available phosphate when soils were subjected to a number of cycles of alternate wetting and drying, Tendille and Eynard (1959), Eynard and Tendille (1960) and Khanna (1960).

Tendille (1959), on the other hand, showed that the transformation of phosphate from exchangeable to non-exchangeable forms was accelerated by alternate wetting and drying. He also showed that the addition of phosphates favoured the fixation of phsophates initially present in the soil solution while the removal of phosphates in the solution favoured the liberation of phosphates initially in solid phase.

Barbier and Tyszkiewicz (1951) found increases in some cases and decreases in others in the fixation of phosphates added before the soils were subjected to cycles of wetting and drying, but found no variations in fixation when the phosphates were added after the soils had been subjected to alternate wetting and drying.

Yuan et al. (1960), also found that increasing the number of cycles of wetting and drying reduced the percentage of aluminium-fixed phosphate in two soils and increased that of iron-fixed phosphorus in two others.

(E) Soil moisture and soil potassium.

Several workers have observed increases in the exchangeable potassium of soils on drying (Gorbunov (1936), Ayres (1944), Seatz and Winters (1944), Attoe (1947) and (1949) Rouse and Bertramson (1950), Aleksandrov (1950), Luebs et al. (1956), Scott and Smith (1957), Bohanon (1958), Hanway and Scott (1959), Malquori and Radelte (1959), Wells (1959) and Grava et al. (1961). This has been confirmed by Reitemeier et al. (1948) and Luebs (1956) who also found a further increase on oven-drying the soil while Lee (1948) found no such further increase on oven-drying.

Contrary to these results several others found drying to cause a fixation of exchangeable or added potassium in the soil (Volk (1934) Gorbunov (1935), Joffe and Levine (1937), Wear and White (1951), Schroeder (1955), Karim and Malek (1957), Grissinger (1957), Graley et al. (1960) and Piper et al. (1960). Same

results have been obtained by Truog and Jones (1938) who also found that the amount of added potassium fixed by dry soils was equivalent to the reduction in the exchange capacity of the soils, while Joffe and Kolodny (1936) and (1938) and York et al. (1953) reported a difference between the amount of potassium fixed and the decrease in the exchange capacity.

Carter (1961) reported the fixation of potassium by potassium-saturated clay minerals, converting them to other minerals while causing the collapse of their lattices, and the release of potassium by aluminium saturated layer-silicates when these minerals were dried.

Cook and Hutcheson (1960), Matthews and Sherrell (1960), Scott et al. (1957), and Hanway and Scott (1957) explained the release and fixation of potassium by drying on the principle of soil potassium equilibrium. When the initial value was high, drying the soil caused fixation, but when it was low, drying caused release.

Bartholomew and Janssen (1931) reported a release of potassium during moist storage of the soil while McLean and Simon (1958) and York et al. (1953) reported a fixation of potassium during wet storage of the soil after cropping.

Stanford (1948), observed fixation of potassium under conditions of moistening and drying of soils while Carter (1961) found that this occurred only with vermiculite. Bray and De Turk (1939), and De Turk et. al (1943) explained these observations on the principle of soil potassium equilibrium, both moist and dry fixation depending on whether the initial potassium content was relatively high or low. They emphasized that different soils had characteristic equilibrium levels between all forms of potassium to which their exchangeable potassium content would tend to approach from either direction.

On the other hand, Larson and Allaway (1950), reported a release of potassium under both moist and dry conditions and have been supported by Larson (1949), who explained that dry release arose from a shift within the release-fixation mechanism, while moist release arose from the weathering of primary minerals. Carter (1961), however,

observed dry release and moist fixation for some Oregon soils, montmorillonite, illite, biotite and prochlorite minerals.

Bray and De Turk (1939), Ayres (1949), and Damsgaard-Sorensen (1942), reported no change in the soil potassium level when the soil was stored moist, but Lachower (1940), Andersen et. al. (1942), Reitemeier (1946) and (1951), Melsted and Bray (1947) and Muller (1954) reported increases in the soluble potassium with increase in soil moisture as a result of hydrolysis of exchangeable potassium, replacement of exchangeable potassium by divalent ions and the dissolution of potassium-bearing minerals. Burns and Barber (1961) found the rate of release of potassium to increase with the temperature of incubation but was unaffected by varying the soil moisture content between 60% and 100% of the moisture equivalent.

Walsh and Cullinan (1945) reported increases in exchangeable potassium when the soil was subjected to a number of cycles of wetting and drying, and this has been confirmed by Thomas and Giddens (1958) using acid soils.

Contrary to this Volk (1934), Joffe and Kolodny (1936) and (1938), Truog and Jones (1938), Damsgaard-Sorensen (1942), Hoyos and Ortega (1953, York et. al. (1953), Chatterjee and Ray (1954), and Hanway and Scott (1959), found that alternate wetting and drying the soil resulted in a fixation of exchangeable or added potassium. It has also been confirmed by Malquori and Wiklander (1950), with synthetic amorphous aluminium and iron silicates.

Mick and Lynd (1957), reported that alternate wetting and drying of soils released a portion of fixed potassium to the exchangeable form in the first few cycles and then fixed a portion of that released in further cycles.

Tendille et. al (1956), on the other hand, found increases in the isotopically exchanged potassium on alternately wetting and drying soils. They further showed that potassium fixation was not necessarily irreversible and that alternate wetting and drying promoted both fixation and liberation of potassium in soils.

McLean and Simon (1958), stated that potassium fixed by alternate wetting and drying was largely available to plants, while Wells (1959), opposing this reported that where little change occurred in soil exchangeable potassium on soil drying, potassium determined on moist or dried samples reliably indicated the potassium available to the plant but where the change was great, determinations on moist samples were more reliable. Matthews and Sherrell (1960) found that the yields of potatoes correlated only with oven-dried soil exchangeable potassium, whilst yields of maize were correlated with exchangeable potassium obtained on moist or oven-dried soils.

Evans and Simon (1950) proposed alternate wetting and drying the soil before extraction with 0.5N HCl at 80°C as a method of assessing the potassium-supplying power of soils. Potassium extracted in this way was highly correlated with potassium uptake by oats and lucerne.

Aleksandrov (1950) attributed the major portion of potassium fixation in Sierozem and Chernozem soils to microbiological processes, and, with Hurwitz and Batchelor (1943), indicated an intensified fixation due to the presence or addition of organic matter. These results had earlier been observed by Feher and Frank (1936) and Pehelkin (1946).

Contrary to these observations, Kryopoulos (1915) found no appreciable potassium fixation in bacterial cultures, Vandecaveye (1924) and York et al (1953) reported the absence of potassium fixation by added organic matter, and Stephenson (1934) concluded that micro-organisms did not retain enough potassium to compete seriously with plants.

(F) Soil moisture and other nutrients.

Comparatively little work has been done on the relation between soil moisture and the status of nutrients other than nitrogen, phosphorus and potassium. Aderikhin (1938) observed decreases in exchangeable calcium and

magnesium and in the exchange capacity of chernozems and meadow podzols on drying. A decreased availability on soil drying has also been observed for boron by Hobbs and Bertramson (1949), and for extractable magnesium after addition to precipitated aluminium and iron silicates following drying by Malquori and Wiklander (1950).

For manganese, DeLong et al. (1940) reported decreases on soil drying, confirmed by Leeper (1947), who showed that such decreases were overcome by water logging, by which manganese was greatly mobilized in the soil.

Increases in manganese on soil drying have, however, been reported by Hammes and Berger (1960a) and (1960b) while Fujimoto and Sherman (1945) and (1948) found that conditions favouring oxidation or hydration in the soil decreased while heating and drying increased, the exchangeable manganese. They postulated that the release of manganese was a reversible process dependent on the oxidation-reduction conditions and on wetting and drying. Zende (1954), on the other hand, observed increases in exchangeable manganese on drying field soils, but a decrease on drying calcareous peat soils, while Marshall and Gurr (1954) found that chloride ions moved in the liquid phase to the soil surface on further drying of a soil at low moisture levels.

Reitemeier (1946), reported increases in dissolved and exchangeable ions of sodium, potassium, ammonium, carbonate-bicarbonate, phosphate and sulphate, with increase in soil moisture. For calcium and magnesium, the ions increased up to a point and then decreased with further increase in soil moisture, but for chloride and nitrate, the ions decreased continuously with increase in soil moisture. Moser and Olson (1953) observed the optimum soil moisture content for added sulphur oxidation to be above the field capacity.

Bromfield (1954) reported active reduction, under anaerobic conditions of ferric to ferrous compounds by Bacillus polymyxa and B. circulans, while bacteria of the genera Escherichia and Aerobacter were active to a limited extent in special media. Khan and Dubash (1958) observed a decrease in the soil cobalt content on reclamation of water logged soils in Pakistan.

(G) Soil moisture and crop yields.

Water is very intimately connected with the physiological and biochemical processes which bring about plant growth and yields, so, the soil moisture content when the plant is growing is bound to have a tremendous effect on the growth and yields of plants.

Several workers in different parts of the world have grown fruit trees and field crops at various soil moisture levels and have generally found that size of trees and yields of fruits have increased with the increase in soil moisture level. Among such workers may be mentioned Miller and Dudley (1925), Hendrickson and Veihmeyer (1929), (1931), (1934) and (1942), Veihmeyer (1927), Beckett and Dunshee (1932), Lewis (1934), Furr and Taylor (1939), Adams et al. (1942), Harris and Hawkins (1942), Kelley et al (1945), Chaklander (1946), Howe and Rhoades(1948), Makkink (1948), Clements (1948), Morgan (1949), Anderson (1951), Oppenheimer (1951) and Taylor (1951).

Others have added irrigation water in the field and in pots as well as fertilizers and also found that the yields of various crops and grasses increased with the soil moisture content with or without application of fertilizers. They include Hudson and Salter (1953), Salter (1954), Bradley (1955), Stanberry et al. (1955), van't Woudt (1955), Bradley and Pratt (1955), Harward et al. (1956), Gingrich and Russell (1956), Hagan et al. (1957), Awada and Ikeda (1957), Bendelow (1958), Fernandez and Laird (1959), Collier (1959), Larsen (1959), Scarsbrook et al (1959), Leggett (1959) and Garton and Barefoot (1959).

These have been supported by Coic (1960), Parups et al. (1960), Mathers et al. (1960), Beaton and Speer (1961), Meriaux and Perry (1961), Godard (1961), Lorenz et al. (1961), Schumaker and Davis (1961) and Cannell et al. (1961).

Contrary to these observations, only van de Merwe et al. (1954), Taylor et al. (1959) and Low and Armitage (1959) reported any increase in yields with decreasing soil moisture down to a limit, while Bernstein and Pearson (1954), Brown et al. (1955), Matusiewicz (1956), Kreeb (1957), Walker and Vickery (1959) and Low and Piper (1960) found yields to increase with decreasing moisture tension to an optimum and then decreased thereafter.

Williams (1954) and Jones (1961) observed no difference in yields at various moisture levels above the wilting percentage while Cannell et al. (1960) found increases in yields with increasing moisture in two soils but increases with decreasing moisture in a third soil. Mederski and Wilson (1960), using the split-root technique, found that at both high and low atmospheric humidities, the dry weight yields of maize increased with increasing moisture content from the wilting point to field capacity in the moist zone of the root area.

Collins (1961) reported increases in yields of strawberry at low soil moisture levels when manures were added but found the growth of the plant to decrease with increasing soil moisture tension.

The effects of soil moisture levels on the germination of seeds have been studied by Dubetz et al. (1959) who reported that soil moisture content alone did not significantly affect the germination of a number of crop seeds, but Chapin and Smith (1960) and Wallace (1960), observed maximum germination at an optimum soil moisture content. High levels of nitrogen fertilizers reduced germination with decreasing soil moisture while mercurial treatments increased it at low soil moisture content.

That the increase in the depth of the water table which controls the oxygen pressure and the redox potential in the root zone, increased crop yields has been reported by Shalhevet and Zwermann (1958), who also found the lowest yields with a fluctuating water table. They were supported by Nicholson and Firth (1958), van Hoorn (1958), Shalhevet (1959) and Cline and Erickson (1959), while Klages and Asleson (1959) observed increases in yield with the decrease in the depth of the water table, confirmed by Gilbert and Chamblee (1959) only when no water was added on the top of the soil.

Pearson et al. (1957) found little difference in yields with various depths of the water table.

Ashton (1956) reported the maintenance of a relatively high rate of photosynthesis until the wilting percentage when he gave five cycles of alternating low and high soil water content to a sugar cane crop.

Workers on the relation of crop yields to soil moisture content cited above have used crops which usually grow under aerobic conditions and have limited the soil moisture to below the saturation percentage. Thus when Lerman (1956) and Savitskaya (1959) grew barley under water logged conditions, they found decreased yields compared with those at field capacity, but Kemper and Amemiya (1957) found that lucerne yielded more when flooded, while Baird (1959) reported greated response of maize to nitrogen fertilization in well-drained soils low in organic matter than in poorly drained soils high in organic matter. Finn et al. (1961), on the other hand, found that grasses yielded more than legumes when a mixed sward was flooded.

With rice, however, Alberda (1953) and Vlamis and Davis (1944) reported the ability of rice plants to grow in oxygen deficient soils since any necessary oxygen was transported through the plants by means of large air spaces in the leaf-sheaths and roots.

This was confirmed by Malavolta (1954), who obtained the greatest yield of rice from nutrient cultures without forced aeration.

Lord and Fernandes (1931) had earlier found increased rice yields by continual water logging while Palis (1935), obtained greater yields at 80% than at 20% saturation.

Tang et al (1941), showed that both lowland and upland rice required excess soil moisture for greater yields, and Jones (1933), reported higher yields of rice on soils submerged below 2-10 inches than on soils in a "mucky" condition.

Contrary to these results, Nearpass and Clark (1960) reported lower yields of rice grown under water logged conditions and Wychie and Cheaney (1951) observed increased response to added nitrogen under lower soil moisture content than under water logged conditions, but Davide (1960) while reporting decreased responses to added dicalcium hydrogen phosphate and aluminium phosphate found increased responses to added iron phosphate under water logged conditions.

Mack and Barber (1960a) found no effects on the yield of millet when the soil was incubated at various moisture levels, 40-100% saturation, prior to

cropping and Lord and Fernandes (1931) reported no effect of soil drying prior to cropping on the yields of rice. But Shiori and Aomine (1940), Kapp (1934) and Huang (1946), found increases in rice yields as a result of drying the soil prior to cropping.

Gasser (1961) correlated significantly the mineral-nitrogen content of fresh soils or the increased mineral nitrogen produced when the rewetted air-dry soils were incubated at 25°C for 21 days, with the unfertilized yield of rye-grass, barley and to a less extent, potatoes.

(H) Soil moisture and nutrient uptake by plants.

A large amount of evidence has shown that generally the yield in dry weight of plants increases with increased soil moisture content. From this, it might be apparently observed that the total uptake by plants of soil nutrients in unlimited availability, would increase with increasing soil moisture, but the percentage of nutrients in the tissues would be independent of the soil moisture. On the other hand, if the nutrients are in limited availability, the total uptake may be independent of the soil moisture while the percentage in the tissues will decrease with increasing soil moisture as a result of the dilution of the nutrients in the tissues.

Because the growth and yield of plants are controlled by the interaction of soil moisture and soil nutrients as well as by other physical factors, it may not be as simple as stated above, since, infact, the soil moisture itself affects the soil nutrients independently of the growing plants. This complicated relationship between the soil nutrients, soil moisture and the plant are shown by the varying and conflicting results which workers have reported for the uptake of nutrients by plants at various soil moisture levels.

Figula (1954) and Cannell et al.(1959) and (1960) reported an increase with increasing soil moisture level in the percentage content of all nutrients in the ash or leaf of plants. Emmert (1936), Trumble (1947), Ilgin (1954), Branton et al.(1961) found a greater percentage of nitrogen, calcium and magnesium and a lower percentage of phosphorus and zinc in the tissues of plants grown under dry conditions than in those grown under moist conditions. For potassium, the results were variable.

On the other hand, Koritskaia (1939) found little or no uptake of nutrients from the dry area of the root zone of maize grown by the split-root technique.

Several other workers found the uptake or percentage content of nutrients in plant tissues to increase with increasing soil moisture (Plice (1944)),

Nour (1956), Awada and Ikeda (1957), Jenne et al (1958), Walker and Vickery (1959), Metwally and Pollard (1959), Brown and Place (1959), and Mederski and Wilson (1960).

Lawton (1945a) using a poorly drained compacted soil, found that the percentage of nitrogen and phosphorus in maize tissues increased, while that of potassium, magnesium and calcium, decreased. On forced aeration of the soil, the percentage of nutrients reversed except for magnesium and calcium which still decreased. Ilgin (1954), however, observed that the percentage content of all nutrients in plants grown under water logged conditions decreased, and Reuther and Crawford (1946) reported intensified chlorosis of citrus trees grown in calcareous soils at high soil moisture levels.

Cannell et al (1961) reported increases in the nitrogen uptake with decreasing soil moisture, and Plice (1944) observed that the total nitrogen uptake increased inversely with soil moisture while Kurtz et al. (1961) found that the nitrogen content of crops was inversely proportional to the moisture level at which the soil was incubated prior to cropping.

Contrary to these reports, Chizhov (1938), Fernandez and Laird (1959), Scarsbrook et al (1959) and Schumaker and Davis (1961) found the uptake of native and added nitrogen and the crop content of proteins and

nitrogen to increase with increasing soil moisture.

Doneen (1942) observed that variations in the soil moisture content did not affect the nitrogen content or total nitrogen uptake as long as there was available water present.

Shalhevet and Zwermann (1958) and van Hoorn (1958) found that the nitrogen uptake and nitrogen content of plants decreased with decreasing depth of the water-table.

Increases in the uptake by plants of phosphorus with increasing soil moisture have been reported by Kuryowicz (1939), Williams (1954) and Olsen et al. (1961); Low and Piper (1960) observed greater increases in phosphorus uptake by clover than by rye-grass with increasing soil moisture up to 80% saturation, and decreases at 100% saturation, but Shapiro (1958) found that flooding increased the phosphorus and nitrogen uptake as well as their efficiency of utilisation by lowland and upland rice. Mack (1959), also, observed greater responses to phosphorus fertilization when the rainfall was low in spring.

Contrary to these results, Dean and Gledhill (1956) reported decreases in phosphorus uptake with increasing soil moisture content. On the other hand, Fawcett and Quirk (1960), Parups et al. (1960), found

that the uptake of phosphorus was unaffected by decreasing soil moisture until the wilting point. Mack and Barber (1960a) observed that varying the soil moisture between 40% and 100% saturation during precropping incubation had no effect on the subsequent uptake of phosphorus, but when the soil was cropped at various moisture levels, after incubation, the uptake of phosphorus increased with the increases in the soil moisture.

Volk (1934), Wadleigh and Richards (1951) reported the unavailability of potassium at low soil moisture levels, to plants. This has been confirmed by McMurtrey et al. (1947) who found that the percentage potassium in tobacco leaves increased on irrigation of the soil.

These results were contradicted by those of Luebs (1956), which showed higher potassium uptake by crops from soils which had been air-dried prior to cropping than from those which had not, confirmed by Breazale (1930) Emmert (1936) and Volk (1947) who reported higher percentage potassium in plants grown at low, than in those grown at high, soil moisture levels. Vlamis and Davis (1944), Lawton (1945a) and (1945b) and Cook and Millar (1953) also found that the percentage potassium in several crops (except rice) grown under water-logged conditions was lower than in those grown at well aerated soil field capacity.

When Walsh and Cullinan (1945) alternately wetted and dried soils prior to cropping, the subsequent uptake of potassium by mustard was increased compared with untreated soils. Attoe (1947) and (1949), also obtained increases in total uptake of potassium by four successive crops of oats when the soil was dried between each crop as compared with no drying between the crops.

Hammond et al (1955) observed that the absorption of potassium by maize roots might be markedly reduced by low supplies of oxygen and high concentrations of carbon dioxide.

Mederski and Wilson (1955), reported less manganese deficiency symptoms in soy beans grown in manganese deficient clay soils at low soil moisture than at high, even though there was no difference in the soil available manganese due to differences in the soil moisture level.

Danielson and Russell (1957), found that the uptake of radioactive rubidium decreased with decreasing soil moisture and increased with increasing oxygen pressure.

Awada and Ikeda (1957) found high percentage total sugars in fruits of papaya, while Walker and Vickery (1959) found low total sugars in the leaves of crops in unirrigated compared with irrigated plots. They also found more total alkaloids and high petroleum extractives.

Woodhams and Kozlowski (1954), however, found that the percentage sugar in beans and tomatoes was unaffected by the soil moisture, but that the percentage of starch increased with increasing soil moisture. They obtained the lowest carbohydrate content by alternating drought and irrigation. Lerman (1956) reported low carbohydrate content of leaves of barley grown under water-logged conditions compared with those under well aerated soil conditions.

CONCLUSIONS

From the foregoing account, it may be concluded that:

(i) Until recent times, soil drying was known to increase the solubility of its constituents. Now, however, that the use of mineral fertilizers has become more important, it has been shown that under dry and moist soil conditions native or added nutrients may be released or fixed depending, among other conditions, on the equilibrium levels of available and unavailable forms and on the type of clay minerals and redox conditions present in the soil.

(ii) Decomposition of organic carbon and nitrification have an optimum soil moisture level around field capacity but ammonification has none.

(iii) Ammonia volatilisation occurs at all soil moisture levels but denitrification becomes appreciable only at medium to high soil moisture levels.

(iv) Under-water logged field conditions nitrogen losses may be offset by fixation of atmospheric nitrogen.

(v) When there is a release of potassium and phosphorus under moist soil conditions, the release increases with the soil moisture content. At water logging, phosphorus generally becomes greatly mobilised.

(vi) The yields and total nutrient uptake by plants generally increases with increase in soil moisture content up to an optimum and at excessive soil moisture they decrease. For rice plants, however, they are higher under excessive than under normal soil moisture levels.

(vii) The percentage nutrients in plant tissues may increase or decrease with increasing soil moisture levels depending on the individual nutrients.

CHAPTER II

OUTLINE OF PRESENT WORK AND ANALYTICAL METHODS

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Outline of present work.

The work in this study deals with the metabolism of nutrients under various soil moisture conditions. This metabolism may be defined as the biological accumulation and mineralisation of the organic matter in the soil and the chemical transformations and uptake by plants of the mineralised nutrients. These processes are controlled by soil chemical and physico-chemical fixation or release of nutrients. Throughout this work the term "fixation" refers to immobilization of inorganic nutrients e.g. conversion of water-soluble or dilute acid-soluble to water-insoluble or dilute acid-insoluble phosphate, conversion of inorganic nitrogen to organically-bound nitrogen, and conversion of water-soluble and exchangeable potassium and ammonium to non-exchangeable forms. The term "release" refers to the conversion of inorganic nutrients from organically-bound forms or from water-insoluble or dilute acid-insoluble forms into water-soluble or dilute acid-soluble forms.

Initially, the accuracy and precision of the methods of soil analysis for total nitrogen, of plant analysis for nitrogen, phosphorus and potassium and of measurement of soil moisture characteristics were investigated.

Under various soil moisture conditions, carbon mineralisation, nitrogen mineralisation and losses of nitrogen, and ammonia, phosphorus and potassium fixation

and release were studied in laboratory incubation experiments. Some of the moisture treatments applied to soils in the incubation experiments were repeated in the greenhouse under potted rice (Oriza Sativa L.) and Rye-grass (Lolium multiflorum Lam. var. italicum Braun.) plants, and the nitrogen balance and the uptake by the plants of nitrogen, phosphorus and potassium were determined.

The moisture treatments given to the soils in the incubation experiments or in the pot tests have been grouped into the following headings:-

(a) Various soil moisture levels and variations within the range "air-dry" to "water-logged".

(b) Different soil moisture levels at different soil pH levels.

(c) Different soil moisture levels in the presence of added oat straw or compost.

(d) Different soil moisture level x pH level x organic matter x inorganic nitrogen treatments.

(e) Different heights of water of submergence of soils.

(f) Different periods of air-dry storage prior to wetting.

(g) Alternate raising and lowering soil moisture regimes.

Soils varying in chemical and physical properties were used in these studies.

ANALYTICAL METHODS

A. SOIL CHEMICAL ANALYSIS.

1. Mineralized carbon.

The mineralized carbon as carbon dioxide was determined during the incubation of soils by Cornfield's (1961) method which involves the absorption of carbon dioxide evolved from soil microbial respiration by an aqueous suspension of barium peroxide which in turn releases oxygen required for respiration.

The carbonate formed during the incubation was then determined by the calcimeter modified from Collins (1906) by Cornfield (1960).

Extraction of nutrients.

For the extraction of nitrate, ammonium, phosphorus and potassium from soils, a reagent which would extract them quantitatively was required. It was found that most conventional extractants of some of these nutrients either contained one of these nutrients or did not contain cations strong enough to displace ammonium and potassium ions from the clay complex.

Morgan's reagent has been considered most suitable because it contains sodium, which has been shown by Barshad (1951) to be among the best cations for replacing ammonium and potassium ions from the exchange positions. Morgan (1937) found that as an extractant of soil phosphorus it was well correlated with crop yield responses.

Morgan's reagent was prepared at double strength by dissolving 200 g. of trihydrated sodium acetate, $CH_3COONa.3H_2O$ and 60 ml. of glacial acetic acid in water and making up to 1 litre.

To use the reagent for soil extraction, enough water was added to the soil, which had been incubated at a known moisture content, to bring the water : soil ratio to 1 : 1. An amount of the double strength reagent equal to the amount of water now present in the soil was added and the stoppered test-tube was shaken vigorously by hand or in and end to end shaker for one minute. The soil suspension was then filtered through a No.42 Watman filter paper into a dry test-tube. 2 ml. of the extract is equivalent to 1 g. of soil.

2. Mineral nitrogen in the Morgan's extract.

Bremner and Shaw (1955) have indicated that acid extractants destroyed part of any nitrite in the soil and oxidised some of the rest to nitrate. In the analysis of the mineral nitrogen here, it has been assumed that nitrite was likely to be present in small quantities and what has been determined here as nitrate might be considered to include nitrite.

The mineral nitrogen, i.e. ammonium-N and nitrate-N, extracted from the soil was determined by the micro-diffusion technique of Conway (1947), as modified by Bremner and Shaw (1955). Ammonium-N was determined immediately after extraction of the soil since it was found that if the determination was delayed after extraction the ammonium-N values changed.

3. Available phosphorus.

The phosphorus extracted by Morgan's reagent was here designated as "available" phosphorus. It was determined as P_2O_5 using the chlorostannous-reduced molybdophosphoric blue colour method of Yuen and Pollard (1955).

It was found that when water-logged soils were extracted and the extract left to stand, ferric iron precipitated and made the extract turbid. Aoki (1941), and Mack and Barber (1960), have shown that phosphate was greatly mobilised under water-logged conditions; therefore only very small aliquots of the extract would be required for the determination and this would result in the ferric iron being diluted to a concentration below the interference limit of 15 p.p.m.

4. Available potassium.

The potassium extracted by Morgan's reagent from the soil would be made up of the potassium in the soil solution and any soil exchangeable potassium displaced by the sodium in the reagent. The extracted potassium may conveniently be designated "available" potassium.

The available potassium was determined photometrically by the EEL photometer (Evans Electroselenium Ltd. Halsted, Essex, England) the galvanometer of which gives full scale deflection at a standard concentration of 10 p.p.m. K^+. Any soluble potassium salt could be used for making up the standard solution since at this concentration of K^+, all anions are at concentrations far below the interference levels determined by Collins and Polkinhorne (1952). Appropriate amounts of Morgan's reagent were added to the standards.

5. Soil organic carbon.

The soil organic carbon was determined by the Walkley-Black (1934) method. Walkley (1947) stated that the organic carbon determined by this method excluded less active organic carbon and most of elementary carbon (charcoal and graphite).

6. Total nitrogen in the soil.

The total nitrogen in the soil was determined by the Kjeldahl method modified with salicyclic acid to include nitrate.

Added nitrate recovery from a 2 mm-sieved soil.

Almost all workers who have used the Kjeldahl method for soil total nitrogen determination used soil samples passing an 0.5 mm. sieve.

In denitrification experiments in which 2 mm. sieved soil samples are used and the total nitrogen determined on the whole of the sample at the end of the experiment, grinding the sample to pass an 0.5 mm. sieve may not be desirable.

The aim of the following short investigation is to confirm the precision and accuracy of the salicylic acid modification of the Kjeldahl method used to analyse a 2 mm.-sieved soil for total nitrogen and recovery of added nitrate.

Experimental.

10 g. of a 2 mm.-sieved sandy loam soil (soil 1) organic carbon 1.32%, was weighed into an 11 cm. No. 1 Watman filter paper. 1 ml. of a solution of potassium nitrate containing 5,000 p.p.m. nitrate-N was added. To another 10 g. sample of the soil, no nitrate but only 1 ml. of distilled water was added. The former treatment was replicated six times and the latter four times.

The solution and water were added in such a way that they did not soak to the filter paper. All replicates were dried in an oven at 60°C for 24 hours. At the end the total nitrogen was determined by the Kjeldahl method modified with salicylic acid.

Results.

The results are shown in Tables I(a) and I(b) below.

TABLE 1.

(a) Total N of soil (Control)

Replicates	N p.p.m.
1	1507.50
2	1488.75
3	1507.50
4	1518.75

Mean* = 1505.60±12.19

Coeff. of variation = 0.83%

(b) Recovery of added Nitrate-N 500 p.p.m. soil

Replicates	% Recovery
1	96.13
2	101.30
3	99.30
4	97.88
5	97.88
6	101.30

Mean* = 98.97±1.65

Coeff. of variation = 2.09%

*Mean of respective replicates plus or minus the standard error at 5% level of probability.

The results were reproducible and the recoveries of nitrate were good. The standard errors of the means, which have been calculated at 5% level, must arise from soil sampling and to some extent from recovery errors.

Since Piper (1944) reported that the presence of moisture in the soil reduced the recovery of nitrate-nitrogen by the salicylic acid modification of the Kjeldahl method, it seems absolutely necessary that the soil be dried before the determination of total nitrogen is made.

The results obtained show that the use of 2 mm.-sieved soil is satisfactory and that grinding the soil to pass an 0.5 mm. sieve as suggested by Bremner and Shaw (1958), or a .15 mm. sieve as suggested by Jackson (1958), is unnecessary for complete recovery of nitrate-nitrogen.

Elimination of nitrogen losses during the drying of alkaline soils.

Several workers including Trickey and Smithey (1955), and Stojanovic and Broadbent (1960), showed that ammonium-nitrogen added to the soil was lost by the volatilisation of ammonia when the soil was dried. Mitra and Singh (1958) had earlier reported heavy losses of added ammonium-nitrogen from alkali soils and proposed the following reaction:

$$(NH_4)_2SO_4 + Na_2CO_3 \longrightarrow (NH_4)_2CO_3 + Na_2SO_4$$

in which the ammonium carbonate being rather unstable

decomposed into gaseous ammonia and carbon dioxide thus:

$$(NH_4)_2CO_3 \longrightarrow NH_3 + CO_2 + H_2O.$$

Wahhab and Uddin (1955), studied the interaction of ammonium and nitrite ions in aqueous and alkaline media and found that in high concentrations and on desiccation of the media, losses of nitrogen resulted. Madhok and Uddin (1945), had earlier reported evolution of nitrous fumes from added nitrite when soils with pH above 7 were dried.

In the light of these results, consideration must be given to the suggestion made by Bremner and Shaw (1958), that drying the soil before total nitrogen determinations in nitrogen balance experiments would involve losses of nitrogen during the drying process; losses which would greatly affect the results of such experiments.

Bremner and Shaw (1958), used a modified Olsen's (1929) method to eliminate any such loss by doing the total nitrogen determination on the wet soil. They used a solution of potassium permanganate to oxidise any nitrite to nitrate and reduced the nitrate with iron and sulphuric acid before doing the Kjeldahl digestion.

In pot experiments involving total nitrogen balances, this method could not be applied since the bulk of the wet soil would be too large for digestion, and sampling of the wet soil cannot easily be done.

The soil would therefore need to be dried and subsampled.

Secondly, in multifactorial incubation experiments in nitrogen balances, a limitation of digestion facilities would make it impossible to analyse all the samples at the same time. To do the analysis at convenience, the soil will have to be dried after the experimental period has ended.

At the same time, any losses of nitrogen during this drying process must be eliminated. The aim of this short investigation was to devise a method of doing this.

Preliminary experiments.

A search for a method led to a consideration of the use of potassium permanganate to oxidise added nitrite to nitrate during the drying process. 10 g. of soil 1, a sandy loam soil whose pH has been raised from 6.5 to 8.5 by the addition of 0.75% of calcium carbonate as described under "soil pH" later, was treated with 100 p.p.m. nitrite-nitrogen and 2 ml. of 10% $KMnO_4$ solution. The soil was dried and the total nitrogen determined by the salicylic acid modification of the Kjeldahl method.

The results showed that the nitrogen lost was even greater than the added nitrite-nitrogen, indicating some loss of nitrogen originally present in the soil.

It was also found that when the permanganate treatment was applied either alone or in conjunction with 1.5 ml. of N sulphuric acid solution to the soil treated with either 100 p.p.m. nitrite-nitrogen, 500 p.p.m. ammonium-nitrogen or both together, there were still significant nitrogen losses. The amount of acid added had been calculated to neutralise the carbonate in the soil.

When, however, only the acid was added and no special attempt was made to oxidise the nitrite, little loss of nitrogen occurred. This method was then tried out in greater detail as described below.

Experiment.

10 g. of the 2 mm.-sieved air-dry soil was weighed into a polythene sheet, which has been shown to be permeable to oxygen and carbon dioxide but impermeable to ions by Eno (1960). Four nitrogen treatments in four replicates were given: (a) no nitrogen, (b) 100 p.p.m. nitrite-nitrogen as sodium nitrite (c) 500 p.p.m. ammonium-nitrogen as ammonium sulphate and (d) 100 p.p.m. nitrite- plus 500 p.p.m. ammonium-nitrogen. For the acid treatment, each of the nitrogen-treated samples was treated with 1.5 ml. N H_2SO_4 solution and for the control 1.5 ml. of distilled water was used instead of the acid.

Appropriate amounts of water were added to bring the soil moisture content to 100% of the maximum water holding capacity. The samples, wrapped in the polythene sheets but open at the top, were placed in test-tubes and left to dry in the green house at a temperature of 25° to 40°C.

For the determination of the total nitrogen, the polythene bags holding the now dry soil samples were lifted out of the test-tubes and the soil pulverised with the fingers from the outside of the polythene bag. Both soil and polythene bag were placed inside a 500 ml. Kjeldahl flask and the total nitrogen determined with the salicylic acid-modified Kjeldahl method.

Blanks were done with polythene sheets of the same size but no soil.

Results.

The results are shown in Tables 2(a) and 2(b) below:

TABLE 2(a).

Change in the total nitrogen of the soil with no nitrogen treatment.

Original soil total nitrogen = 1460 p.p.m.

Acid treatment:	Mean* loss or gain %
Control	0.00 ± 1.00
1.5 ml. N H_2SO_4	+0.17 ± 0.49

TABLE 2(b).

Recovery of added nitrogen.

Acid treatment	100 p.p.m. NO_2-N	
	Mean* recovery %	C.V.**
Control	75.50±9.62	13.00
1.5ml. H_2SO_4	57.75±11.56	20.00
	500 p.p.m. NH_4-N	
Control	86.50±4.39	5.17
1.5ml. H_2SO_4	100.15±1.55	1.58
	100p.p.m. NO_2- + 500p.p.m.NH_4-N	
Control	72.88±5.12	7.15
1.5ml. H_2SO_4	99.01±1.00	1.03

* Mean of four replicates plus or minus the standard error at 5% level of probability.

** Coefficient of variation.

There was virtually complete recovery of the original total nitrogen of the soil when no nitrogen was applied with or without acid treatment.

For added nitrite-nitrogen, there was a significant deficit of the recovery with or without acid-treatment although the deficit was greater with acid treatment than without it. The variabilities were greater than 10%, being higher with acid treatment than without it.

For added ammonium- and added nitrite-plus ammonium-nitrogen the recovery was virtually complete with the acid treatment and significantly higher than without it. The variabilities were greater than 5% without acid treatment and less than 2% with acid treatment.

Discussion.

The high losses of nitrogen observed in the preliminary experiments, when potassium permanganate was added to the soil before drying may arise from the fact that the permanganate, being a powerful oxidising agent, vigorously decomposed the organic matter at the temperature of drying. This would result in the possible oxidation of organic nitrogen to gaseous oxides of nitrogen. Thus, even if it oxidised the nitrite to nitrate, this was unable to balance the nitrogen losses arising from the oxidation of the organic nitrogen compounds in the soil.

In the main experiment, the nitrogen losses experienced when only nitrite was added to the alkaline soil not neutralised with acid have confirmed the observations of Madhok and Uddin (1945), and it seems that during the drying process, there is a spontaneous decomposition of the nitrite. When the carbonate is removed by neutralisation with acid, the even greater losses of nitrite-nitrogen probably arises from the acidity of the soil which under drying conditions would stimulate the formation of nitrous acid from the nitrite. This nitrous acid being rather unstable decomposes easily into gaseous oxides of nitrogen.

The losses of ammonium-nitrogen when the carbonate is not removed follow the reaction suggested by Mitra and Singh (1958), and when the carbonate is removed by acid treatment, no ammonium-nitrogen is lost.

When the ammonium- and nitrite-nitrogen were both added without the removal of the carbonate, the nitrogen losses were even greater than when ammonium- or nitrite-nitrogen was added alone. This seems to follow from the observations made by Wahhab and Uddin (1955), that when drying an alkaline medium containing nitrite and ammonium ions, they would react to form ammonium nitrite which would spontaneously decompose into gaseous ammonia and nitrogen oxides. It seems that on removal of the carbonate with acid, this spontaneous

decomposition of ammonium nitrite does not take place since nearly all the ammonium- plus nitrite-nitrcgen is recovered.

Conclusion.

In nitrogen balance experiments where alkaline soils are used and mineral nitrogen treatments given or where accumulation of ammonium- or nitrite-nitrogen is likely, losses of nitrogen during the soil drying process can be prevented by acidifying the soil to a pH between 5·5and 6·5just before drying.

7. Soil pH.

Soil pH was determined at a soil : water ratio of 1 : 2 by means of the glass electrode using the Cambridge bench pH meter.

Preparation of a soil of varying pH.

Four 500 g. lots of a 2 mm.-sieved air-dried soil were mixed with aluminium chloride, $ALCl_3.6H_2O$, at rates of 0.1%, 0.2%, 0.5% and 1.0%. Amounts of calcium carbonate corresponding to 0.1%, 0.2% and 0.5% were mixed with three other lots and one lot was untreated.

Each lot was placed in a plastic pot, wetted until saturation and watered every three days for three weeks. The pots were then treated with 5 inches of water to leach out excess soluble salts, the soils then air-dried and their pH determined as above.

8. Carbonate content of the soil.

The carbonate content, calculated as calcium carbonate was determined with the calcimeter modified from Collins (1906), by Cornfield (1960).

F. SOIL MECHANICAL ANALYSIS.

1. Clay, silt and sand fractions.

The clay and silt fractions were determined with the Bouyoucos (1953), hydrometer after dispersal in 0.1N NaOH solution containing 1% calgon (sodium meta hexa-phosphate), and the sand fraction determined by decantation of the clay plus silt suspension.

2. Moisture content.

The soil moisture content on the oven-dry basis was determined by heating in an oven for 24 hours at 105°C.

The maximum water holding capacity was determined by saturating, overnight, the soil contained in a porcelain dish with a porous bottom, and is expressed on oven-dry basis.

3. Moisture characteristic curve of soils.

For moisture tensions above one atmosphere the soil moisture contents (on oven-dry basis) at various soil moisture tensions were determined with the pressure membrane apparatus of Richards (1941).

For tensions below one atmosphere, suction through a layer of kaolin on No. 54 Waterman filter paper contained in a Buchner funnel was used and the suction pressure measured by means of a water or mercury manometer.

Using these methods, the soil moisture characteristics of soil 1 are shown in Table 3 below.

TABLE 3.

Moisture characteristics of soil 1.

p^F	Tension	*Mean moisture% (oven-dry basis)	Coefficient of variation
0.00	1cm.(water)	43.20±0.303	0.61
1.00	10cm. "	42.90±0.132	0.27
1.70	50cm. "	37.12±0.176	0.41
2.00	100cm. "	34.24±0.139	0.36
2.30	15.2cm.(Mercury)	28.13±0.454	1.41
3.00	76cm. "	12.66±0.231	1.60
3.70	5 Atmos.	7.30±0.172	2.06
4.00	10 "	6.58±0.011	0.15
4.18	15 "	5.62±0.121	1.88

*Mean of triplicate determinations plus or minus the standard error at 5% level.

The high reproducibility of the results indicates that the methods are very suitable for the determination of the soil moisture characteristics of the soils used in the present work. These are shown in Fig. 1,2,3,4 and 5.

General.

The chemical and physical characteristics of the soils used in the present work are shown in Table 4.

TABLE 4.

Characteristics of soils used for experiments.
(Oven-dry basis)

Soil	pH	% Org. C.	%N	% $CaCO_3$	%Clay	%Silt	%Sand	Texture*	M.W.H.C. %
1	6.50	1.32	0.15	0.18	11.00	25.00	63.00	Sandy Loam	43.20
2	6.67	3.50	0.44	1.40	12.00	14.00	70.00	Sandy Loam	60.00
3	6.46	13.88	2.27	4.40	-	-	-	Organic Soil	120.00
4	7.62	6.98	1.01	41.67	4.16	4.68	43.16	Calcereous Loamy Sand	80.00
5	4.58	3.90	0.50	0.38	28.00	21.00	47.00	Sandy Clay Loam	56.00
6	6.75	2.93	0.33	0.48	37.50	32.50	27.00	Clay Loam	70.00
7	5.05	5.28	0.62	0.28	28.00	22.50	44.50	Sandy Clay Loam	54.00
8	7.41	3.62	0.40	1.33	36.00	32.00	27.00	Clay Loam	70.00
9	6.12	1.66	0.23	0.22	10.00	27.00	61.00	Sandy Loam	54.00

* Determined with the U.S.D.A. soil identification diagram, Lyon et.al. (1952).

Fig 1: MOISTURE CHARACTERISTIC CURVES OF SOIL 1 AND SOIL 1 + 2% COMPOST

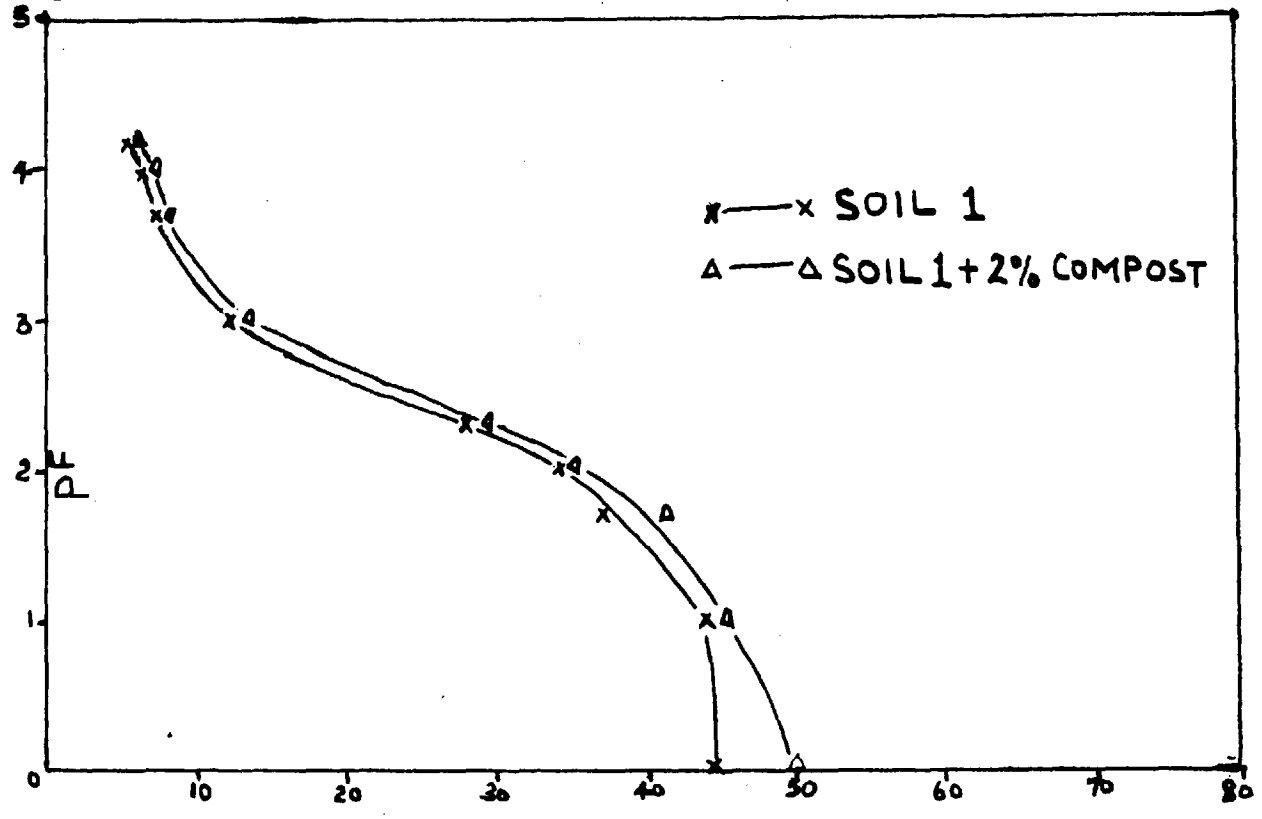


Fig. 2: MOISTURE CHARACTERISTIC CURVES OF SOIL 1+2% STRAW AND SOIL 2.

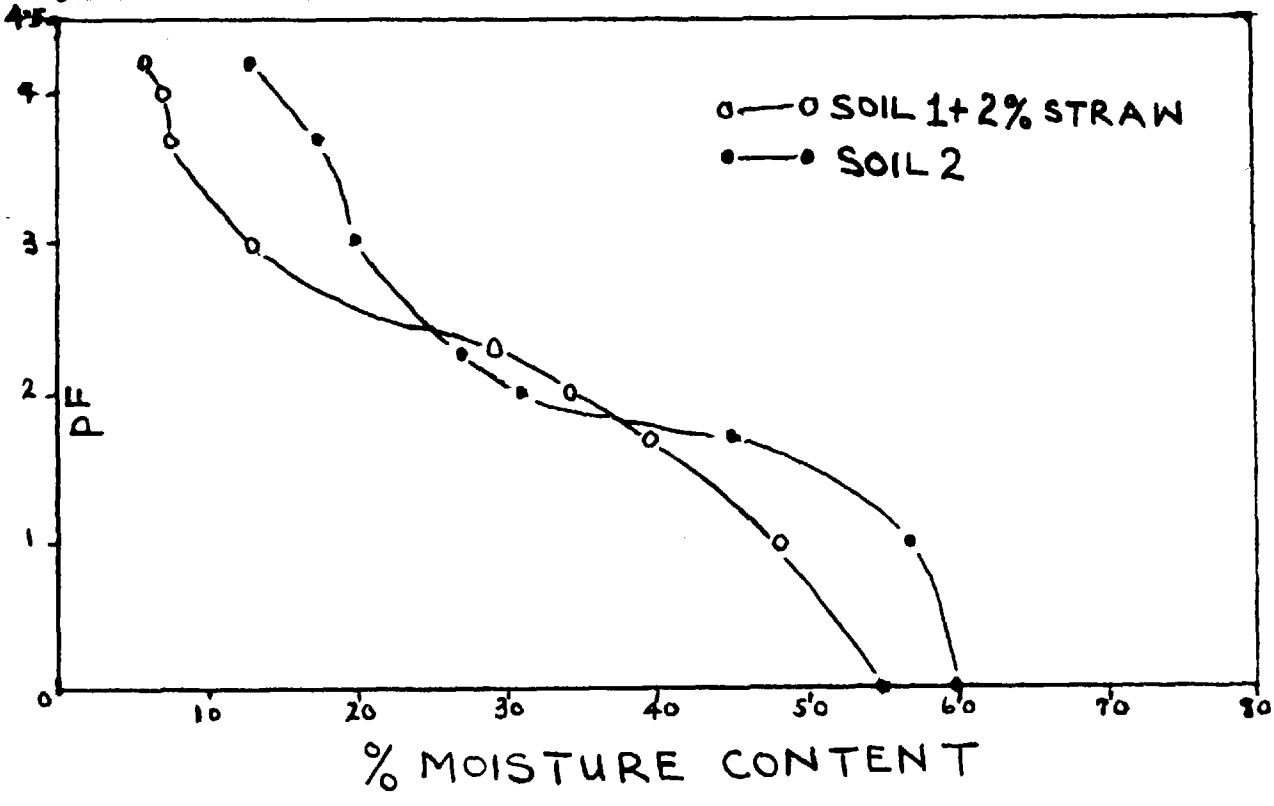


Fig.3; MOISTURE CHARACTERISTIC CURVE OF SOIL 3.

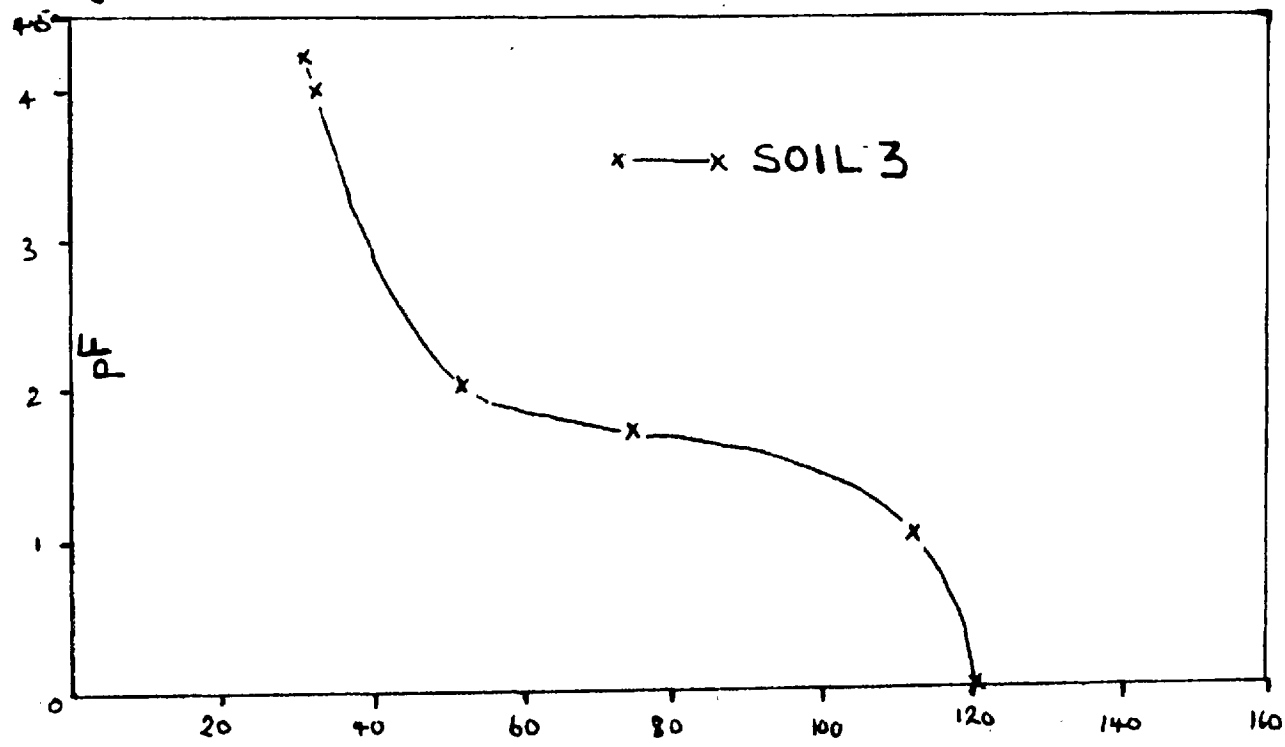


Fig.4: MOISTURE CHARACTERISTIC CURVES OF SOILS 4, 5 AND 6.

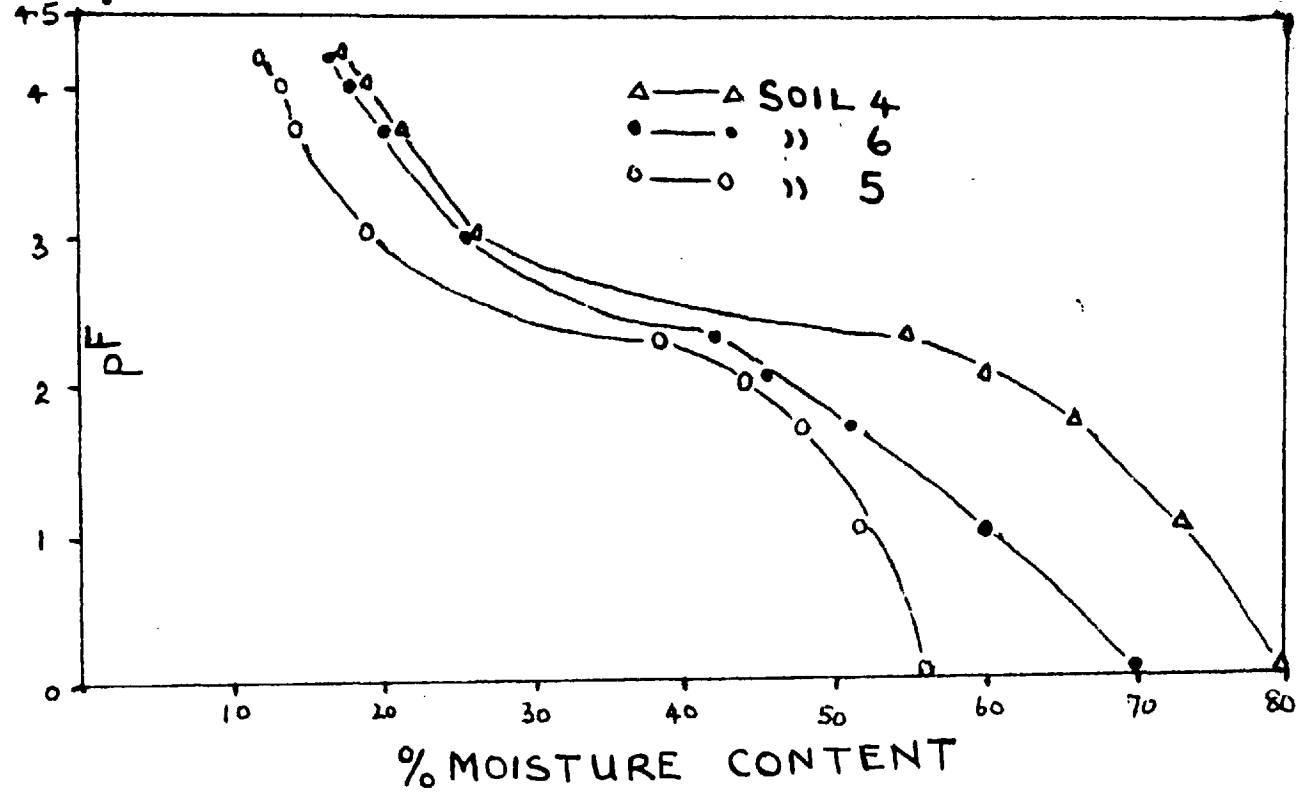
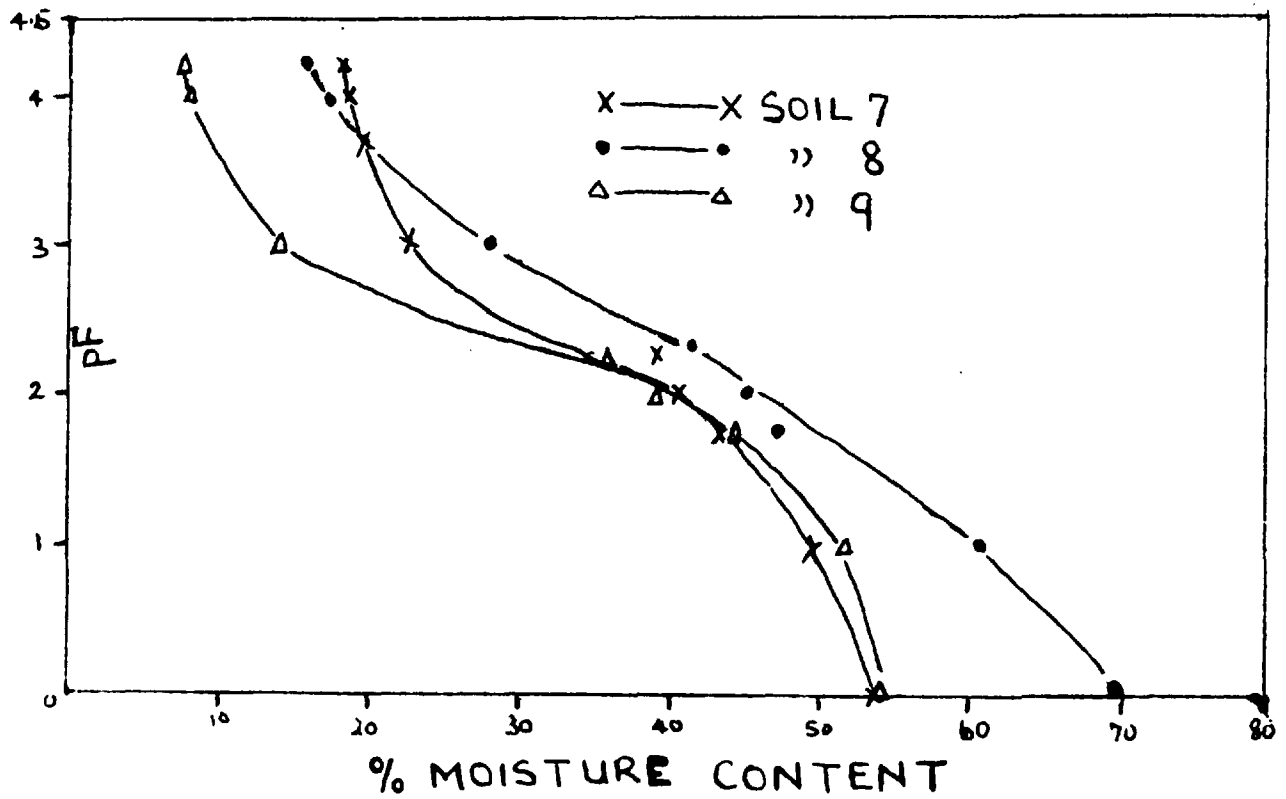


Fig. 5: MOISTURE CHARACTERISTIC CURVES OF SOILS 7, 8 AND 9.



Analysis of plant material for nitrogen, phosphorus and potassium.

For the analysis of the large numbers of samples of plant materials obtained during this study, accurate and rapid methods were required. Dickman and De Turk (1938), first employed the wet digestion with sulphuric acid and hydrogen peroxide for the determination of organic phosphorus in the soil. Later, Yuen (1948), employed it for the determination of phosphorus in plant materials.

The sulphuric acid and hydrogen peroxide wet digestion method was used for the determination of total nitrogen in the soil by Koch and McMeekin (1924), and they reported no loss of nitrogen when 30% H_2O_2 was used with sulphuric acid. Yuen and Pollard (1954), employed it for the determination of nitrogen in plant materials and obtained a complete recovery of ammonium-nitrogen but large losses of nitrate-nitrogen added to the plant materials in the digestion flask. They suggested, however, that the nitrate content of plants, except when they were very young, was negligible.

Potassium in plant materials is usually determined by the wet digestion of the plant materials with a mixture of nitric and perchloric acids (Parks et al. (1943), or with further addition of sulphuric acid (Piper, (1944). In this study, prior to flame photometric determination, wet digestion with sulphuric acid and hydrogen peroxide gave satisfactory results for potassium in plant materials.

In view of the fact that in this study total nitrogen contents of grass recently receiving heavy nitrate dressings were to be determined, and the possibility that some of this added nitrogen might be present in the plant tissue as nitrate thus giving rise to the possibility that some nitrogen might be lost through this source during the ordinary Kjeldahl or sulphuric acid-H_2O_2 digestion methods, the following study on the effects of salicylic acid plus thiosulphate on the recovery of nitrogen by both methods was carried out.

Materials.

Tops were taken from four grasses (Italian Rye-grass, Cocksfoot, Meadow fescues and Timothy) which had been grown in pot tests with (a) no nitrate and (b) heavy potassium nitrate (equivalent to 200 lb. N per acre every 2 weeks) treatments, and Italian Rye-grass grown in the field with (a) no nitrochalk, (b) 4 cwt. nitrochalk, and (c) 16 cwt. nitrochalk per acre. All materials were dried at 70°C and ground to a fine powder.

METHOD (I): Wet digestion (H_2SO_4 + H_2O_2).

To 0.2 g. of plant material accurately weighed into a dry 50 ml. conical flask, 2 ml. of conc. H_2SO_4 was added and the flask rotated to mix the contents. It was then heated on a hot plate until charring and fuming occurred. The flask was cooled, 1 ml. of 100 vol. H_2O_2 was added

and the flask heated again to fuming. This process was repeated, adding 0.5 ml. of H_2O_2 each time, until no colour appeared on heating to fuming.

METHOD (I+S): Wet digestion modified with salicylic acid and thiosulphate.

The procedure was as in method (I) except that the concentrated sulphuric acid contained 3 g. of salicylic acid per 100 ml. and that after the first cooling of the flask, before the addition of the 1 ml. H_2O_2 solution, about 0.1 g. of sodium thiosulphate pentahydrate ($Na_2S_2O_3.5H_2O$) was added to the contents of the flask.

For Methods (I) and (I+S), the digestion flask was finally cooled, the digest washed with water into a 50 ml. volumetric flask and made up to mark. The ammonia was determined by micro-distillation of a suitable aliquot of this solution.

METHOD (II): Kjeldahl digestion.

0.2 g. of the plant material was weighed into a 7 cm. No. 1 Watman filter paper, wrapped up and dropped into a dry 250 ml. Kjeldahl flask. 10 ml. of conc. H_2SO_4 was added and the flask heated on a low flame for 10 minutes with occasional shaking. The flask was then cooled. 3g. of K_2SO_4 and one drop of selenium oxychloride added and heated on a luminous full flame until the digest turned a straw colour. Thereafter, it was heated with a non-luminous flame so that it just simmered for one hour.

METHOD (II+S): Kjeldahl digestion modified with salicylic acid and thiosulphate.

The procedure was as in method (II) except that the conc. H_2SO_4 contained 3 g. of salicylic acid per 100 ml. and that 1.5 g. of sodium thiosulphate pentahydrate ($Na_2S_2O_3.5H_2O$) was added with the K_2SO_4.

For Methods (II) and (II+S) the flask was cooled after the digestion and the ammonia determined by distillation on the whole digest.

For all methods, appropriate blanks were done with filter paper replacing the plant material. All determinations were done in triplicates.

Phosphorus and potassium.

The phosphorus and potassium in the plant materials were determined on aliquots of the digest solutions from Methods (I) and (I+S).

Phosphorus was determined by the molybdenum blue-aminonaphthol sulphonic acid colorimetric method of Yuen and Pollard (1951).

Potassium was determined with the E.E.L. flame photometer.

Results.

The results are shown in Tables 5, 6 and 7.

Nitrogen (Table 5): The coefficients of variability of the means of the percentage nitrogen of the plant materials

determined by all the methods were less than 5%. The average coefficients for method (I) was 1.25%; method (I+S), 0.98%; method (II), 1.12%; and method (II+S), 0.74%. The coefficients were invariably higher for materials with low nitrogen content than for those with high nitrogen content, but the standard errors were independent of the nitrogen contents of the plant materials.

Results of the differences between the totals of the triplicate values of percentage nitrogen obtained by the various methods may be summarised as follows:

where (I) represents the totals determined by Method (I)
(I+S) " " " " " Method (I+S)
(II) " " " " " Method (II)
(II+S) " " " " " Method (II+S)

The values are arranged in descending order of magnitude and those included above the same horizontal line are not significantly different at 5% level.

For all plant materials (except Timothy) with no nitrate treatments and Italian Rye-grass with heavy nitrate treatment, there were no significant differences between the four methods.

For all plant materials (except Timothy and Italian Rye-grass) with heavy nitrate treatment and Italian Rye-grass with no nitrochalk and the heaviest nitrochalk treatments,

$$\underline{(II+S),\ (I+S),\ (I)}\ ,\ \underline{II}\ .$$

For Timothy with no and heavy nitrate treatments,

(II+S), (I+S) , (I) , (II)

For Italian Rye-grass with medium nitrochalk treatment

(II+S), (I+S) , (I) , (II)

Discussion.

Generally there was no significant difference between the nitrogen contents determined by all the methods for all plant materials with low nitrogen content. This would mean that it would not be necessary to modify either the wet digestion or the Kjeldahl method with salicylic acid when plant materials had received no nitrate treatment during growth and consequently had low nitrogen contents.

For materials from the high nitrate treatments and hence having high nitrogen contents, the nitrogen contents determined by the ordinary Kjeldahl method were significantly less than those determined by all other methods. It also meant that in this case, the Kjeldahl method should be modified by the addition of salicylic acid if all the nitrogen was to be recovered in the plant materials.

TABLE 5.

Percentage nitrogen in plant materials determined by two methods and their salicylic acid modifications.

Plant Materials	WET DIGESTION				KJELDAHL DIGESTION			
	I		I + Salicylic acid		II		II + Salicylic acid	
	%Nitrogen*	C**%	%Nitrogen	C%	%Nitrogen	C%	%Nitrogen	C%
Italian Rye-grass No NO_3	1.44±0.0766	4.08	1.45±0.0078	0.48	1.43±0.0253	1.57	1.45±0.0120	0.69
Italian Rye-grass Heavy NO_3	5.44±0.0550	0.95	5.46±0.0334	0.55	5.33±0.1548	2.55	5.45±0.0904	1.46
Timothy No NO_3	1.22±0.293	1.84	1.24±0.0078	0.57	1.21±0.0178	1.31	1.25±0.0078	0.57
" heavy NO_3	4.68±0.0234	0.45	4.75±0.0564	1.05	4.66±0.0548	1.03	4.76±0.0176	0.36
Cocksfoot No NO_3	1.01±0.0334	2.89	1.03±0.0430	3.69	1.03±0.0333	2.91	1.03±0.0176	1.53
" heavy NO_3	5.01±0.0196	0.35	5.01±0.0234	0.42	4.95±0.0120	0.20	4.96±0.0451	0.81
Meadow fescus No NO_3	1.34±0.0078	0.53	1.34±0.0178	1.18	1.31±0.0137	0.93	1.36±0.0353	2.32
" heavy NO_3	5.40±0.0293	0.47	5.42±0.0234	0.37	5.38±0.7960	1.31	5.45±0.0000	0.00
Italian Rye-grass No Nitrochalk	3.45±0.0430	1.10	3.47±0.0564	1.43	3.27±0.0078	0.22	3.48±0.0000	0.00
Italian Rye-grass x 4 Nitrochalk	3.56±0.0410	1.01	3.59±0.0392	0.96	3.47±0.0120	0.29	3.62±0.0000	0.00
Italian Rye-grass x 16 Nitrochalk	4.28±0.0000	0.00	4.28±0.0234	0.47	4.02±0.0000	0.00	4.28±0.0000	0.00

* Mean of triplicate determinations plus or minus the standard error at 5% level of probability.

** Coefficient of variability.

TABLE 6.

Percentage P_2O_5 of plant materials determined by wet digestion method and its modification with salicylic acid.

Plant Materials	Wet digestion		Wet digestion and Salicylic acid	
	% P_2O_5 *	C** %	% P_2O_5	C%
Italian Rye-grass No NO_3	0.682±0.0196	2.58	0.667±0.0138	1.74
Timothy No NO_3	0.442±0.0157	3.28	0.440±0.0000	0.00
Cocksfoot No NO_3	0.342±0.0157	4.24	0.346±0.0078	1.99
Meadow Fescues No NO_3	0.600±0.0196	2.88	0.598±0.0020	0.05
Italian Rye-grass No Nitrochalk	1.000±0.0000	0.00	1.080±0.0196	1.60
Italian Rye-grass 4 Nitrochalk	0.985±0.0550	5.08	0.993±0.0234	2.33
Italian Rye-grass 16 Nitrochalk	1.033±0.0650	5.60	1.070±0.0334	2.80

* Mean of triplicate determinations plus or minus the standard error expected at 5% level of probability.

** Coefficient of variability.

TABLE 7.

Percentage K_2O of plant materials determined by wet digestion method and its modification with salicylic acid.

Plant materials	Wet digestion		Wet digestion and Salicylic acid	
	% K_2O*	C**%	% K_2O	C%
Italian Rye-grass No NO_3	3.98±0.0392	0.87	4.00±0.0392	0.87
Timothy No NO_3	3.94±0.0392	0.88	4.02±0.0000	0.00
Cocksfoot No NO_3	4.06±0.0392	0.85	3.97±0.0138	0.31
Meadow Fescus No NO_3	4.58±0.0792	1.51	4.48±0.1900	3.85
Italian Rye-grass No Nitrochalk	4.33±0.0470	0.94	4.39±0.2550	5.10
Italian Rye-grass 4 Nitrochalk	3.77±0.0293	0.69	3.75±0.0000	0.00
Italian Rye-grass 16 Nitrochalk	3.43±0.0470	1.18	3.38±0.0860	2.23

* Mean of triplicate determinations plus or minus the standard error expected at 5% level of probability.

** Coefficient of variability.

There were no significant differences between the nitrogen contents determined for all the plant materials by the salicylic acid modifications of the wet digestion and the Kjeldahl methods and either of them could be used to recover all the nitrogen in the materials.

There were no significant differences between the nitrogen contents of all plant materials determined by the wet digestion method and those determined by its salicylic acid modification and it would seem that such modification was therefore unnecessary. This might be explained by the suggestion made by Yuen and Pollard (1954) that the organic carbon in the plant material might act as a reducing agent, reducing any nitrates to ammonia during the digestion when there was no salicylic acid to react with the nitrate and preserve it for eventual reduction by the sulphuric acid.

It is also possible that the hydrogen peroxide itself acts as a reducing agent in a way similar to its reaction with potassium permanganate where it would be an acceptor of oxygen. In this way it might reduce the nitrates to ammonia by accepting oxygen from the nitrate.

The temperature of digestion for the wet digestion was lower than that for the Kjeldahl digestion and this might account for the greater loss of any nitrates in the ordinary Kjeldahl digestion than in the ordinary wet digestion for materials from heavy nitrate treatments.

Phosphorus and Potassium.

Results: The results of the percentage phosphorus as P_2O_5 and potassium as K_2O of the plant materials as determined by the wet digestion method with or without the salicylic acid modification are shown in Tables 5 and 6.

The coefficients of variability were up to 5% only in two cases for phosphorus determined by the unmodified wet digestion method and in one case for potassium determined by the salicylic acid modified method. They generally increased with increasing phosphorus or potassium content.

Generally there were no significant differences between the percentages of potassium or phosphorus determined by the modified and unmodified wet digestion method.

Discussion: There is no doubt that at the temperatures of the wet digestion, there is no likelihood of losses of phosphorus and potassium occurring as a result of vaporisation. Furthermore, since there is an absolute certainty of complete oxidation of the organic matter, all the phosphorus in the organic form and the potassium within the fabric of the organic matter are released.

It is also seen that the addition of the salicylic acid and sodium thiosulphate during the digestion does not affect the subsequent colorimetric determination of phosphorus or flame photometric determination of potassium.

General conclusions.

The modification of the wet digestion method (H_2SO_4 + H_2O_2) with salicylic acid has been used to determine the nitrogen contents of plant materials. Results obtained were in close agreement with the nitrogen contents determined by the Kjeldahl method modified with salicylic acid. The nitrogen, phosphorus and potassium contents determined by this modified wet digestion method were in close agreement with those determined by the unmodified method, but because the results obtained by the modified method were, on the whole less variable than those obtained by the unmodified method, the former was adopted for the analysis of plant materials in the present work.

The method is convenient for doing large numbers of determinations, about six dozen samples can be digested in about one and a half hours and larger numbers on wider hot plates. Since the silica in the plant material seems to be dehydrated during digestion, as evidenced by the silica powder left sticking to the bottom of the digestion flask, calcium, magnesium and possibly iron and manganese can be determined immediately on the digest after appropriate neutralisation.

CHAPTER III

THE EFFECT OF VARIATIONS IN THE SOIL MOISTURE CONTENT (AIR-DRY TO WATER-LOGGING) ON THE MINERALIZATION OF CARBON AND NITROGEN AND THE AVAILABILITY OF PHOSPHORUS AND POTASSIUM

INTRODUCTION

Soil moisture content is one of the most important factors controlling the availability of plant nutrients in the soil and the physiological performance of the plant. In different parts of the world where rainfall is scarce, optimum soil moisture for crop production is mitigated by irrigation from lakes and rivers; where the rainfall is excessive flooding of farmlands results and optimum soil moisture for upland crops is obtained by land drainage. In many tropical countries, however, where rice is grown, flooding the soil during the period of rice growth is practised.

In the present chapter of this work, an attempt has been made to relate the soil moisture level with the mineralization of soil organic matter and the availability (Morgan's extracted) of soil phosphorus and potassium during the incubation of the soil. The mineralization of organic matter and the availability of phosphorus and potassium have also been studied (1) under simulated irrigation treatments of raising soil moisture from low to high levels and (2) under simulated drainage treatment of lowering soil moisture from high to low levels.

MATERIALS

Soil (2), a sandy loam soil, whose chemical and physical characteristics are shown in Table 4 and Fig. 2 and which received an annual application of about 4 cwt. of lime

per acre, was used for the experiment. The soil was collected from the top 6" layer, air-dried at a greenhouse temperature of 25°-30°C and ground to pass a 2 mm. sieve. The air-dry moisture content was determined on oven-dry basis.

The incubation was done in flat-bottomed sampling glass tubes 4" x 1" (internal diameter).

EXPERIMENTAL METHOD

10 g. samples of the well mixed soil were weighed into the glass tubes and given the following moisture treatments: air-dry (0), 10, 20, 30, 40, 50, 60, 70, 80, 90 and 100 per cent of the maximum water holding capacity (m.w.h.c.) and water-logged (133% m.w.h.c.) by adding to each sample 0, 0.5, 1.1, 1.7, 2.3, 2.9, 3.5, 4.1, 4.7, 5.3, 5.9 and 7.9 ml. of water respectively. Air-dry moisture content was 1.0% and maximum water holding capacity was 60% absolute moisture content (oven-dry basis).

The soil samples were mixed thoroughly by means of a thin glass rod to obtain an even distribution of the water. To avoid any loss of soil particles, the end piece of the glass rod which had been in contact with the soil was broken off and left in the soil sample.

Each moisture treatment 0 to 50% m.w.h.c. had 16 replicates and each moisture level 60 to 133% m.w.h.c. had 12 replicates. All samples and replicates, except those left air-dry, were incubated at 28°C with glass vials con-

taining a suspension of barium peroxide for mineral carbon determination. Duplicates of each moisture level treatment were analysed for mineralized carbon and nitrogen and for available (Morgan's extracted) phosphorus and potassium after three weeks and six weeks from the start.

At the end of six weeks, for each of the moisture level treatments 0 to 50% m.w.h.c., 4 replicates were left at the original moisture level, 4 were irrigated to 50% m.w.h.c. and 4 were irrigated to water-logging, by the addition of appropriate amounts of water; for each of the moisture level treatments 60 to 133% m.w.h.c., 4 replicates were left at the original moisture level, and 4 were dried in the greenhouse at a temperature of 25° to 30°C to 50% m.w.h.c. The drying was achieved by weighing the tubes twice a day and when the lower moisture levels dried to 50%, they were held there by appropriate additions of water until the higher moisture levels dried down. This took 48 hours to achieve.

Each sample was again mixed with a glass rod and incubated at 28°C. The carbon and nitrogen mineralization and the available phosphorus and potassium were then determined after three weeks and six weeks.

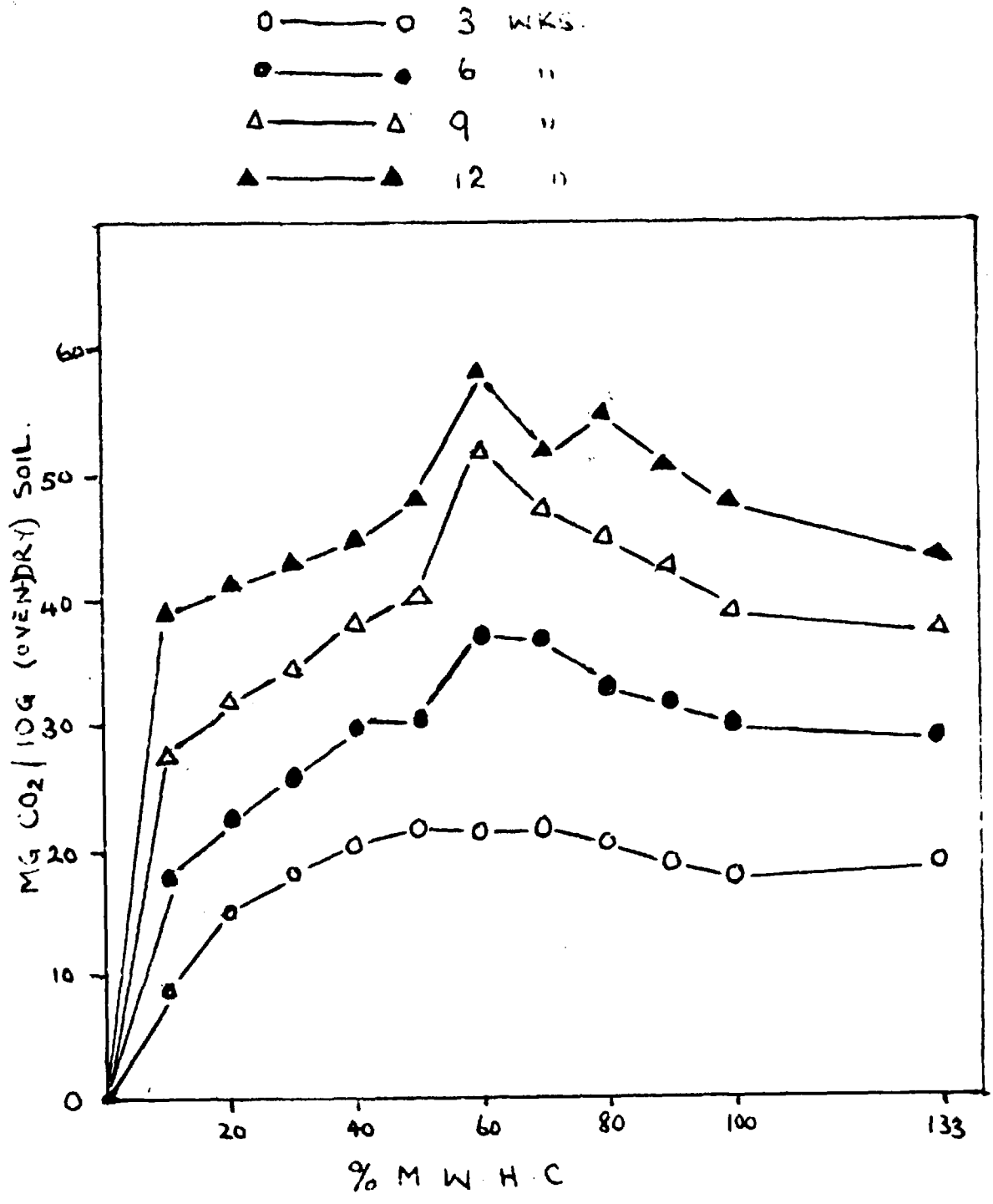
TABLE 8.

Mineralized carbon *(mg.CO_2/10g. soil oven-dry) during the incubation of soil 2 with various moisture treatments.

Original soil moisture levels (%m.w.h.c.)	At original soil moisture content during the whole incubation time				Changed to 50% m.w.h.c. for last 6 weeks		Water-logged (133%m.w.h.c.) for last 6 weeks	
	3 wks.	6 wks.	9 wks.	12 wks.	9 wks.	12 wks.	9 wks.	12 wks.
0	0	0	0	0	16.6	30.4	7.3	15.0
10	9.1	18.0	27.8	39.2	30.9	43.0	23.0	27.8
20	15.0	22.7	31.7	41.4	34.6	46.2	27.5	31.2
30	18.0	26.0	34.6	42.9	37.3	46.2	30.6	33.3
40	20.7	30.4	38.1	45.4	40.7	48.4	34.2	37.2
50	21.8	30.6	39.9	48.0	39.7	47.6	36.3	40.3
60	21.4	37.5	51.8	58.6	53.4	64.2	-	-
70	22.0	37.0	47.3	52.4	46.9	55.9	-	-
80	20.7	33.1	45.4	55.3	48.5	61.5	-	-
90	19.0	31.9	41.5	51.1	50.1	62.8	-	-
100	17.7	30.9	39.4	48.0	52.2	66.9	-	-
133	19.0	26.5	35.0	42.6	49.6	65.0	-	-

* Means of duplicate determinations.
L.S.D. (Least significant difference) = 4.3 at 5%, 5.8 at 1% and 7.5 at 0.1% levels.

Fig. 6: MINERALIZATION OF CARBON IN SOIL 2 INCUBATED AT DIFFERENT MOISTURE LEVELS.



Because of the self-sufficiency of the incubation tube closed system in which the evolved carbon dioxide was absorbed by the barium peroxide which in turn supplied the oxygen for respiration, there was no loss of water from the soil and the moisture contents were thus well controlled.

The mixing of the soil and the water was considered necessary especially in the lower moisture levels since, otherwise, the added drops of water formed saturated crumbs and diffused slowly and incompletely through the soil sample mass.

The mineralized carbon was determined as mg. CO_2 per 10 g., the mineral nitrogen, ammonium- and nitrate-nitrogen determined as p.p.m. less the original soil content, the available phosphorus as P_2O_5 p.p.m. and the available potassium as K_2O p.p.m., all based on the oven-dry soil.

N.B.

Throughout this chapter where a water percentage is given (e.g. 50%) it refers to percentage of the maximum water holding capacity.

(1) Mineralized Carbon.

(a) Soil moisture content, 0-133%.

(i) Results.

The carbon dioxide produced during twelve weeks incubation at the original soil moisture levels 0 to 133% is shown in columns 2 to 5 of Table 8 and graphically in Fig. 6.

During the first three weeks incubation the carbon dioxide production increased with increasing moisture level up to 50%, remained constant till 70% and then decreased slightly with further increases in the soil moisture till 100%. At water-logging it increased again slightly.

At six and nine weeks incubation the total carbon dioxide production also increased with increasing moisture but to a maximum at 60% (optimum moisture level) and then decreased with further increases in the soil moisture level. At twelve weeks incubation, the same trend of carbon dioxide production was observed except that there were two maxima, one at 60% and the other at 80%.

The significance at 5% level of probability of the differences between the mean carbon dioxide values may be summarised as follows:

Where the original soil moisture level represents the mean carbon dioxide values in descending order of magnitudes and figures above the same line are not significantly different from one another but are significantly different from all others.

At 3 weeks: 70, 50, 60, 40, 80, 90, 133, 30, 100, 20, 10, 0

At 6 weeks: 60, 70, 80, 90, 100, 50, 40, 133, 30, 20, 10, 0

At 9 weeks: 60, 70, 80, 90, 50, 100, 40, 133, 30, 20, 10, 0

At 12 weeks: 60, 80, 70, 90, 50, 100, 40, 30, 133, 20, 10, 0

Generally, from six weeks incubation, the total carbon dioxide produced was higher at the higher moisture levels above 50% than that at the lower moisture levels up to 40% except at water-logged where it was consistently lower than that at 40%.

(ii) Discussion.

The greater part of the bodies of micro-organisms is made of water and they depend on water for reproduction and vital activities. The results of carbon dioxide production obtained here after three weeks incubation show that although the carbon dioxide production increased with increasing soil moisture up to an optimum between 50%and 70% there was no significant difference between the carbon dioxide produced at moisture levels ranging from 30% to 133%, and that within this range within a period of three weeks microbial activity was independent of the soil moisture level. Below this range of soil moisture however, soil moisture seemed to be limiting microbial activity.

The fact that the carbon dioxide produced at moisture levels of 50% to 100% was generally greater than that produced at lower moisture levels after six weeks incubation agrees closely with the results of Stover (1953), who showed that the optimum moisture level for bacterial activity was 75% of the water holding capacity although here the optimum microbial activity occurred at 60%.

Several other workers have, however, reported that organic matter decomposition and microbial numbers increased with increasing soil moisture to near saturation (i.e. 100%). (Gorbunov and Tokarev (1946) and Weissenberg (1954)).

With increase in soil moisture, the solubility of oxygen in soil water tends to approach that in open water (Runkles et al. (1958); there are possibilities of the existence of large numbers of strictly aerobic bacteria even in water-logged soil (Mukerji and Vishnoi (1936)) and the respiration of water-saturated soil crumbs is not inhibited unless the oxygen concentration is extremely low (Greenwood (1961)).

In the partially aerobic media represented by the soil samples at 60 to 100% there might be a mixed population of micro-organisms, strict aerobes, facultative aerobes and strict an-aerobes actively decomposing the organic matter and thus producing more carbon dioxide than at lower moisture levels where strictaerobes would predominate.

At water-logging, the carbon dioxide production was generally reduced since here water was standing 0.5 cm. above the soil surface, anaerobiosis was more complete and only anaerobic respiration was important. The carbon mineralization being higher at the higher moisture levels near saturation than at lower moisture levels below 50% may obtain in this soil which is a sandy loam. This may possibly not be the

Fig. 7: MINERALISATION OF CARBON IN SOIL 2 INCUBATED WITH VARIOUS MOISTURE TREATMENTS (0-50% M.W.H.C.)

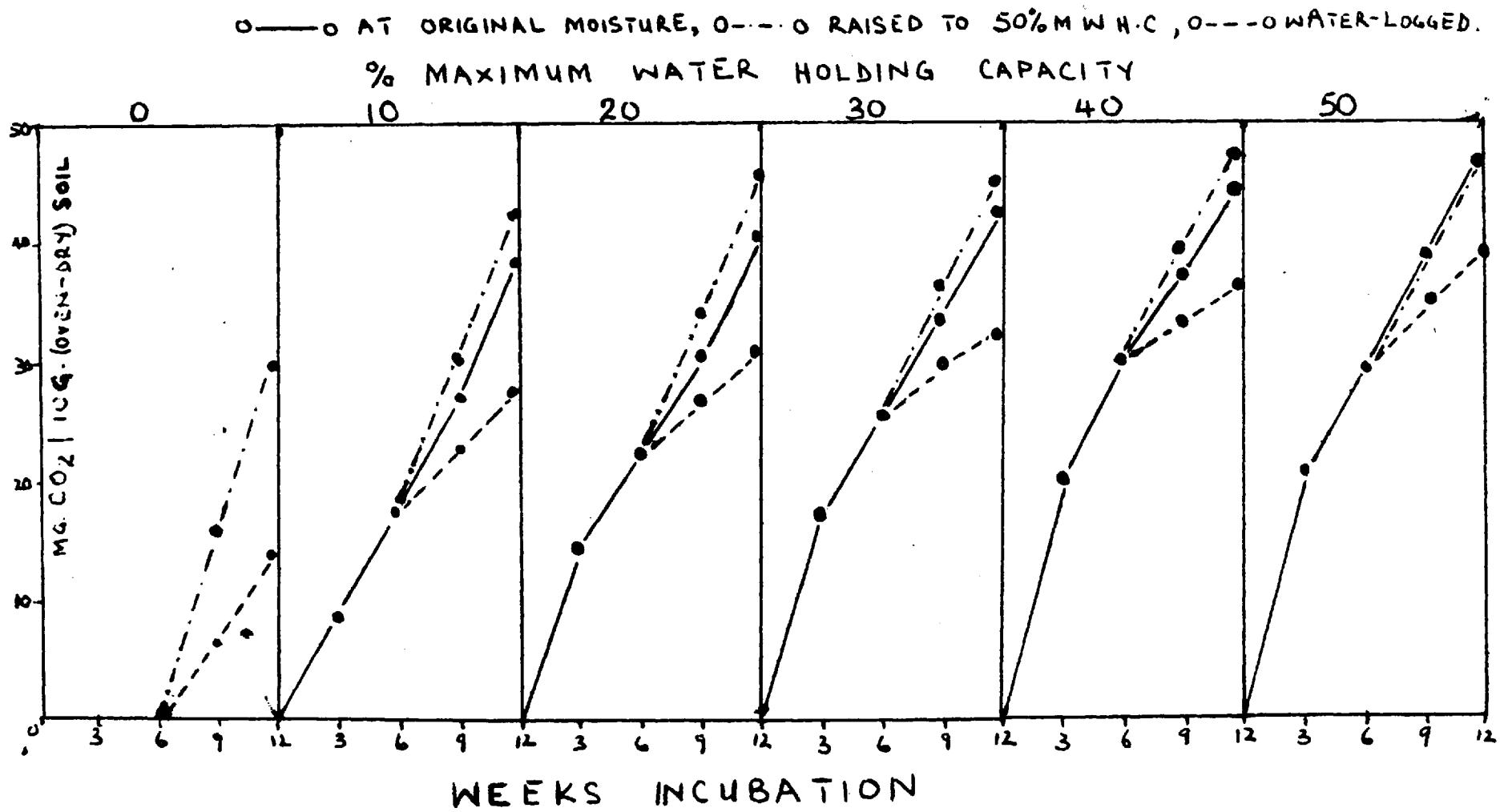
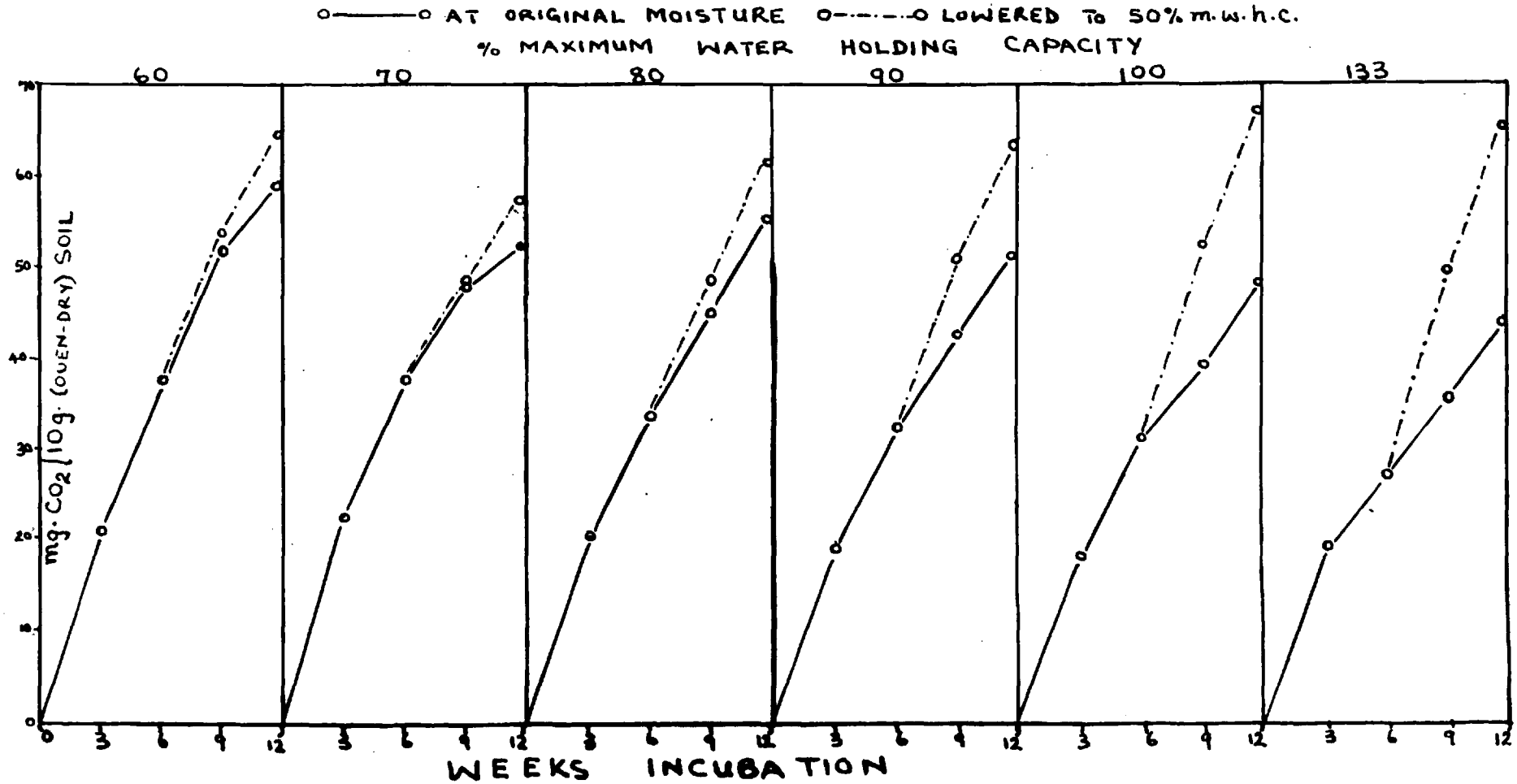


Fig. 8: MINERALISATION OF CARBON IN SOIL 2 INCUBATED WITH VARIOUS MOISTURE TREATMENTS (ORIGINAL, 60-133% M.W.H.C.)



case with more clayey soils where greater degrees of anaerobiosis may be obtained at similar high moisture levels.

(b) Change of original soil moisture levels to 50% or to water-logging.

(i) Results:

The total carbon dioxide produced when the soil at original moisture levels of 0 to 40% was irrigated to 50% and that at original moisture levels of 60 to 133% were dried to 50% are shown in columns 6 and 7, while that produced when the soil at original moisture levels of 0 to 50% were irrigated to water-logging is shown in columns 8 and 9 all of Table 8. These values include the carbon mineralized at the original moisture levels prior to the change in moisture levels.

The changes in the rate of carbon dioxide production accompying the changes in moisture levels are shown in Fig. 7 and 8. The carbon dioxide produced within six weeks as a result of this change has been built into Table 9 and Fig. 9 by subtracting the values of carbon dioxide produced in the initial six weeks at the original moisture levels from the values after the next six weeks incubation at the same original moisture levels (c), at the new moisture level of 50% (a), and at the new moisture level of water-logging (b).

The results show that on changing the original moisture from low or high levels to 50%, there is an increase in the rate of carbon dioxide production over the rate in the

soil continuously maintained at the original moisture levels. This increase in the rate of carbon dioxide production resulted in total carbon dioxide production which increased with decreasing original soil moisture levels below 50% and increased with increasing original soil moisture levels above 50%.

The results also show that on changing the original moisture levels from low to water-logging, there was a highly significant decrease in the rate of carbon dioxide production compared with the rate in the soil continuously maintained at the original moisture levels. This decrease in the rate of carbon dioxide production resulted in total carbon dioxide production which also tended to increase, though not significantly, with decreasing original soil moisture levels. The decrease in the rate of carbon dioxide production did not, however, apply to the air-dry original moisture level where hitherto, there had been no carbon mineralization.

In the soil maintained continuously at the original moisture levels, the rate of carbon dioxide production remained constant and the resultant total carbon dioxide production was more or less similar for all moisture levels with a few significant differences.

The differences between the carbon dioxide produced when the change in moisture level was to 50% and when no change in moisture took place was (a)-(c) and the difference when the change was to water-logging was (b)-(c).

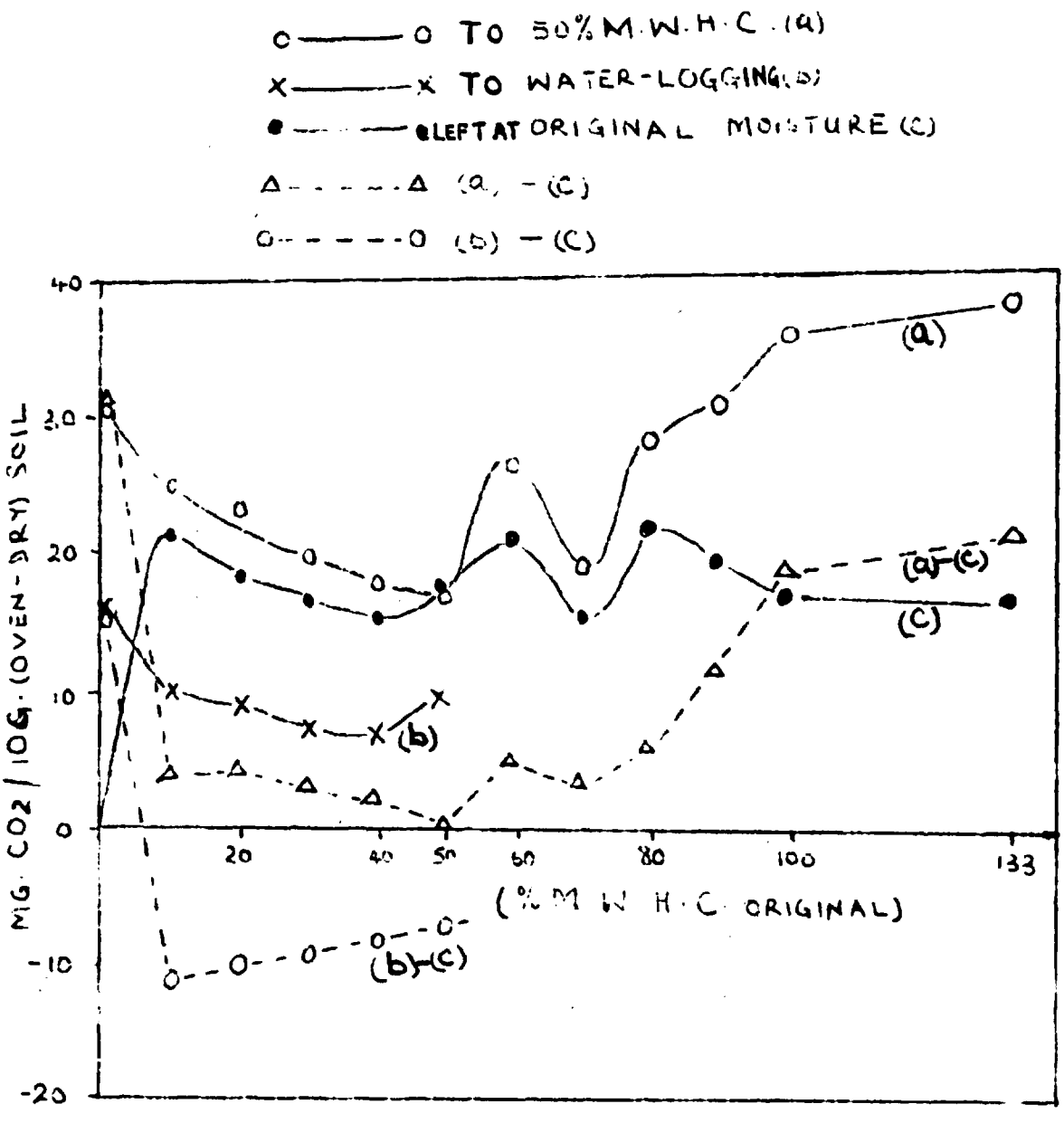
TABLE 9.

Carbon mineralized (mg.CO_2/10g. soil, oven-dry) in soil 2 after changing the original moisture levels from below and above 50% to 50% and from below 50% to water-logging.

Original moisture levels(%m.w.h.c.)	(a)To 50%	(b)To water-logging	(c)Left at original moisture levels	(a) - (c) Increase at 50% compared with that left at original moisture level.	(b) - (c) Increase at water-logging compared with that left at original moisture level
0	30.4	15.0	0	30.4	15.0
10	25.0	9.8	21.2	3.8	-11.3
20	23.4	8.5	18.7	4.7	-10.2
30	20.1	7.3	16.8	3.3	-9.5
40	17.9	6.7	15.0	2.9	-8.2
50	17.0	9.7	17.3	0.0	-7.6
60	26.7	-	21.0	5.6	-
70	18.8	-	15.3	3.5	-
80	28.3	-	22.1	6.1	-
90	30.9	-	19.2	11.6	-
100	35.9	-	17.0	18.9	-
133	38.5	-	16.0	22.4	-

L.S.D., (a), (b) and (c) = 4.0 at 5%, 5.3 at 1% and 7.1 at 0.1% levels.

Fig.9: CARBON DIOXIDE PRODUCED AFTER CHANGING THE ORIGINAL MOISTURE LEVEL FROM ABOVE AND BELOW 50% TO 50% M.W.H.C. AND FROM UP TO 50% TO WATER-LOGGING.



The former shows that carbon dioxide production was increased by the change in the moisture level to 50% while the latter shows (except for air-dry original moisture level) that it was reduced by the change in moisture levels to water-logging.

For original soil moisture levels below 50%, there was no significant advantage in so far as carbon mineralization is concerned, in increasing the moisture level to 50% except if it was originally at below 20% but there were significant advantages in reducing the original moisture level from above to 50% except if it was at 70%.

On the other hand, there were very significant disadvantages in increasing the original moisture below 6.0% to water-logging except if it was originally air-dry.

The significance of the differences between the carbon dioxide produced after the change in the original moisture may be summarised as follows:

(a) To 50%: 133, 100, 90, 0, 80, 60, 10, 20, 30, 70, 40, 50

(b) To water-logged: 0, 10, 50, 20, 30, 40

(c) Unchanged at original soil moisture:

80, 10, 60, 90, 20, 50, 100, 30, 133, 70, 40, 0

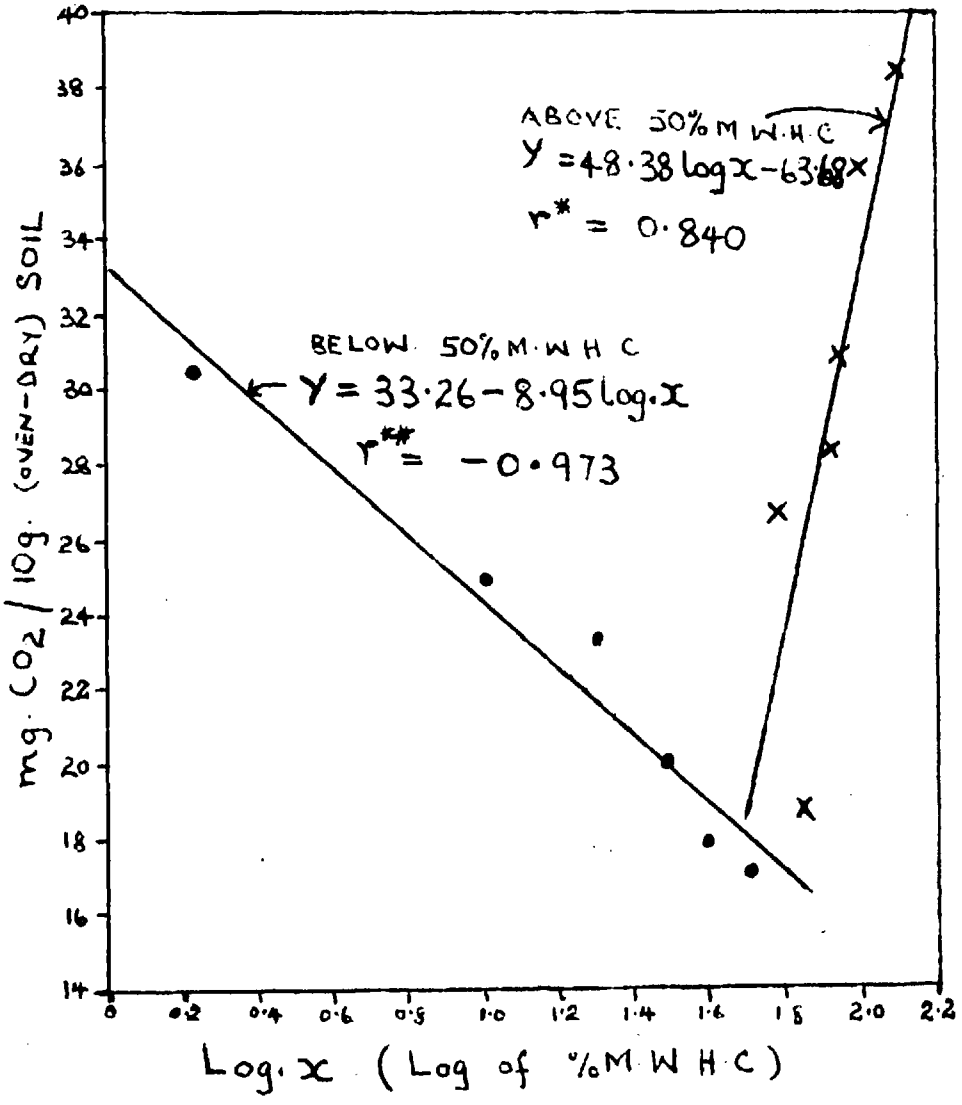
(ii) Discussion.

It has been shown that at low soil moisture levels, moisture was a controlling factor in carbon mineralisation. Within this range of soil moisture therefore, the higher the original soil moisture level, the more the easily mineralizable organic carbon was depleted and so the less that remained for mineralization when the optimum moisture level (50%) was subsequently applied.

There is a flush of organic matter decomposition on wetting air-dried soils, as a result of a rapid increase in microbial numbers (Birch (1958)). The samples here originally at low moisture levels were really at different "levels of drought" and the significant increases over the carbon dioxide produced when the moisture levels were unchanged observed for original moisture levels below 20% when changed to 50% shows that this effect of drought in producing a flush of decomposition becomes significant only when the samples were originally at less than 20% maximum water-holding capacity.

That the first notion may be as important as the second is shown by the highly significant negative correlation ($r = -0.969$ significant at 1% level) between the carbon dioxide produced after irrigating the lower moisture levels to 50% and that produced before the irrigation shown in Fig. 11 and by the equally highly significant negative correlation ($r = -0.973$ significant at 1% level) between the carbon

Fig.10: LINES OF REGRESSION OF THE CARBON DIOXIDE PRODUCED AFTER CHANGING THE SOIL MOISTURE LEVELS FROM ABOVE AND BELOW 50% TO 50% M.W.H.C. ON THE LOG OF THE ORIGINAL MOISTURE LEVELS.



** SIGNIFICANT AT 1% LEVEL

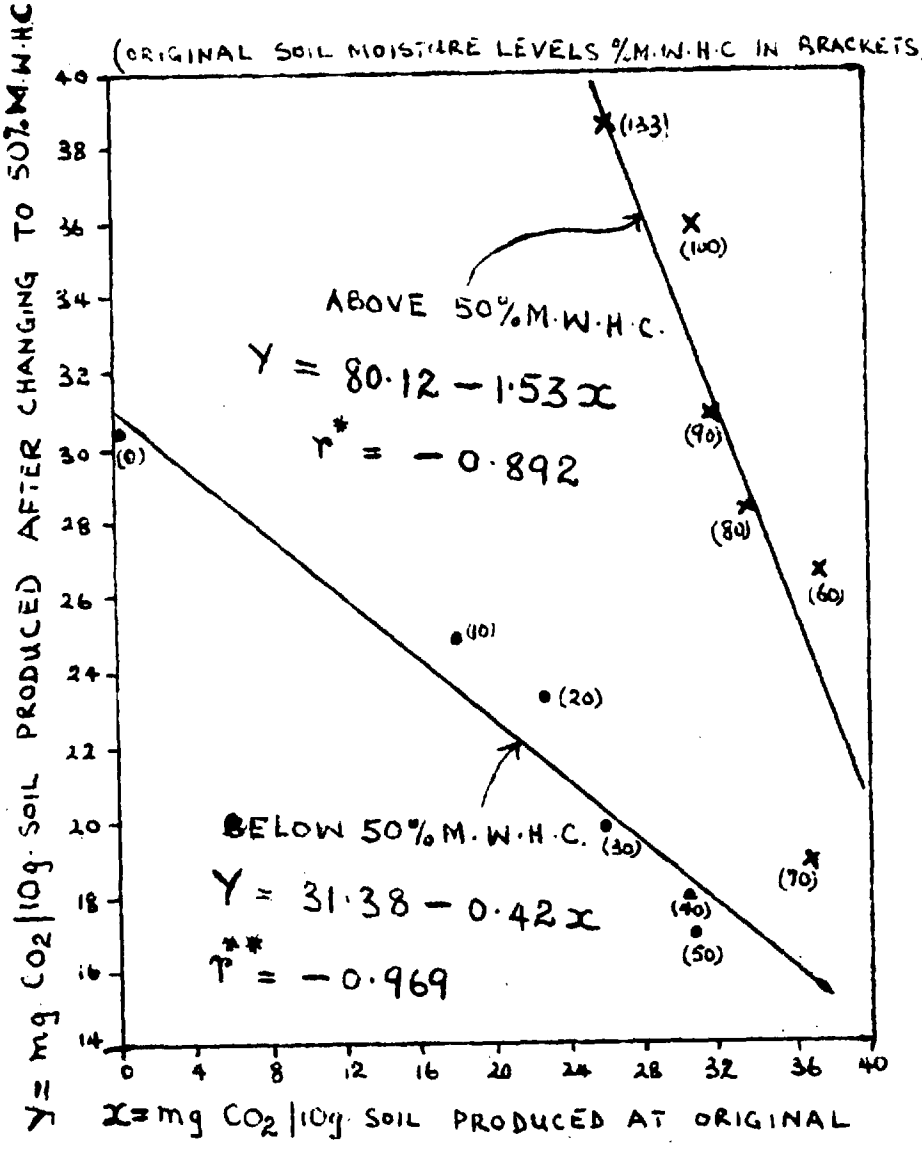
* " " 5% "

dioxide produced after irrigating the lower moisture levels to 50% and the logarithm of the moisture level before the irrigation shown in Fig. 10. The regression equation of the former relationship is $Y = 31.38 - 0.42x$ and that of the latter is $Y = 33.26 - 8.95\log x$. Thus Y is about the same when the mineralized carbon was nil and the degree of drought most severe and also about the same value when the mineralized carbon was highest and degree of drought least severe before the irrigation.

On increasing the lower moisture levels to water-logging, anaerobic conditions were created and anaerobic microbial activity was predominant. There is a possibility that some easily mineralizable organic carbon would still exist, hence the carbon dioxide produced even though always lower than at the unchanged moisture levels, increased with decreasing original soil moisture as shown by curve (b) of Fig. 9.

At continuously maintained soil moisture levels above 50%, the degree of anaerobiosis increased with increasing soil moisture and as a result carbon mineralization decreased from 60% to water-logging. Increased anaerobiosis would therefore result not only in a higher residual easily mineralizable organic carbon originally present in the soil, but also in an increased **accumulation** of easily oxidizable organic carbon derived from anaerobic respiration (Scott and Evans (1955), viz. methane, alcohol, lactic acid, butyric acid and various other complex organic compounds (Waksman (1952)).

Fig·11: LINES OF REGRESSION OF CO_2 PRODUCE AFTER ON CO_2 PRODUCED BEFORE CHANGING THE ORIGINAL SOIL MOISTURE LEVELS FROM ABOVE AND BELOW 50% TO 50% M·W·H·C.



** SIGNIFICANT AT 1% LEVEL

* " " 2% "

Anaerobiosis brought about by excess moisture would have the effect of reducing the numbers of aerobic microbes, whilst drying the soils would reduce the numbers of all microbes. Thus drying soil at high moisture levels down to 50% would result in increases in carbon mineralization over that occurring at undried levels because of the two reasons stated above. The importance of these for the results obtained here is shown by the highly significant negative correlation ($r = -0.892$ significant at 2% level) between the carbon dioxide produced after drying and that produced before drying to 50% (Fig. 11) and also by the significant positive correlation ($r = 0.840$ significant at 5% level) between the carbon dioxide produced after drying and the logarithm of the original soil moisture (above 50%) before drying, (Fig. 10). The regression equation for the former relationship is $Y = 80.12-1.53x$ and for the latter, $Y = 48.38\log x - 63.68$, from the significance of the correlation coefficients, it seems that the accumulation of or the residual easily oxidizable organic carbon may be more important than high moisture levels in determining the amount of carbon mineralization when excess moisture is removed from the soil at originally high moisture levels.

From Fig. 9 and Table 9, it is evident that there is a consistent decrease in carbon dioxide production at 70% compared with that at 60% before there is a final general trend in the relationship between the original moisture

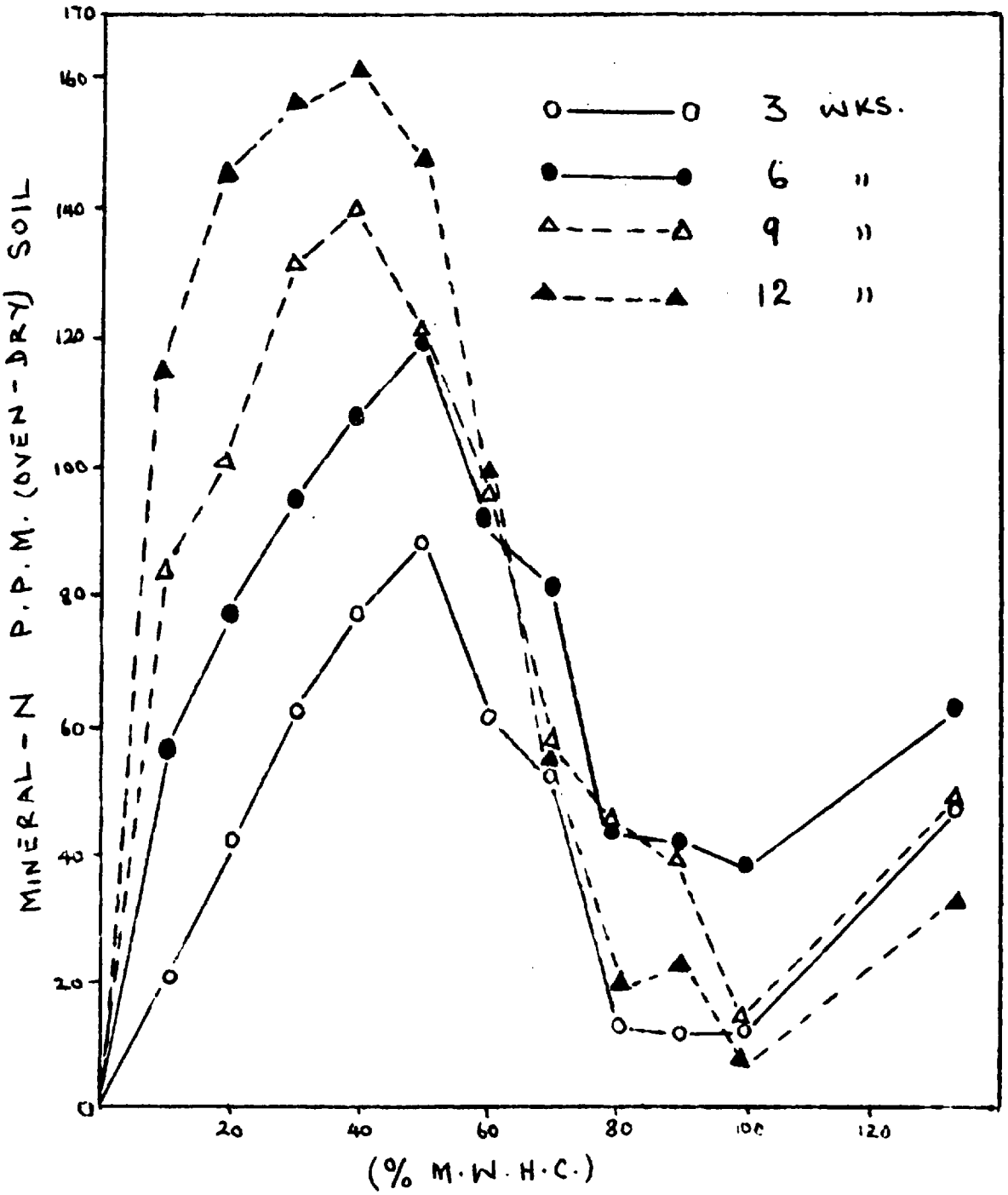
TABLE 10.

Mineralized nitrogen (p.p.m. soil oven-dry) during the incubation of soil 2 with various moisture treatments.

Original soil moisture levels (%m.w.h.c.)	At original soil moisture content during the whole incubation time				Changed to 50% m.w.h.c. for last 6 weeks		Water-logged (133%m.w.h.c. for last 6 weeks	
	3 wks.	6 wks.	9 wks.	12 wks.	9 wks.	12 wks.	9 wks.	12 wks.
0	0	0	0	0	100.8	154.0	50.4	33.6
10	21.0	56.0	83.8	116.2	90.0	134.0	21.0	32.2
20	42.0	77.0	100.8	145.6	115.6	141.0	11.2	32.2
30	62.3	94.5	131.6	156.8	98.0	148.4	11.2	25.0
40	76.5	107.8	140.0	162.2	123.2	162.2	9.6	23.8
50	88.6	119.0	120.0	147.0	119.0	147.0	18.2	30.8
60	61.5	91.0	95.0	98.0	112.0	200.4	-	-
70	52.3	81.2	58.0	51.8	124.6	131.6	-	-
80	14.0	43.4	44.8	19.6	50.4	84.0	-	-
90	12.6	42.0	40.2	23.8	22.4	72.8	-	-
100	12.6	37.8	14.0	8.4	50.4	61.6	-	-
133	48.3	65.8	49.0	33.6	78.4	107.8	-	-

L.S.D. (means) = 9.6 at 5%, 12.7 at 1% and 16.5 at 0.1% levels.

Fig.12: MINERALIZATION OF NITROGEN IN SOIL 2 INCUBATED AT DIFFERENT MOISTURE LEVELS.



level and carbon dioxide produced. This decrease occurs whether the original moisture levels were reduced to 50% or not. 70% seems therefore to be the critical moisture level above which the effects of anaerobiosis produced by soil moisture become pronounced.

2. Mineralized Nitrogen.

(a) Soil moisture content, 0-133%.

(i) Results.

The mineralized nitrogen (NH_4-N+NO_3-N) produced during twelve weeks incubation at the original soil moisture levels 0 to 133% is shown in columns 2 to 5 of Table 10 and graphically in Fig. 12.

At three and six weeks incubation, the mineralized nitrogen increased with increasing soil moisture up to the optimum of 50%, then decreased rapidly with further increases in soil moisture to low values at 90 and 100% and finally increased at water-logging.

Similar trends were observed for the nine and twelve week periods except that the optimum moisture level shifted from 50 to 40%. The significance of the differences between the mineralized nitrogen produced at the various moisture levels may be summarised as follows:

At 3 weeks: 50, 40, 30, 60, 70, 133, 20, 10, 80, 90, 100, 0.

At 6 weeks: 50, 40, 30, 60, 70, 20, 133, 10, 80, 90, 100, 0.

At 9 weeks: 40, 30, 50, 20, 60, 10, 70, 133, 80, 90, 100, 0.

At 12 weeks: 40, 30, 50, 20, 10, 60, 70, 133, 90, 80, 100, 0.

(ii) Discussion.

Since organic carbon and organic nitrogen are so intimately related in the soil, any soil conditions which limit carbon metabolism may be expected to limit nitrogen metabolism. At soil moisture levels below 50% soil moisture was a limiting factor for nitrogen mineralization just as it was for carbon mineralization.

On moistening a dry soil the maximum microbial population is quickly attained, the culture soon becomes aged and microbial activity decreases in later generations (Birch (1958)). This might have happened here at the optimum moisture level of 50% so that after six weeks incubation, the microbial activity decreased, while at lower moisture levels the moisture deficit delayed the attainment of the maximum microbial numbers. The rate of mineralization would therefore continue to be high for a longer period at 40% than at 50% hence the shift in the maxima of mineralization from 50% to 40% as time of incubation increased. The same reasoning may

show why the differences between the mineralized nitrogen at 40% and 30% were insignificant at this same incubation period.

Nitrification in water-logged or nearly saturated soils (Michniewicz (1951) and Cyplenkin and Schilin (1936) is slow, but ammonification is high (Traaen (1916) (Kapp (1933) and (Bamji (1938)). At the high moisture levels above 50% nitrogen mineralization may be expected; but because of the partial or complete anaerobiosis imposed by the excess soil moisture, mineralized nitrogen may be lost by assimilation by a mixed population of aerobes, anaerobes and facultatives thriving in the partially anaerobic media. In the presence of free carbonates derived from this soil which was limed annually and excessive soil moisture, the soil pH may increase (Subrahmanyan (1927)) and (Kapp (1933)). These conditions are ideal for ammonia volatilization (Wahhab et al. (1957)).

Nitrification of some accumulated ammonium takes place in partially anaerobic soils and the denitrification of the nitrate produced by anaerobic denitrifiers may also be taking place at the same time (Wijler and Delwiche (1954)) and (Arnold (1954)) especially if carbon mineralization is vigorous (Bremner and Shaw (1958)). At moisture levels between 60 and 100%, loss of mineralized nitrogen through these various means would be balanced against the nitrogen mineralized. The losses increased with increasing partial anaerobiosis and so accumulation of mineral nitrogen decreased with increasing soil moisture levels from 60% to 100%.

At complete water-logging the medium would be completely anaerobic and mineralized nitrogen loss would be mainly by denitrification of any nitrates originally present. Because ammonia volatilization decreases on water-logging (Wahhab et al. (1957)), the accumulated mineral nitrogen was higher than in the partially anaerobic conditions created by near-saturation moisture levels.

Alternatively, it may be possible that carbon mineralization takes place without concommitant nitrogen mineralization (Birch (1960)) and that the low mineralized nitrogen observed at the high moisture levels was due to this fact and not to the loss of the mineralized nitrogen.

Nitrate- and ammonium-N.

(i) Results.

It was found as shown in columns 2 to 5 of Tables 11 and 12 and in Fig. 13 that at moisture levels up to 50% maintained continuously during the twelve weeks incubation no ammonium-nitrogen accumulated and that values of mineralized nitrogen represent only nitrate-nitrogen.

At moisture levels above 50%, in the first three weeks, ammonium-N accumulation was observed only for moisture levels above 90%. After six weeks the ammonium-N accumulated at all the moisture levels and increased with increasing moisture level. After nine and twelve weeks, ammonium-N

TABLE 11.

Nitrate-N (p.p.m. soil oven-dry) accumulated during the incubation of soil 2 with various moisture treatments.

Original soil moisture levels (% m.w.h.c.)	At original soil moisture content during the whole incubation time				Changed to 50% m.w.h.c. for last 6 weeks		Water-logged (133% m.w.h.c.) for last 6 weeks	
	3 wks.	6 wks.	9 wks.	12 wks.	9 wks.	12 wks.	9 wks.	12 wks.
0	0	0	0	0	100.8	154.0	-33.6	-4.2
10	21.0	56.0	84.8	116.2	90.0	134.0	-9.8	32.2
20	42.0	77.0	100.8	145.6	115.6	141.0	11.2	32.2
30	62.3	94.5	131.6	156.8	98.0	148.4	11.2	25.0
40	76.5	107.8	140.0	162.2	123.2	162.2	9.6	23.8
50	88.6	119.0	120.0	147.0	119.0	147.0	18.2	30.8
60	61.5	77.0	79.6	84.0	98.0	200.4	-	-
70	52.3	58.8	23.0	37.8	103.6	131.6	-	-
80	14.0	-23.8	-6.4	-15.4	32.2	84.0	-	-
90	-23.8	-26.6	-17.2	-22.4	-9.8	72.8	-	-
100	-30.8	-36.4	-35.0	-29.4	30.8	61.6	-	-
133	-27.3	-29.4	-7.0	-25.2	50.4	107.8	-	-

Fig. 13: NO_3-N AND NH_4-N ACCUMULATION IN SOIL 2 INCUBATED AT DIFFERENT MOISTURE LEVELS.

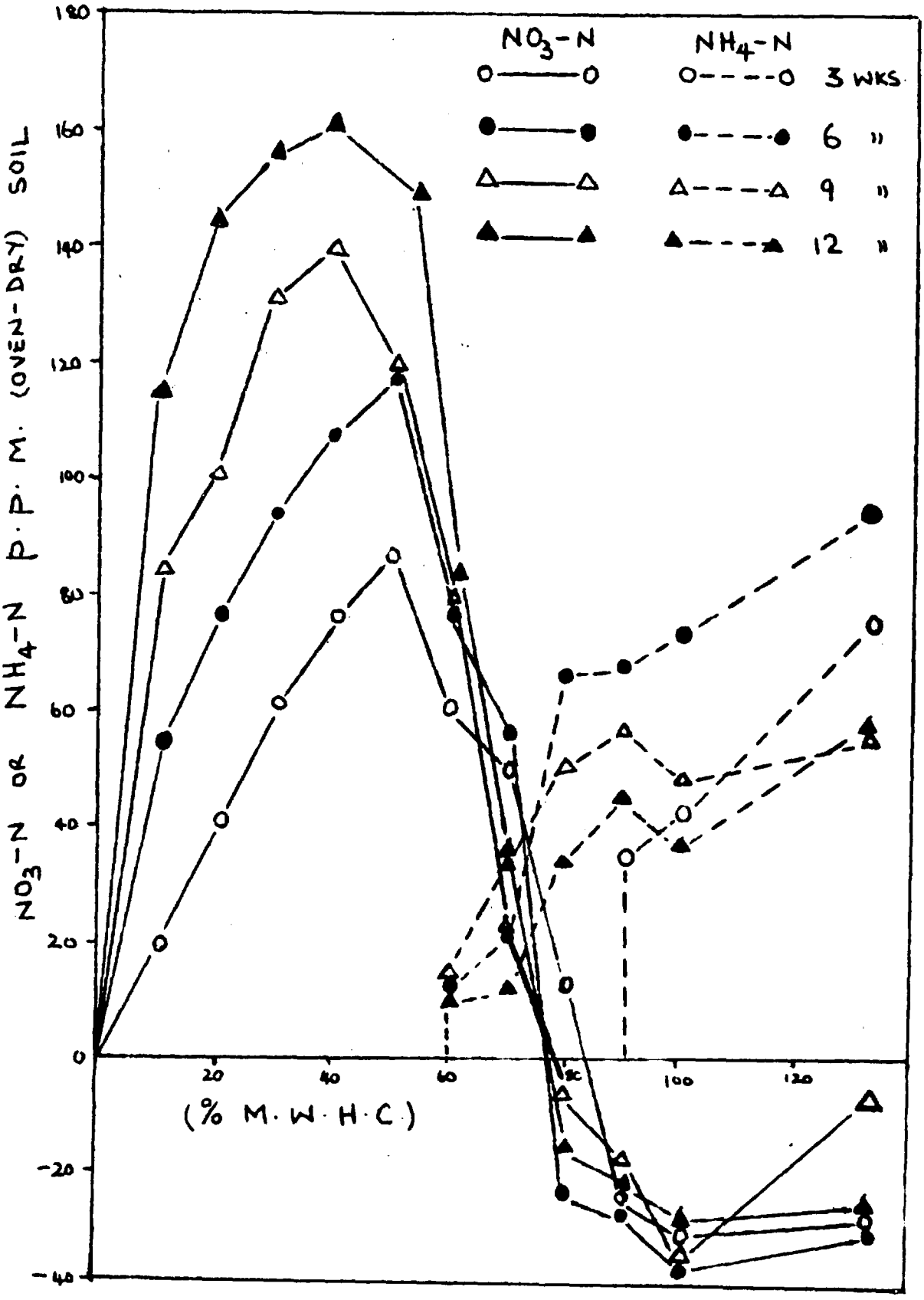


TABLE 12.

Ammonium-N (p.p.m. soil oven-dry) accumulated during the incubation of soil 2 with various moisture treatments.

Original soil moisture levels (% m.w.h.c.)	At original soil moisture content during the whole incubation time				Changed to 50% m.w.h.c. for last 6 weeks		Water-logged (133% m.w.h.c.) for last 6 weeks	
	3 wks.	6 wks.	9 wks.	12 wks.	9 wks.	12 wks.	9 wks.	12 wks.
0	0	0	0	0	0	0	84.0	37.8
10	0	0	0	0	0	0	23.8	0
20	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0
40	0	0	0	0	0	0	0	0
50	0	0	0	0	0	0	0	0
60	0	14.0	15.4	14.0	14.0	0	-	-
70	0	22.4	35.0	14.0	21.0	0	-	-
80	0	67.2	51.2	35.0	18.2	0	-	-
90	36.4	68.6	57.4	46.2	32.2	0	-	-
100	43.4	74.2	49.0	37.8	19.6	0	-	-
133	75.6	95.2	56.0	58.8	28.0	0	-	-

also increased with moisture level, but the extent of accumulation decreased with increasing time from six to twelve weeks except at 60% where it remained constant.

The variations in ammonium-N were reflected in the variations in nitrate-N, where ammonium-N increased nitrate-N decreased and vice versa except at water-logging where the nitrate-N remained fairly constant and was independent of time and of ammonium-N values. The negative values obtained for nitrate-N resulted from subtracting the soil original mineral nitrogen from the total mineral nitrogen determined for each treatment and then subtracting the ammonium-N determined for the same treatment.

(ii) Discussion.

At moisture levels below 50% where the conditions were essentially aerobic, ammonium-N produced from organic matter decomposition was quickly nitrified hence there was no ammonium-N accumulation. It has been reported that there is a slow nitrification even on water-logging soils (Cyplenkin and Schilin (1936)) whilst ammonification is uninterrupted (Traaen (1916), (Kapp (1933) and (Bamji (1938)). It is therefore possible that here the net result of slow nitrification and uninterrupted ammonification has resulted in the accumulation of ammonium-N in this soil at the high moisture levels in which there were different degrees of anaerobiosis.

Fig. 14: MINERALIZATION OF NITROGEN IN SOIL 2 WITH VARIOUS MOISTURE TREATMENTS (ORIGINAL, 0-50% M.W.H.C.)

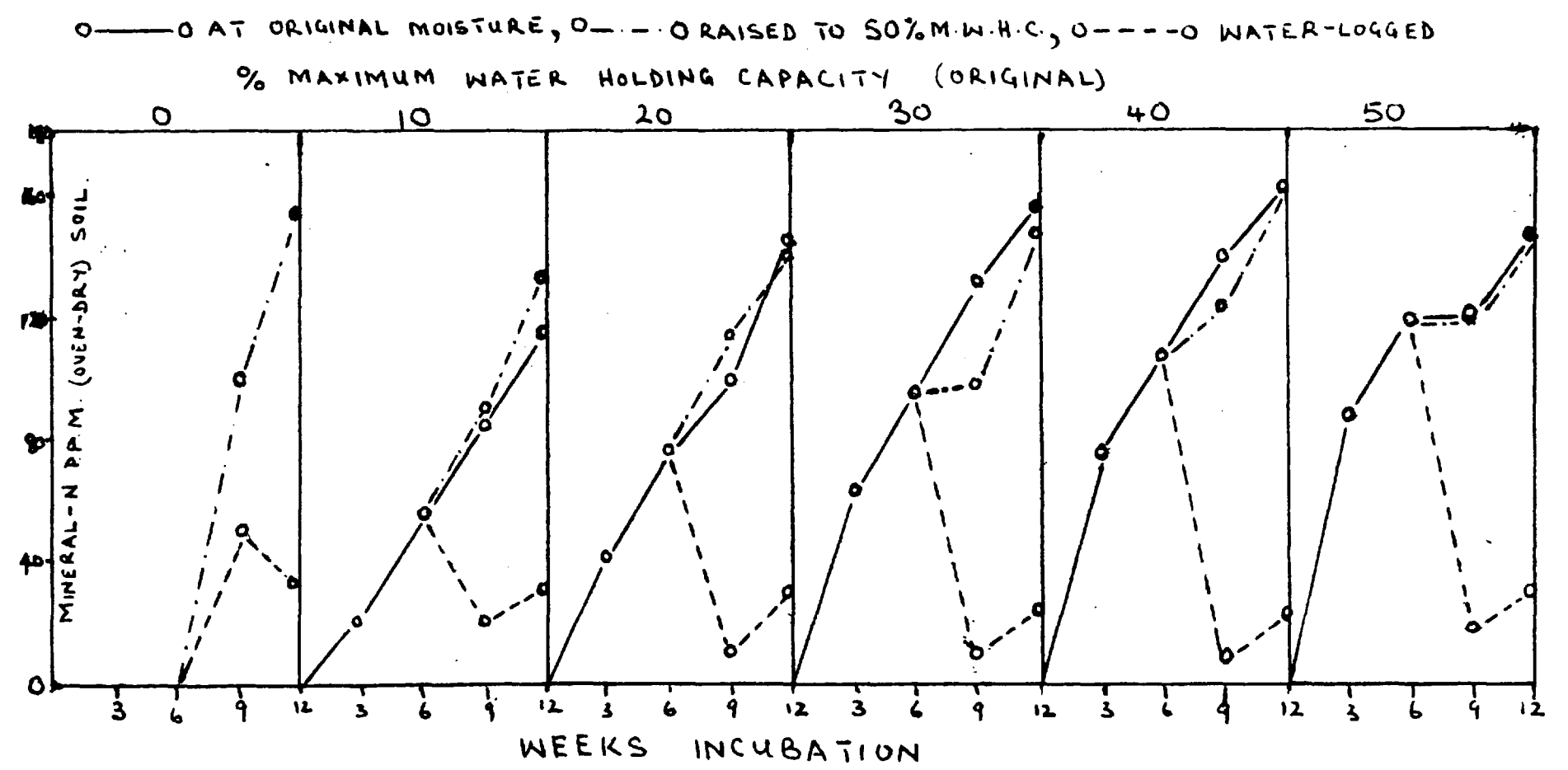
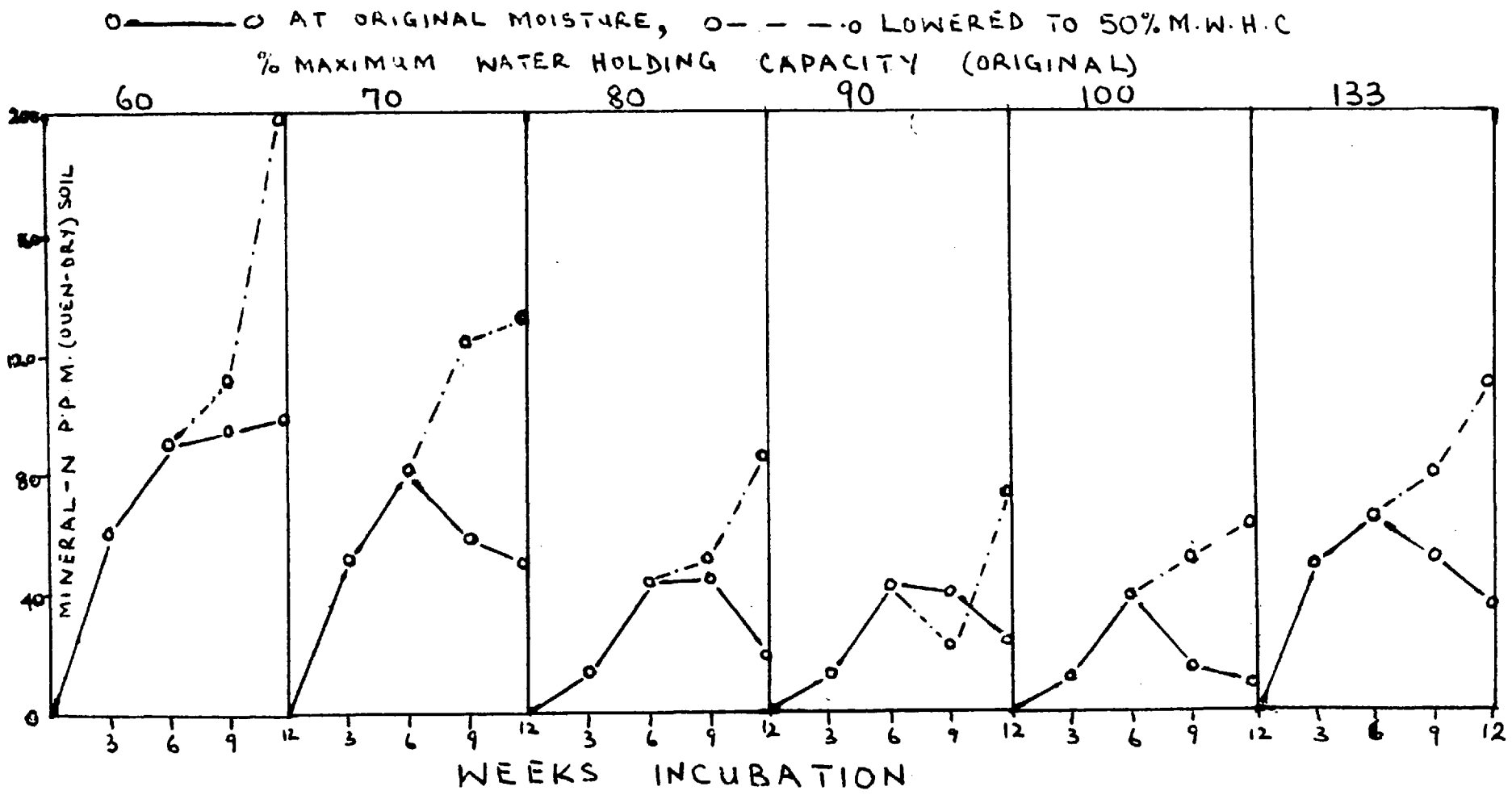


Fig. 15: MINERALIZATION OF NITROGEN IN SOIL 2 INCUBATED WITH VARIOUS MOISTURE TREATMENTS (ORIGINAL, 60–133% M.W.H.C.)



Little or no ammonium-N is produced from nitrate reduction during denitrification (Bremner and Shaw (1958)) and the gaseous nitrogen, nitric oxide and nitrous oxide evolved during denitrification are derived entirely from the nitrate-N any ammonium-N accumulated under anaerobic conditions is derived direct from organic matter decomposition (Wijler and Delwiche (1954)). Nitrate may also disappear in water-logged soils by microbial assimilation (De and Sarkar (1936)).

It seems therefore that in this study although the nitrate-nitrogen decrease was accompanied by ammonium-nitrogen increase at high moisture levels, it is likely that the ammonium-N produced was not derived from nitrate-N.

(b) Change of original soil moisture levels to 50% or to water-logging.

(i) Results.

The total mineral nitrogen produced when the soil at original moisture levels of 0 to 40% was irrigated to 50% and that at original moisture levels of 60 to 133% was dried to 50% are shown in columns 6 and 7 (Table 10), while that produced when the soil at original moisture levels of 0 to 50% was irrigated to water-logging is shown in columns 8 and 9 (Table 10). These values include the mineral nitrogen produced at the original moisture levels prior to the change in moisture levels.

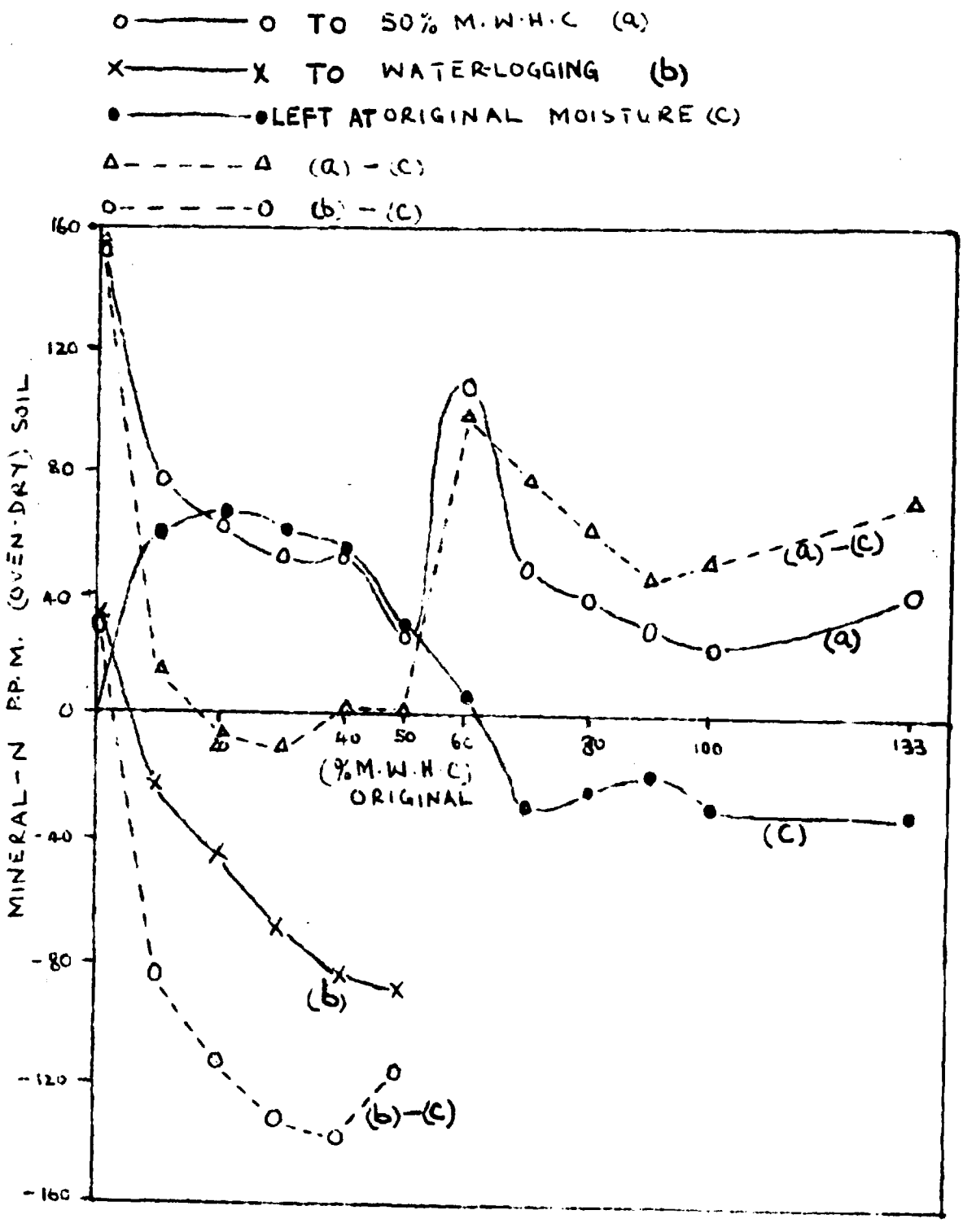
TABLE 13.

Nitrogen mineralized (p.p.m. soil oven-dry) in soil 2 after changing the original moisture levels from below and above 50% to 50% and from below 60% to water-logging.

Original moisture levels(%m.w.h.c.)	(a)To 50%	(b)To water-logging	(c)Left at original moisture level	(a) - (c) Increase at 50% compared with that left at original moisture level	(b) - (c) Increase at water-logging compared with that left at original moisture level
0	154.0	33.6	0	154.0	33.6
10	78.0	-23.8	60.2	17.8	-84.0
20	64.0	-44.8	68.6	-4.6	-113.4
30	53.9	-69.5	62.3	-8.4	-131.8
40	54.4	-84.0	54.4	0.0	-138.4
50	28.0	-88.2	28.0	0.0	-116.2
60	109.4	-	7.0	102.4	-
70	50.4	-	-29.4	79.8	-
80	40.6	-	-23.8	64.4	-
90	30.8	-	-18.2	49.0	-
100	23.8	-	-29.4	53.2	-
133	40.0	-	-28.2	68.2	-

L.S.D., (a), (b) and (c) = 13.5 at 5%, 18.3 at 1% and 24.2 at 0.1% levels.

Fig. 16: MINERAL-N PRODUCED AFTER CHANGING THE ORIGINAL SOIL MOISTURE LEVELS FROM ABOVE AND BELOW 50% TO 50% M.W.H.C. AND FROM UP TO 50% TO WATER-LOGGING.



The changes in the rate of mineral nitrogen production accompanying the changes in moisture levels are shown in Fig. 14 (0-50%) and Fig. 15 (60-133%). The mineral nitrogen produced within six weeks as a result of these changes is shown in Table 13 and Fig. 16, by subtracting the values of mineral nitrogen produced in the initial six weeks at the original moisture levels from the values after the next six weeks incubation at the same original moisture levels (c), at the new moisture level of 50% (a), and at the new moisture level of water-logging (b).

The results show that on changing the original moisture from low or high levels to 50% there is an increase in the rate of nitrogen mineralization over the rate in the soil continuously maintained at the original moisture levels for moisture levels 0 to 20%, a decrease for 30% and 40%, and an increase for moisture levels 60 to 133%. This increase or decrease in the rate of mineralization of nitrogen resulted in total mineral nitrogen production which increased with decreasing original moisture below 50% and in general decreased with increasing original soil moisture levels above 50% (Curve (a), Fig. 16).

The results also show that on changing the original moisture levels from low to water-logging, there was a very significant decrease in the rate of nitrogen mineralization below the rate in the soil continuously maintained at the original moisture levels.

This decrease in the rate of nitrogen mineralization resulted in total mineral nitrogen that increased with decreasing original soil moisture levels (Curve (b), Fig. 16). Again the decrease in the rate of nitorgen mineralization as a result of water-logging did not apply to the air-dry original moisture level where hitherto, there had been no nitrogen mineralization.

In the soil maintained continuously at the original moisture levels, the rate of nitrogen mineralization remained rather constant for each of moisture levels 0 to 20%, was decreasing but still higher than that irrigated to 50% for moisture levels 30 and 40%, and was decreasing rapidly for moisture levels above 50%. The resultant mineral nitrogen produced was about equal for moisture levels 10 to 30% and then decreased with increasing moisture level to 70% where again it was more or less constant up to 133% (Curve (c), Fig. 16).

The differences between the mineral-nitrogen produced when the change in moisture level was to 50% and when no change took place (Curve (a)-(c), Fig. 16) shows the advantage obtained by the change; the difference between the mineral-nitrogen produced when the change was to water-logging and when no change took place (Curve (b)-(c), Fig. 16) shows the disadvantage obtained by the change (except for the air-dry original moisture level).

For original moisture levels below 50% there was no significant advantage in increasing the moisture level to 50% except if it was originally below 10% but there were highly significant advantages in reducing the original moisture level from above 50% to 50%.

On the other hand, there were highlysignificant disadvantages in increasing the original moisture below 60% to water-logging except if it was originally air-dry.

The significance (5% level) of the differences between the mineral nitrogen produced after the change in the original moisture may be summarised as follows:

(a) To 50%: 0, 60, 10, 20, 40, 30, 70, 80, 133, 90, 50, 100

(b) To water-logging: 0, 10, 20, 30, 40, 50

(c) Unchanged at original soil moisture:

20, 30, 10, 40, 50, 60, 0, 90, 80, 133, 70, 100

(ii) Discussion.

It has been shown that at moisture levels below 50%, nitrogen mineralization more or less followed the same pattern as carbon mineralization. On increasing the moisture levels to 50% the patter of change in nitrogen mineralization was similar to that observed for carbon mineralization and it may be expected that the explanations of the effects of residual

organic matter and degree of drought prior to the change in moisture levels adduced for carbon mineralization applied equally to nitrogen mineralization.

The advantage obtained as a result of increasing the lower moisture levels to 50% ((a)-(c)) became significant only when the moisture level prior to the change was below 10% and this was largely due to the high rate of mineralization which persisted in the soil with unchanged moisture levels. Thus the effects of drought or residual easily mineralizable organic nitrogen on the increase in the mineralization of nitrogen when the moisture levels were changed to 50% over the mineralization taking place when the original moisture levels were maintained seems to be significant only when the original soil moisture was below 10%. The limit for carbon mineralization was 20%.

On increasing the moisture levels below 60% to water-logging, anaerobic conditions were created and the anaerobic process of denitrification reduced the already accumulated mineral nitrogen (in form of nitrate-N) to very low values. The decrease in the mineral nitrogen was therefore due to denitrification of the accumulated mineral nitrogen and varies directly with it.

In the soil maintained at high moisture levels above 50%, the degree of anaerobiosis increased with increasing soil moisture. On reducing the soil moisture levels to 50%, the mineral nitrogen increased for all original moisture levels over that produced when the original moisture levels were maintained. This increase first decreased with increasing original moisture 60% to 90% and then increased.

Spores of micro-organisms survive adverse conditions and on restoration of optimum conditions grow into active cultures which cause a flush of organic matter decomposition (Birch (1958)). Anaerobic accumulation of easily mineralizable organic nitrogen (Scott and Evans (1955)) would result on restoration of aerobic conditions, in increased mineralization of nitrogen. These notions might explain as they did for carbon mineralization, the observed increase in nitrogen mineralization on reducing the high moisture levels to 50%.

Scott and Evans (1955) showed that the more reduced a soil medium, the more slowly it returned to the fully oxidized state even when the oxygen supply was abundant. There was greater anaerobiosis at saturation and water-logging hence a possible greater accumulation of easily mineralizable organic matter than at sub-saturation moisture levels 80% and 90%. The former may account for the decrease in the advantage obtained on drying to 50% with increase in original soil moisture from 60 to 90% and the latter may account for the final increase in the advantage with increase in original soil moisture from 100 to 133%.

Fig. 17: NO_3-N ACCUMULATION IN SOIL 2 INCUBATED WITH VARIOUS MOISTURE TREATMENTS (ORIGINAL, 60–133% M.W.H.C.

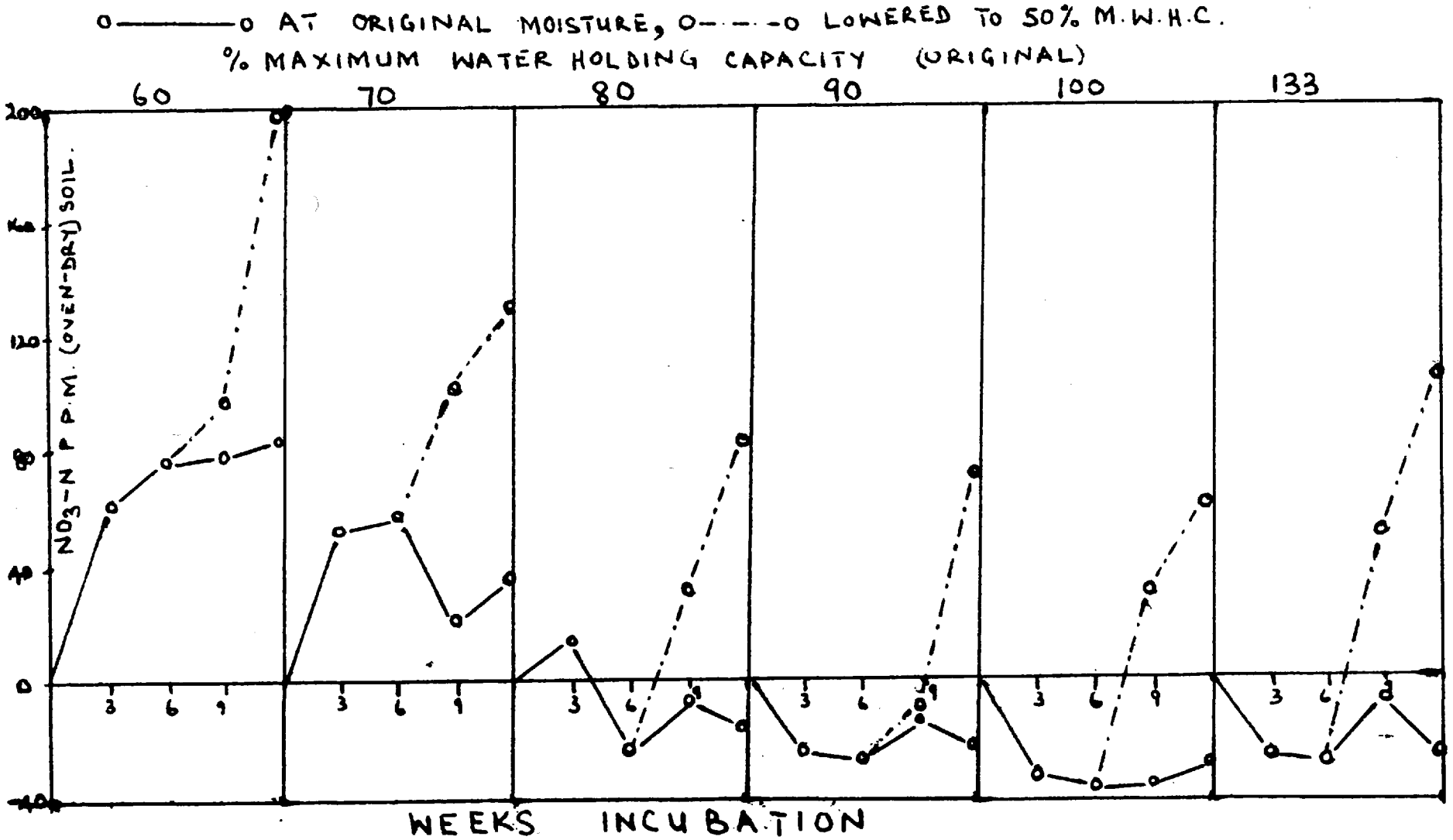
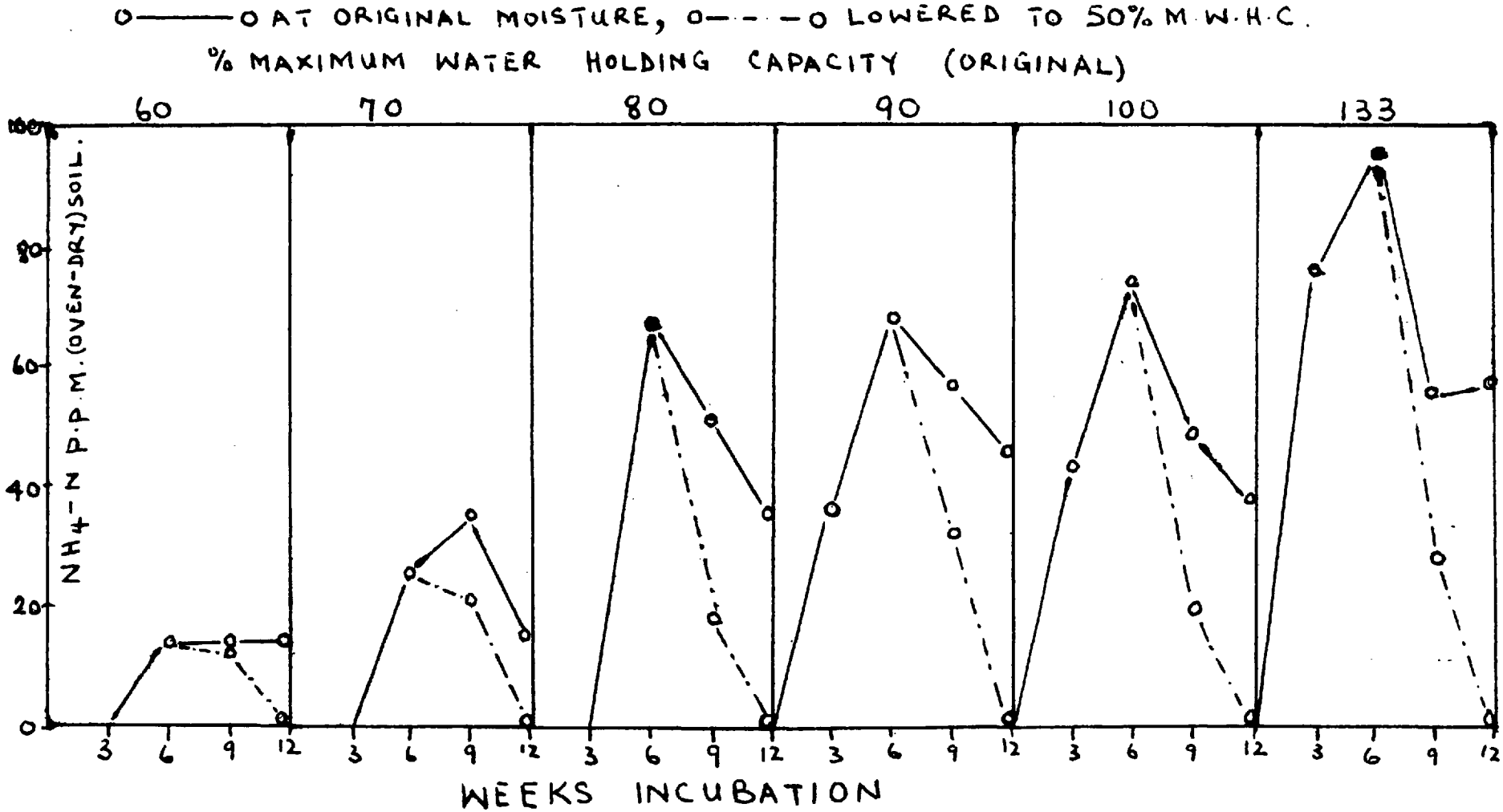


Fig 18: NH_4-N ACCUMULATION IN SOIL 2 INCUBATED WITH VARIOUS MOISTURE TREATMENTS (ORIGINAL, 60-133% M.W.H.C.)



As in changes in carbon mineralization, 70% seems to be the critical moisture level above which the effects of pre-drying partial or complete anaerobiosis on subsequent nitrogen mineralization become pronounced.

Nitrate- and Ammonium-N.

(i) Results.

The nitrate- and ammonium-nitrogen accumulated when the soil at original moisture levels of 0 to 40% was irrigated and that at original moisture levels 60 to 133% was dried to 50% are shown in columns 6 and 7 while those accumulated when the soil at original moisture levels of 0 to 50% was irrigated to water-logging, are shown in columns 8 and 9 of both Tables 11 and 12. These values are cummulative from the very beginning of the experiment.

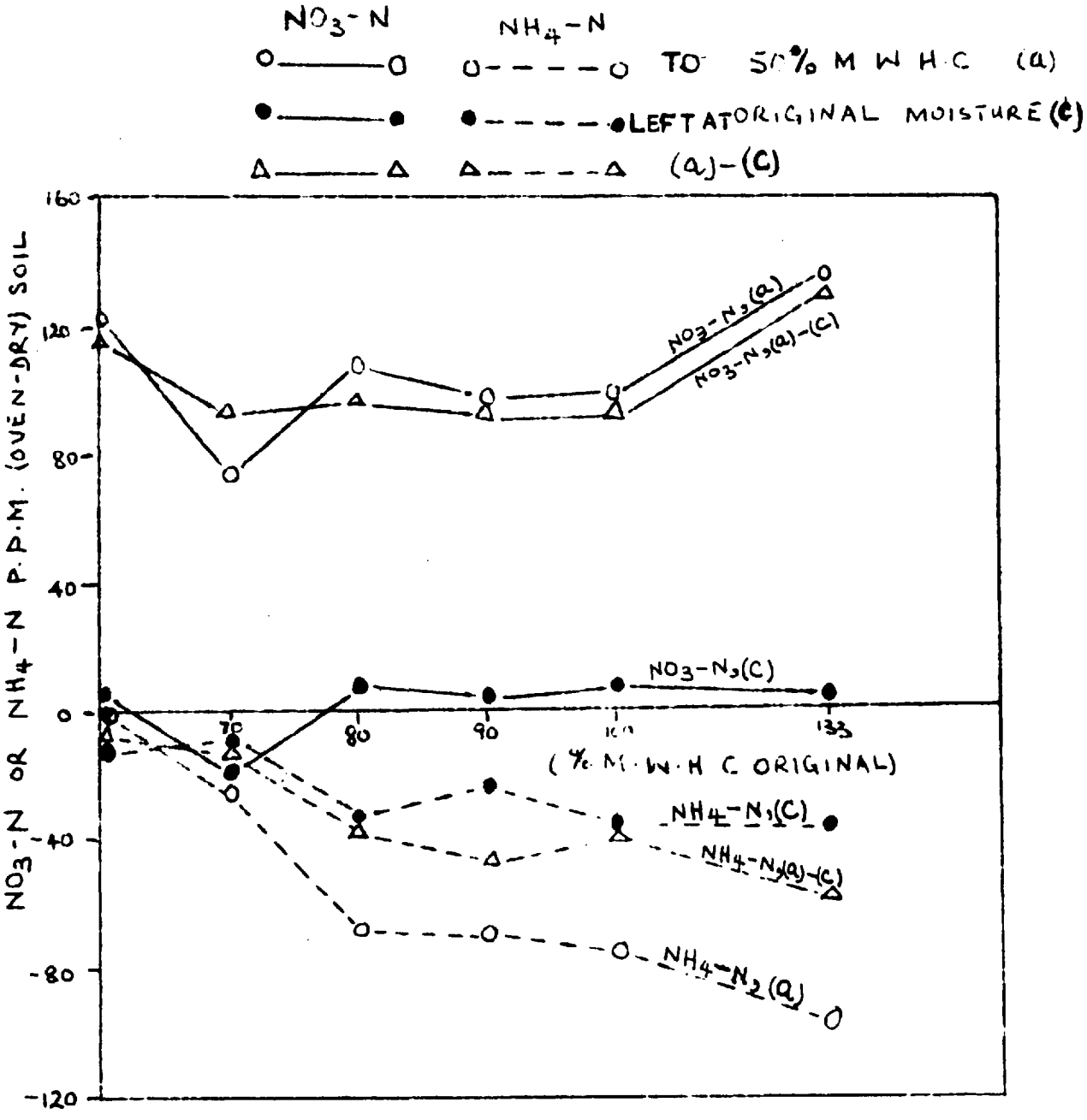
Since there was no ammonium-N accumulation at moisture levels up to 50% both before and after the change in moisture levels to 50% or to water-logging, the corresponding values of changes in mineral-nitrogen in Table 13 and Fig. 14 and 16 represent the nitrate-nitrogen accumulated, except for the original moisture levels 0 (air-dry) and 10% where ammonium-N accumulated in the first three weeks and decreased at six weeks.

TABLE 14.

NH_4-N and NO_3-N (p.p.m. soil, oven-dry) produced in soil 2 after changing the moisture levels from above 50% to 50%.

Original moisture levels (%m.w.h.c.).	(a)To 50%		(c)Left at original moisture levels.		(a) - (c) Increase at 50% compared with that left at original moisture level.	
	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N
60	-14.0	123.4	0.0	7.0	-14.0	116.4
70	-22.4	72.8	-8.4	-21.0	-14.0	93.8
80	-67.2	107.8	-32.2	8.4	-35.0	99.4
90	-68.6	99.2	-22.4	4.2	-46.2	95.2
100	-74.2	98.0	-36.4	7.0	-37.8	91.0
133	-95.2	137.2	-36.4	4.2	-58.8	133.0

Fig. 19: NO_3-N AND NH_4-N PRODUCED IN SOIL 2 AFTER CHANGING THE MOISTURE LEVELS FROM ABOVE 50% TO 50% M.W.H.C.



The changes in the rate of accumulation of nitrate- and ammonium-nitrogen accompanying changes in moisture levels for the moisture levels 60 to 133% are shown in Fig. 17 and 18 respectively. The accumulated nitrate- and ammonium-N within six weeks as a result of decreasing these high moisture levels to 50% are shown in Table 14 and Fig. 19 by subtracting the values of nitrate- or ammoniun-N accumulated in the initial six weeks at the original moisture levels, from the corresponding values after the next six weeks incubation at the same original moisture levels (c) and at the new moisture level of 50% (a).

The results show that at dried and undried moisture levels, the accumulated ammonium-N was decreasing, the decrease being greater for dried than undried, resulting ir the disappearance of all accumulated ammonium-N on drying to 50% within six weeks. The disadvantage obtained by the drying ((a)-(c)) increased with increasing original moisture level.

While the decreases in ammonium-N were taking place there were corresponding increases in nitrate (except for 70% where there was a large decrease when maintained at the original moisture level). The increases in nitrate-N were similar and low for all undried moisture levels except at 70% and the increases were slightly varied and very high for all dried moisture levels except again at 70% where it was not as high as the others.

The advantage thus obtained by the drying was about the same between 70 and 100% original moisture levels with increases at 60 and 133%.

(ii) Discussion.

The accumulation of ammonium when 0(air-dry) and 10% moisture levels were raised to water-logging indicates that the low nitrate-N present at these moisture levels was not high enough to render denitrification, (observed when water-logging original moisture levels of 20 to 50%) the major process of mineral nitrogen transformation. It would seem therefore, that when the moisture level is such that nitrate-N accumulation is high, denitrification or nitrate-N assimilation by micro-organisms takes place without concommitant ammonification when the moisture level is raised to water-logging; when it is such that nitrate-N accumulation is low(at air-dry and 10%) denitrification or nitrate-N assimilation may take place but ammonification of soil organic nitrogen also takes place. This is possible since during denitrification the nitrate is not reduced to ammonium but to gaseous nitrogen and its oxides (Bremner and Shaw (1958)) and (Wijler and Delwiche (1954)).

On reducing the higher moisture levels to 50%, aerobic conditions were restored and the aerobic process of nitrification reduced the accumulated ammonium-N to zero level, while increasing the nitrate-N to levels higher than the amount of ammonium-N oxidized. This would indicate that as well

as the nitrification of the accumulated ammonium-N, there was aerobic mineralization of organic nitrogen.

At undried high moisture levels, decreases in ammonium-N were greater than the increases in nitrate-N and this might be due to ammonia volatilization (Wahhab et. al. (1957)).

The advantage obtained by reducing the original soil moisture ((a)-(c) of Table 14 and Fig. 19) also indicated a much greater increase in nitrate-N over the decrease in ammonium-N. The advantage of the increase in nitrate-N is high if the soil was originally at 60% and 133% before the drying, possibly because of the more rapid restoration of aerobic redox-potential for the former moisture level (Scott and Evans (1955)), hence greater aerobic mineralization of organic nitrogen, and because of the greater accumulation of ammonium for the latter moisture level. Original moisture levels between these extremes owe their deficit of nitrate to both the above causes, hence their lower nitrate-N accumulation when they were dried to 50%.

The exceptionally low amounts of accumulated nitrate-N for dried and undried 70% moisture level, as also occurred for carbon and nitrogen mineralization, indicates that this is the critical moisture level above which the effects of partial anaerobiosis become pronounced.

3. Availability of Phosphorus.

(a) Soil moisture content, 0-133%.

(i) Results.

The available phosphorus (Morgan's extracted) status during twelve weeks incubation at original soil moisture levels 0 to 133% is shown in columns 2 to 5 of Table 15 and as parts of Fig. 20 and 21.

At three weeks incubation the available phosphorus varied non-significantly from the original air-dry soil status and between 10 and 90% moisture levels and then increased with increasing soil moisture up to 133%.

At six weeks it decreased significantly from the original air-dry soil status of 118 p.p.m. at moisture levels 20 to 40% and 60 to 70%, and became greatly increased at moisture levels 80 to 133%, the increase increasing with moisture level.

At nine and twelve weeks it varied non-significantly within moisture levels 10 to 70% but still lower than the air-dry soil status. At moisture levels above 70%, there were further increases both at each moisture level and with increasing moisture levels to 240 p.p.m. at 80% and 370 p.p.m. at 133% (water-logged).

The significance (5% level) of the differences between the mean values of available phosphorus at the different moisture levels are summarised as follows:

TABLE 15.

Available P_2O_5 *(p.p.m. soil oven-dry) status in soil 2 incubated with various moisture treatments.

Original soil moisture levels (%m.w.h.c.)	At original soil moisture content during the whole incubation time				Changed to 50% m.w.h.c. for last 6 weeks		Water-logged (133%m.w.h.c.) for last 6 weeks	
	3 wks.	6 wks.	9 wks.	12 wks.	9 wks.	12 wks.	9 wks.	12 wks.
0	118	118	118	118	117	104	143	208
10	118	114	100	103	117	104	143	210
20	112	104	105	103	117	104	143	210
30	112	100	102	103	117	104	143	214
40	112	100	100	104	117	104	143	220
50	112	112	118	104	117	104	147	220
60	113	101	100	100	91	84	-	-
70	116	103	100	107	85	84	-	-
80	116	125	190	240	81	81	-	-
90	120	170	290	348	56	56	-	-
100	126	180	290	357	44	44	-	-
133	153	250	315	370	34	36	-	-

*Mean of duplicates.
L.S.D. = 10 at 5%, 14 at 1% and 18 at 0.1% levels.

Fig. 20: AVAILABLE P_2O_5 IN SOIL 2 INCUBATED WITH VARIOUS MOISTURE TREATMENTS (ORIGINAL, 0-50% M.W.H.C.)

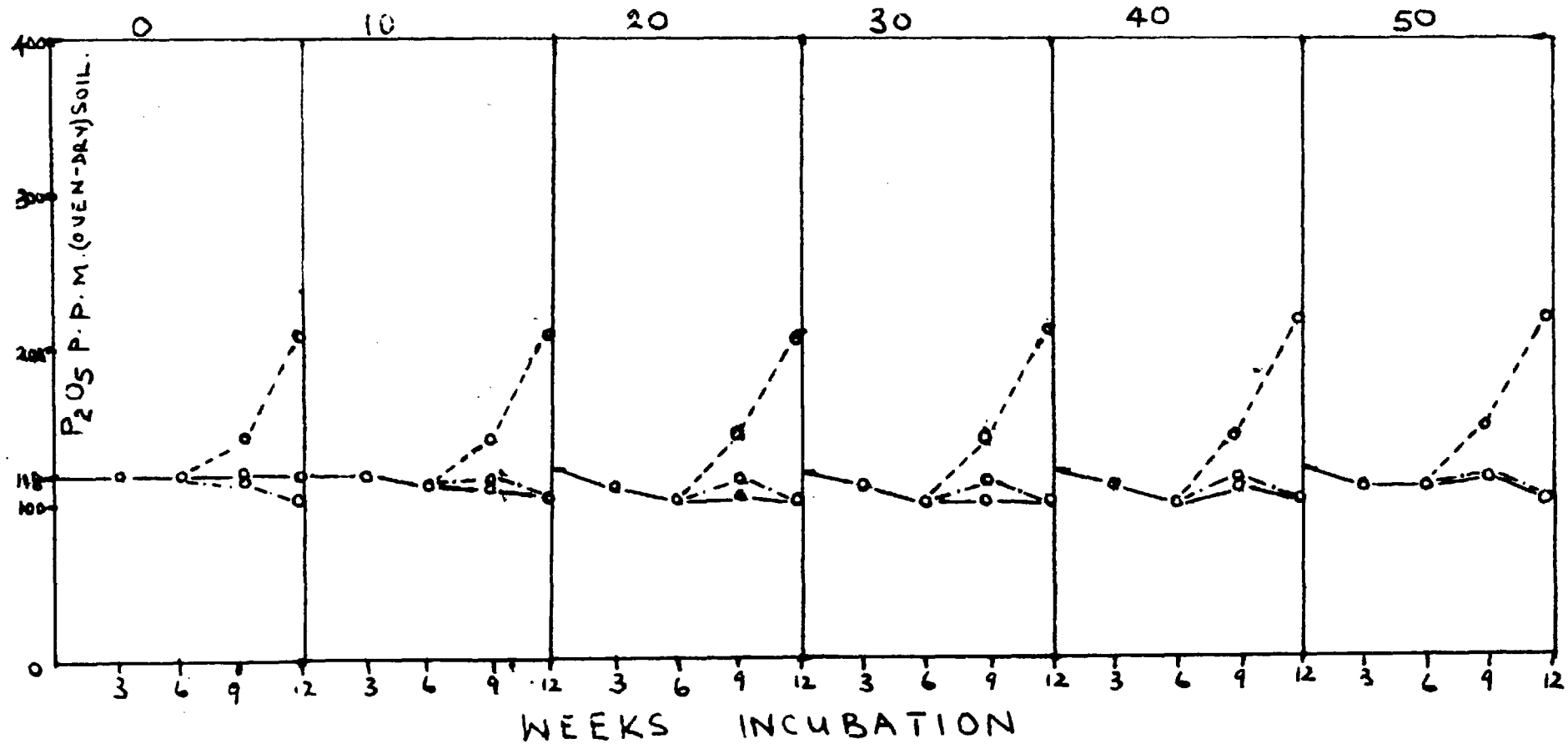
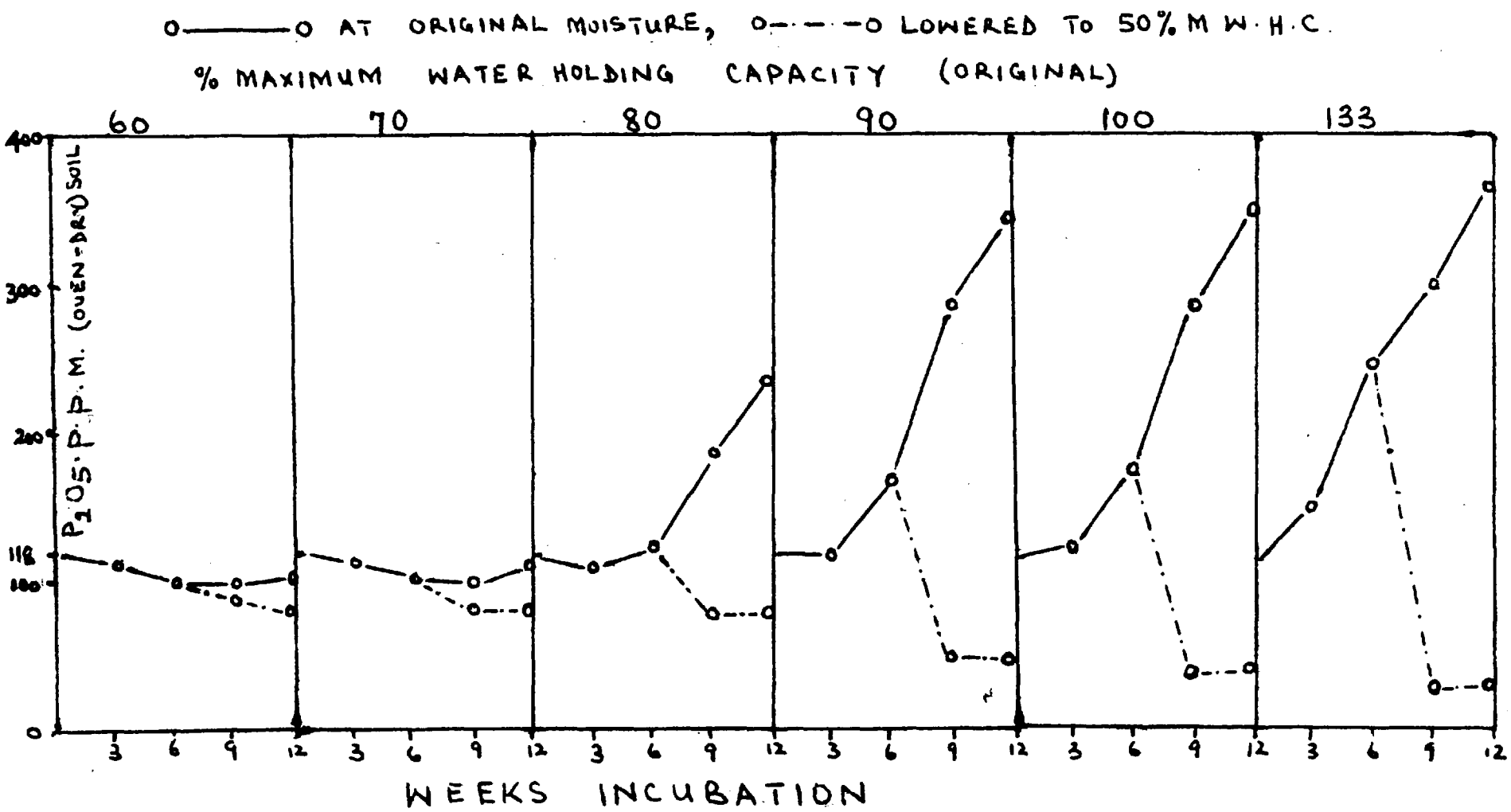


Fig. 21. AVAILABLE P_2O_5 IN SOIL 2 INCUBATED WITH VARIOUS MOISTURE TREATMENTS (ORIGINAL, 60–133% M.W.H.C.)



At 3 weeks: 133, 100, 90, 0, 10, 80, 70, 60, 50, 40, 30, 20

At 6 weeks: 133, 100, 90, 80, 0, 10, 50, 20, 70, 60, 40, 30

At 9 weeks: 133, 100, 90, 80, 0, 50, 10, 40, 20, 30, 60, 70

At 12 weeks: 133, 100, 90, 80, 0, 70, 50, 40, 30, 20, 10, 60

(ii) Discussion.

The results indicate that in this soil significant fixation of some of the available phosphorus originally present in the air-dry soil took place after six weeks incubation at moisture levels 10 to 70% and enormous increases in the available phosphorus at higher moisture levels.

Phosphorus fixed in the soil against dilute acid extraction exists as ferric, aluminium or calcium compounds (Chang and Chu (1961)) and (Russell and Low (1954)). Moist ferric hydroxide fixes more phosphorus than air-dried or heated (Thermlitz (1953). Sun-drying of soils in central Asia increases phosphorus mobility and reduces the activity of sesquioxides in soils, (Ryzhov and Machigan (1939)). It would seem therefore that at moisture levels 10 to 70%, moistening the soil activated the sesquioxides (Fe_2O_3 and Al_2O_3) and brought about the observed fixation of phosphorus.

Since microbial activity was brought about by moistening the soil, the assimilation of the available phosphorus by the micro-organisms may contribute to the fixation of the phosphorus.

Crystallinity of iron and aluminium phosphates reduces the availability of phosphorus under upland conditions and crystallinity is produced by ageing, (Shapiro (1958a). Crystallinity produced by the ageing of the moistened and thus hydrated sesquioxides might also have brought about the increased fixation of phosphorus during the later compared with that during the earlier part of the incubation period.

The fixation occurring at moisture levels 10 to 70% may be important only where the hydrated iron sesquioxides are in high oxidation states, i.e. where their phosphate compounds are not available. At moisture levels 80% to water-logged, the enormous mobilization of the soil phosphorus may be attributed to the reduction of the ferric to ferrous phosphate by anaerobic micro-organisms (Bromfield (1954) and Shapiro (1958)), the hydrolysis of aluminium and clay phosphates (Shapiro (1958)), and the increase in the solubility of iron, calcium and clay phosphates by the action of organic acids formed during anaerobic microbial activity (Gasser and Bloomfield (1955)).

Phosphate solubility is high under water-logged conditions if iron phosphate is predominant, high under dry conditions if tricalcium phosphate is predominant, and high

under both conditions if both phosphates are present (Barber (1960) and (Kawaguchi (1944)). Thus the significant difference in available phosphorus between the air-dry soil and the soil at moisture levels 10 to 70%, plus the large increase in available phosphorus near or above soil saturation moisture level would indicate that the effect of iron phosphate was more important than that of tricalcium phosphate (Chang and Chu (1961)).

70% seems to be the critical moisture level above which the anaerobic effects of soil moisture on phosphorus mobilization becomes evident.

(b) Change of Original Soil Moisture Levels to 50% or Water-logging.

(i) Results.

The available phosphorus status after the soil maintained for initial six weeks at original moisture levels of 0 to 133% was irrigated or dried to 50% is shown in columns 6 and 7, and after that at 0 to 50% was irrigated to water-logging is shown in columns 8 and 9 , all of Table 15 and as parts of Fig. 20 and 21.

On increasing the soil moisture levels from below 50% up to 50% for all original moisture levels, there were increases, in the first three weeks, in available phosphorus to values near the original air-dry soil status. In the next three weeks, the values decreased again to the pre-irrigation levels.

On increasing the soil moisture levels from below 60% to water-logging, there were large increases in available phosphorus to about the same extent for all original moisture levels.

On reducing the soil moisture levels from above to 50% there were reductions in the available phosphorus; these reductions increased with both the original moisture level and with the available phosphorus present at each moisture level before the drying. On drying the soil at high moisture levels down to 50% the percentage fixation (i.e. amount of decrease over the amount available before drying) has been plotted against the amount available before the drying (Fig. 25).

(ii) Discussion.

Because of the reduced solvent action of "bound" water, the mobility of ions in the soil may be restricted (Chang and Chu (1961)) and the concentration of polyvalent anions in soil solution decreases as the soil moisture decreases (Wadleigh and Richards (1951)). The migration of phosphate ions which are restricted to the vicinity of a phosphate fertilizer granule in a medium loam soil increases with increasing soil moisture (Muller (1954)). The immediate increase in available phosphorus on raising the low moisture levels to 50% might have been a result of increased mobility of phosphate ions. Later the

extra mobile phosphate ions would react with aged hydrated sesquioxides and thus become fixed (Shapiro (1958a)), thus reducing the available phosphorus to its pre-irrigation level.

The increases in the available phosphorus on increasing the low moisture levels to water-logging would follow the suggestions already adduced for the mobilization of phosphorus under anaerobic or water-logged conditions.

Iron mobilized as ferrous under anaerobic or water-logged conditions precipitates the mobilized phosphorus as ferric phosphate when the medium is reoxidized, (Chang and Chu (1961)), and (Gasser and Bloomfield (1955)).

Aluminium may also be mobilized by hydrolysis under anaerobic conditions. On dehydration both iron and aluminium present large reactive surfaces and may react with phosphates to form insoluble crystalline compounds (Shapiro (1958a). Active hydrated oxides of aluminium, gibbsite ($Al_2O_3.3H_2O$) and of iron, goethite ($Fe_2O_3.H_2O$) produced as a result of oxidizing anaerobic media would react with phosphates in the presence of ammonium or potassium ions to form insoluble palmerites, e.g. potassium aluminium palmerite ($HK_2Al_2(PO_4)_3.7H_2O$) (Haseman et. al. (1950)). These reactions and several others may take place during the reoxidation of anaerobic or water-logged soil and might have resulted in the fixation not only of the excess available phosphorus produced as a result of the mobilization but also some of the available phosphorus

present in the soil before the anaerobiosis was imposed. This may explain why the status after the drying to 50% of the available phosphorus was far below the original air-dry soil status, and why the percentage fixation (Fig. 25) increased with both the amount of available phosphorus present and with the moisture level or degree of anaerobiosis before drying.

4. Availability of Potassium.

(a) Soil moisture content, 0-133%.

(i) Results.

The available potassium (Morgan's extracted) status during twelve weeks incubation at original soil moisture levels 0 to 133% is shown in columns 2 to 5 of Table 16 and as parts of Fig. 22 and 23.

After three weeks incubation, there were significant decreases in available potassium at all moisture levels 10 to 133% below the available potassium of the original air-dry soil. These decreases were to values which were similar at all moisture levels up to 70%, except at 10% where they were much lower. From 80%, the available potassium decreased further with increasing soil moisture level to 100% and then finally increased at water-logging (133%).

The same trend of the relationship between the available potassium and the soil moisture levels was observed during the rest of the incubation period with minor variations.

TABLE 16.

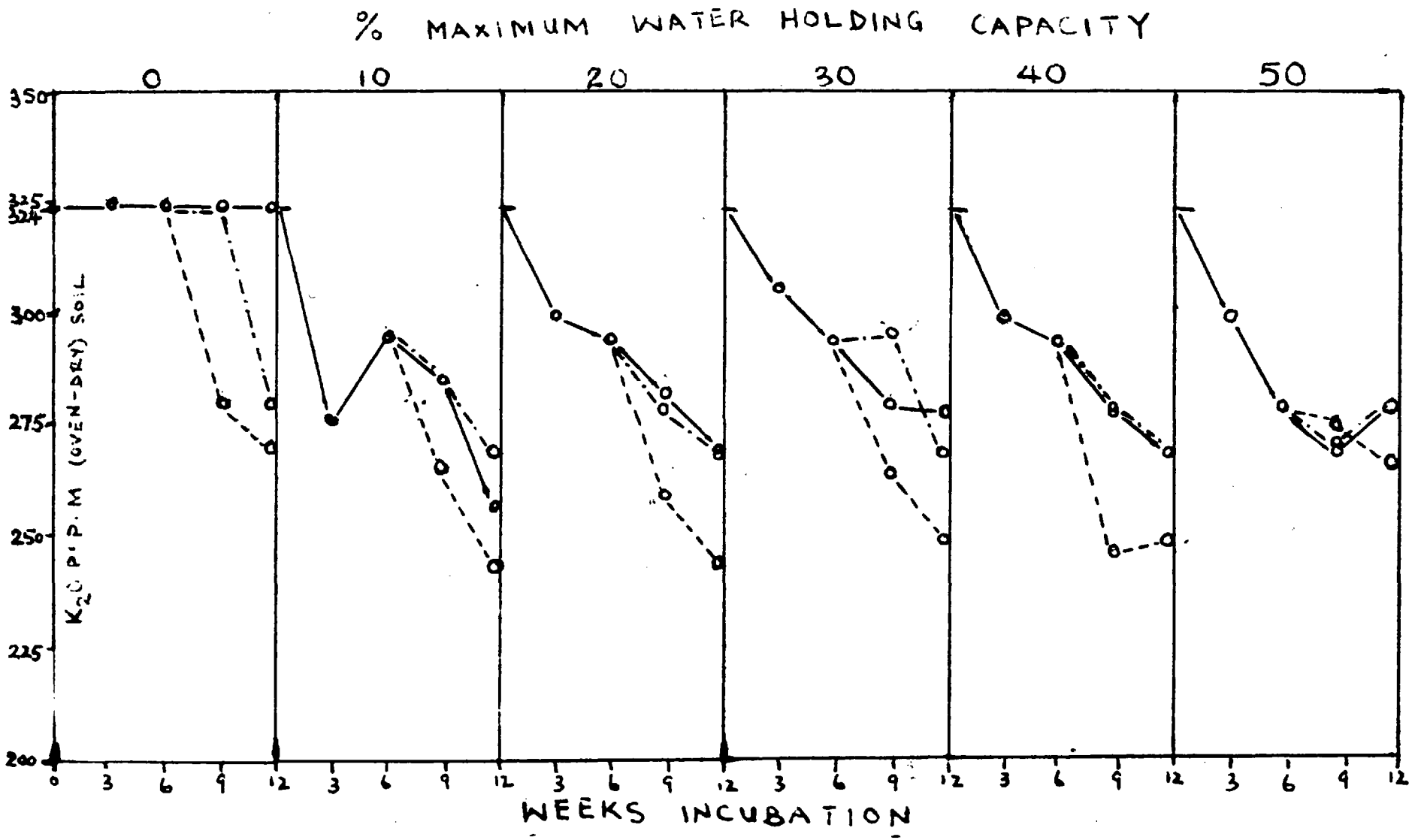
Available K_2O * (p.p.m. soil oven-dry) status in soil 2 incubated with various moisture treatments.

Original soil moisture levels (%m.w.h.c.)	At original soil moisture content during the whole incubation time				Changed to 50% m.w.h.c. for last 6 weeks		Water-logged (133%m.w.h.c.) for last 6 weeks	
	3 wks.	6 wks.	9 wks.	12 wks.	9 wks.	12 wks.	9 wks.	12 wks.
0	324	324	324	324	324	279	280	270
10	276	294	284	258	284	270	268	246
20	300	294	281	270	278	270	260	246
30	306	294	280	279	296	270	264	250
40	300	294	279	270	278	270	248	250
50	300	279	270	279	272	279	279	270
60	291	282	297	299	330	352	-	-
70	300	294	297	309	336	289	-	-
80	279	257	270	268	324	309	-	-
90	270	257	258	258	297	289	-	-
100	240	257	257	258	297	268	-	-
133	279	263	283	309	259	268	-	-

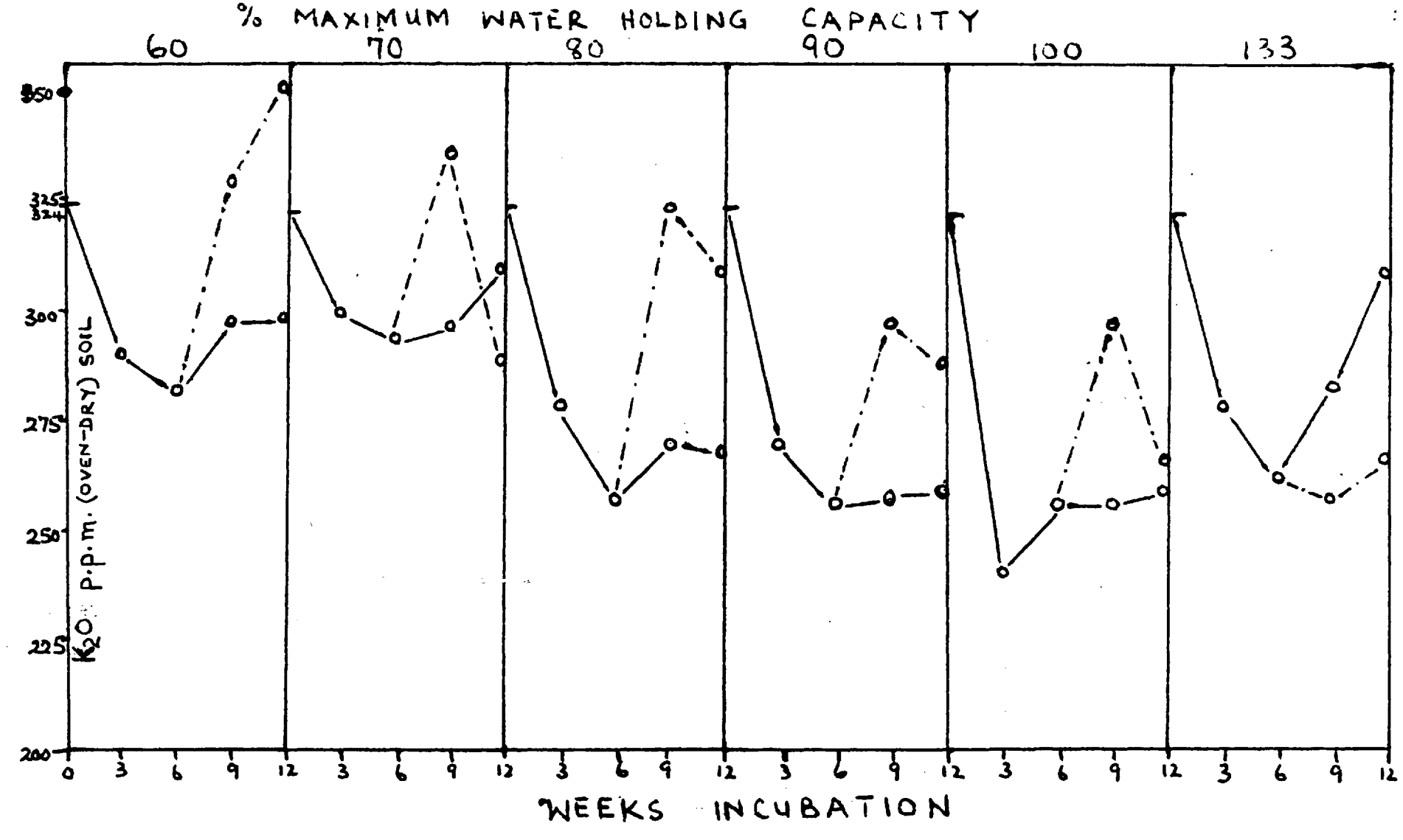
* Mean of duplicates.
L.S.D. = 10 at 5%, 13 at 1% and 17 at 0.1% levels.

Fig. 22: AVAILABLE K_2O IN SOIL 2 INCUBATED WITH VARIOUS MOISTURE TREATMENTS (ORIGINAL, 0-50% M.W.H.C.)

O——O AT ORIGINAL MOISTURE, O- - -O RAISED TO 50% M.W.H.C., O- - -O WATER-LOGGED



Fig·23: AVAILABLE K_2O IN SOIL 2 INCUBATED WITH VARIOUS MOISTURE TREATMENTS (ORIGINAL, 60-133% M.W.H.C.).
o——o AT ORIGINAL MOISTURE, o-·-·-o LOWERED TO 50% M.W.H.C



During this period, the available potassium decreased with increase in the time of incubation at moisture levels 10 to 40%. Between 50 and 100%, it remained more or less constant with increase in the time of incubation except at 60 and 70% where there were increases. At water-logging there was a definite increase with time.

The significance (5% level) of the differences between the available potassium at different moisture levels may be summarised as follows:

At 3 weeks: 0, 30, 20, 40, 50, 70, 60, 80, 133, 10, 90, 100

At 6 weeks: 0, 10, 20, 30, 40, 70, 60, 50, 133, 80, 90, 100

At 9 weeks: 0, 70, 60, 10, 133, 20, 30, 40, 50, 80, 90, 100

At 12 weeks: 0, 70, 133, 60, 30, 50, 40, 20, 80, 10, 90, 100

(ii) Discussion.

Nearly all studies in potassium fixation and release in soils have been done by extraction of potassium with N-ammonium acetate (Stanford (1948)) and (Karim and Malek (1957)) or with boiling N- nitric acid (DeTurk et. al. (1943)). Hanway and Scott (1959), however showed that although N-ammonium acetate extracted more potassium than Morgan's reagent, there was a highly significant correlation ($r = 0.98$) between the potassium extracted with both reagents from top soils. The results

of Morgan extracted potassium can therefore confidently be discussed in relation to results of ammonium acetate extracted potassium obtained by other workers.

Some of the available potassium in air-dry soils may be fixed on wetting the soils, especially if the soils are limed, (Stanford (1948)) and (Karim and Malek (1957)). Moist or dry fixation of soil available potassium takes place if the original available potassium is above a certain equilibrium status while a release takes place if it is below (Matthews and Sherrell (1960) and (DeTurk et. al. (1943)). While the observed moist fixation of potassium may be due to the original air-dry value being above the equilibrium status of this soil, this equilibrium status is not known. The factors which may influence the tendency of the available potassium to be fixed may be examined in order to suggest the possible mechanisms involved in moist fixation.

From the "f" value of Bray (1942), calcium will displace potassium from a clay complex if the relative concentration of calcium is higher than that of potassium in the surrounding soil solution. Liming increases moist fixation of potassium in soils (Evans and Attoe (1948), (Blume and Purvis (1939)) and this lime provides calcium hydroxide which brings alumina and silica into solution, (Volk (1934)). In the presence of hydrated aluminium and iron oxides (gibbsite and

goethite respectively) potassium or ammonium ions react with phosphates to form insoluble palmerites, (Haseman et. al. (1950). The soil under study was limed annually and the presence of calcium carbonate possibly brought about the moist fixation observed at all moisture levels 10 to 133%.

The mobilization of iron and hydrolysis of aluminium phosphates at the high moisture levels 80% to 100% might have resulted in the greater fixations observed at these moisture levels that at lower, especially as some of the mobilized iron and hydrolysed aluminium in these partially aerobic conditions may oxidize to the reactive hydrated oxides. It is also possible that as a result of hydrolysis of alumina and silica and mobilization of iron, iron and aluminium are removed from their exchange positions on the clay complex at the higher moisture levels and thus make way for more potassium to be fixed in these positions (Stanford (1948)).

At complete water-logging, the mobilized iron and aluminium compounds would not be oxidized to hydrated oxides and this might explain the observed fixation being about the same as for the aerobic soil samples (moisture levels of 50% and less).

During organic matter decomposition, up to 15% of the soil available potassium may be fixed (Hurwitz and Batchelor (1943)) and a major part of moist potassium fixation may be attributed to microbiological process

(Aleksandrov (1950)), so it is possible that some of the decrease in available potassium observed here was due to microbial assimilation.

The greater decreases in available potassium at moisture levels above than below 70% indicate that this is the critical moisture level above which the effect of excess moisture in causing more potassium fixation, becomes pronounced.

(b) Change of Original Moisture Levels to 50% or Water-logging.

(i) Results.

The available potassium status after the soil maintained for initial six weeks at original moisture levels of 0% to 133% was irrigated or dried to 50%, is shown in columns 6 and 7 and that at 0% to 50% was irrigated to water-logging is shown in columns 8 and 9, all of Table 16 and as parts of Fig. 22 and Fig. 23.

When moisture levels 10% to 40% were raised to 50%, there were decreases in the available potassium which were similar to those occurring where the moisture levels were not increased.

When moisture levels 0% to 50% were raised to water-logging, there were decreases, after three weeks, below the available potassium at the unchanged moisture levels.

Six weeks after the increase in moisture levels, there were further decreases in available potassium except when the original moisture level was air-dry or 50%.

When the moisture levels 60% to 100% were reduced to 50%, in the first three weeks, there were significant increases over the available potassium at the unchanged moisture levels. For original moisture levels 60% to 80%, the increase was up to the air-dry soil status, for 90% and 100%, the increase was not up to the air-dry status, and for water-logging (133%), change in moisture levels brought practically no change in the available potassium. After six weeks since the decrease in moisture levels, the available potassium significantly decreased again except for the original moisture levels of 60% where it increased further and 133% where no change was observed.

(ii) Discussion.

The increase in the moisture level from below 50% up to 50% seems to have no effect on the course or mechanism of moist fixation of potassium.

The decreases observed on raising the moisture levels from below 60% to water-logging seems to be due to extra fixation as a result of displacing iron and aluminium from fixation positions as a result of the mobilization of these elements, and thus increasing potassium fixation, (Stanford (1948)).

Reducing the moisture levels 60% to 100% down to 50% brought immediate increases in available potassium, some of which was fixed later. Precipitation of mobilized iron and hydrolysed aluminium and silica into fixation positions on the clay complex might release the potassium fixed when the iron was mobilized and aluminium hydrolysed (Shapiro (1948)). The displaced potassium remaining in the soil solution would probably be fixed later by other mechanisms of moist fixation (Blume and Purvis (1939)).

The fact that available potassium remained unchanged after the water-logged soil was dried to 50%, that available potassium increased with decreasing original moisture level and that there were decreases after initial increases on reducing the original moisture levels of 70% to 100%, might all be connected with microbial assimilation of released potassium, since the carbon mineralization had increased after the drying of these high moisture levels to 50% (Aleksandrov (1950)).

Fig. 24: REGRESSION LINES OF C AND N MINERALIZATION DURING THE FIRST 3 WEEKS ON THE LOG. OF SOIL MOISTURE LEVELS (10 – 50% M.W.H.C.)

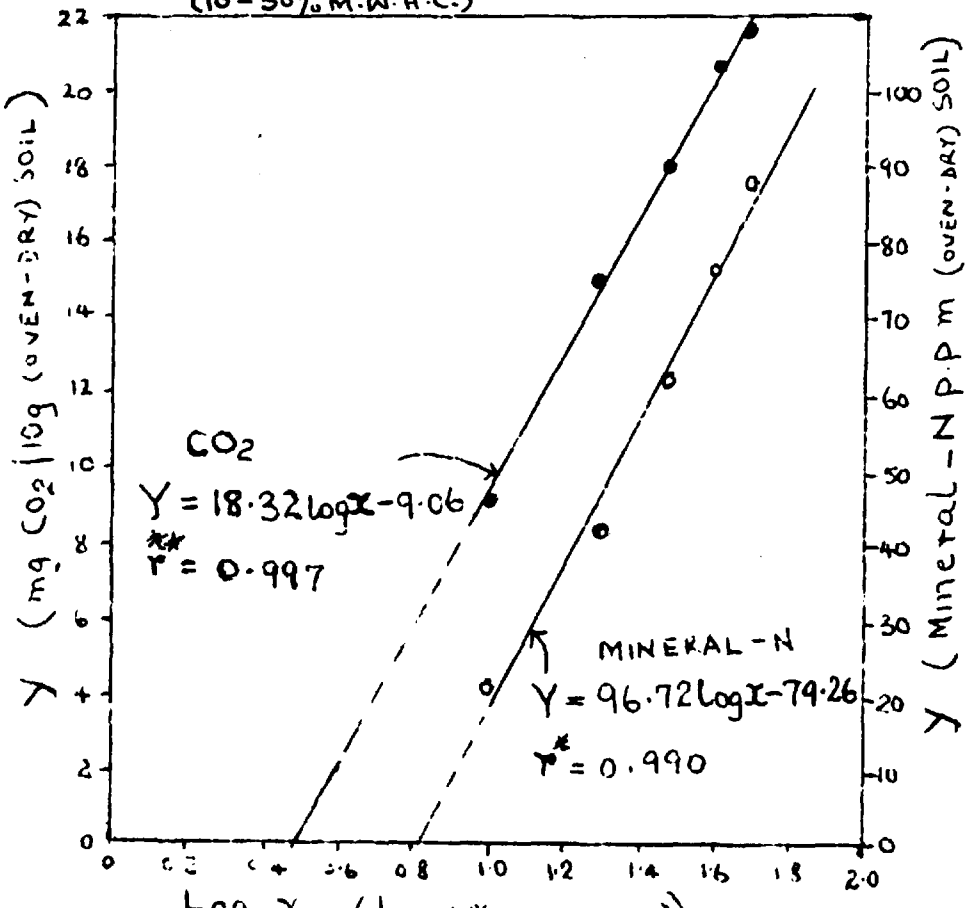
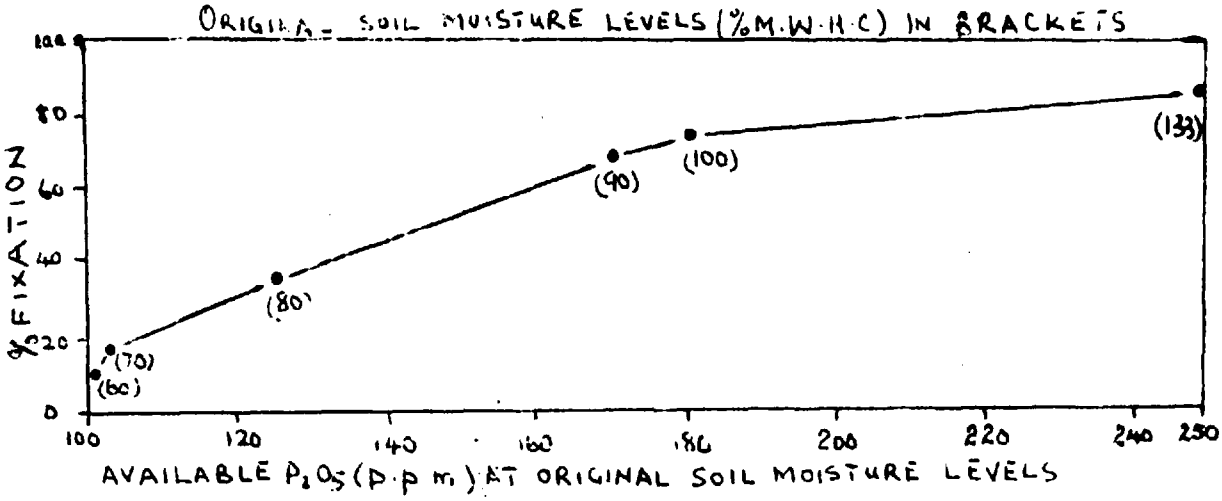


Fig. 25: % FIXATION ON DRYING TO 50% M.W.H.C. OF P_2O_5 MOBILIZED AT HIGH ORIGINAL MOISTURE LEVELS.



General Discussion.

Carbon and nitrogen mineralization is essentially a microbiological process in the soil, and the results here indicate that at moisture levels below 50%, the soil moisture content controls carbon and nitrogen mineralization. The regression lines of carbon and nitrogen mineralization, after three weeks incubation, upon the logarithm of the moisture levels in the low range are shown in Fig. 24. The regression equation for carbon mineralization is $Y = 18.32\log x - 9.06$ ($r = 0.997$, significant at 0.1%) and that for nitrogen mineralization is $Y = 96.72\log_e x - 79.26$ ($r = 0.990$, significant at 1%). The highly significant correlations emphasize the importance of soil moisture in controlling the organic matter decomposition up to about field capacity.

The parallelism of the regression lines (Fig. 24) of carbon and nitrogen mineralizations indicate that the mineralized C:N ratios are similar at all moisture levels up to 50%.

By extra-polation and calculation, the threshhold moisture level at which carbon mineralization begins is 3.7% and that at which nitrogen mineralization begins is 6.6% of the maximum water holding capacity. The threshhold moisture level is therefore lower for carbon than for nitrogen mineralization indicating that carbon mineralization proceeds

at moisture levels 3.7% to 6.6% without concommitant nitrogen mineralization (Birch (1960)). This may be due to the microbial assimilation of mineral nitrogen during carbon mineralization hence no mineral nitrogen accumulation at very low soil moisture levels.

For organic matter decomposition, Birch (1958) obtained a threshhold moisture content of 11% while Bartholomew (1947) obtained 10% to 20% actual moisture for various straws.

The permanent wilting percentage (15 atmosphere moisture tension) for this soil is 20% m.w.h.c. (12% actual moisture, Fig. 2) and the threshhold moisture contents for carbon and nitrogen mineralizations are below the permanent wilting percentage. They indicate that organic matter decomposition can take place below the wilting point.

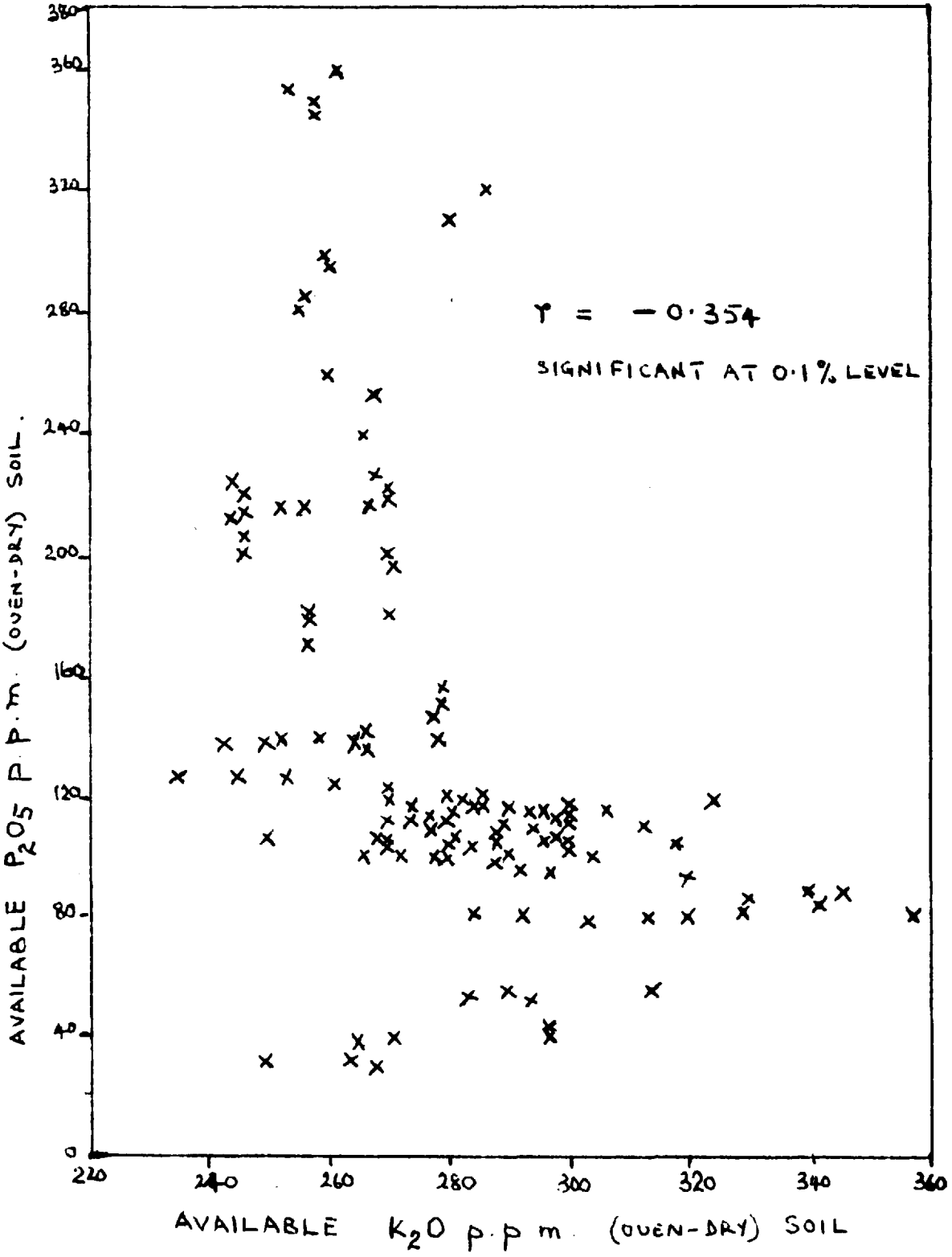
With increasing moisture levels above 50%, carbon mineralization remained constant or decreased slightly, while nitrogen mineralization decreased to low levels. Either carbon mineralization goes on without concommitant nitrogen mineralization (Birch (1960)), or both go on, but due to possible losses of mineralized nitrogen either to the atmosphere or by microbial assimilation, the accumulated mineral nitrogen is low.

On irrigation of low moisture levels and drying high moisture levels to 50%, there are significant advantages

over maintaining the original moisture levels in carbon and nitrogen mineralization, if the moisture level is above 50% before the drying or if it is below 20% for carbon and 10% for nitrogen before irrigation. The effect of partial sterilization caused by soil drying increases with length of drying period (Birch (1960)), (Gasser (1961)), i.e. with increase in the degree of sterilization. Since low moisture levels reduce microbial numbers and high moisture levels reduce the numbers of aerobic microbes, the advantages obtained in organic matter decomposition as a result of changing moisture to optimum levels may be taken as a measure of their effect of partial sterilization imposed by the low or high moisture levels prior to the change. It seems therefore that these effects become significant for the low moisture levels when the moisture level is below the wilting percentage, since the wilting percentage for this soil is 20% m.w.h.c. (12% actual moisture, Fig. 2).

Although there is no direct relationship between carbon or nitrogen mineralization on the one hand and the fixation or release of available phosphorus and potassium on the other under the different soil moisture treatments, the possibility of microbial assimilation contributing to phosphorus and potassium moist fixation must not be overlooked, (Hurwitz and Batchelow (1943))(Aleksandrov (1950)).

Fig. 26: CORRELATION OF AVAILABLE P_2O_5 WITH K_2O WITHIN ALL THE SOIL MOISTURE TREATMENTS.



At moisture levels below 50% and when they are changed to 50%, potassium and phosphorus fixation occurred concurrently. When moisture levels above 50% and their change to 50% are considered, increases in available potassium occurred with concurrent exceptional decreases in available phosphorus and vice versa. The importance of this inverse relationship in the limed soil under study with various moisture treatments is shown by the highly significant negative correlation ($r = -0.354$, significant at 0.1%) between the available phosphorus and potassium (Fig. 26).

For moisture levels above 50%, after drying to 50% there is a consistent minimum of carbon and nitrogen mineralization at 70% (Fig. 9, 16, 19), whether the original moisture levels are continuously maintained or dried to 50%. For high moisture levels, there are two maxima of carbon mineralization, the first probably due to active specialised aerobic flora in the first few days giving way to the second due to anaerobic or facultative flora, as the degree of partial or complete anaerobiosis increases, (Bhaumik (1948)). It may be suggested, therefore, that the maximum observed for changed and unchanged 60% moisture level is due to the activities of similar specialized aerobic flora while that observed for 80% is due to facultative and anaerobic flora, and the minimum observed for 70% may represent a lag between the activities of the two types of flora. 70% may, therefore, represent the critical moisture

level above which the effects of partial anaerobiosis caused by excess soil moisture become substantial.

This is confirmed by the results for available phosphorus and potassium, where anaerobic mobilization of phosphorus and the extra fixation of potassium when the soil is maintained continuously at the original moisture levels, become pronounced at 80%.

Conclusions.

Carbon and nitrogen mineralization and the variations in the availability of phosphorus and potassium were determined at soil moisture levels air-dry to water-logging continuously maintained during twelve weeks incubation, changed to 50% of the maximum water holding capacity and changed to water-logging from below 60% after initial six weeks incubation at the original moisture levels.

1. Carbon and nitrogen mineralization increased with increasing soil moisture level to optima around 60% for carbon and 40% to 50% m.w.h.c. for nitrogen and then decreased. The effect of moisture levels at levels below about 60% and of anaerobiosis at higher moisture levels on microbial activity is suggested as being the cause of these results.

2. Organic matter decomposition took place below the permanent wilting percentage (15 atmosphere percentage).

3. The available phosphorus and potassium decreased at moisture levels 10% to 70% m.w.h.c. from the original air-dry soil status; thereafter, available phosphorus was mobilized while available potassium decreased further with increasing moisture level .

4. On increasing low moisture levels and decreasing high moisture levels, the mineralization of carbon and nitrogen generally increased with decreasing original low moisture levels and with increasing original high moisture levels. Partial sterilization effect is suggested for these increases. On reducing the moisture levels from high to 50% m.w.h.c. mobilized phosphorus was fixed whilst the fixed potassium was released.

5. There was no direct relation, within all the moisture treatments between carbon and nitrogen mineralization on the one hand and the availability of phosphorus and potassium on the other, but microbiological assimilation of phosphorus and potassium might contribute to some observed fixations.

6. Within all moisture treatments, there was a highly significant negative correlation between the available phosphorus and potassium.

7. 70% m.w.h.c. seemed to be the critical soil moisture level above which effective partial anaerobiosis commenced.

The results obtained here for nitrogen mineralization under the simulated irrigation and drainage treatments may give an insight into the availability of nitrogen to plants when these cultural practices are applied in the field but it is not sure whether the release and fixation of potassium and phosphorus observed here will be of practical importance under crops in the field, since Kereszteny (1953) suggested that phosphorus mobilized under water-logged condition might not all be available to the plant and Dabin (1951) stated that plants took up more phosphorus than acid extractable. Also McLean and Simon (1958) stated that potassium fixed by alternate wetting and drying was largely available to plants.

CHAPTER IV

THE EFFECT OF SOIL MOISTURE LEVELS ON (A) CARBON AND NITROGEN MINERALIZATION AT DIFFERENT SOIL pH LEVELS, (B) CARBON AND NITROGEN MINERALIZATION AND AVAILABILITY OF PHOSPHORUS AND POTASSIUM WHEN STRAW AND COMPOST ARE ADDED TO THE SOIL

Introduction.

Soil reaction plays an important part in determining the performance of various crops grown in farmlands and where the soil is acid, the condition is ameliorated by liming. Several soil microbiological studies show that microbes taking part in organic matter decomposition i.e. transformation of complex organic carbon and nitrogen compounds into simpler and inorganic forms, have different pH optima and ranges for their activities and numbers.

In farmlands, as a result of microbial activity, the soil humus may become depleted and it is an accepted farming practice to mitigate this by the addition of organic matter in various forms (decomposed materials such as farmyard manure and compost and undercomposed plant materials such as straw and green manures). This practice affects crop performance and soil microbial activity and numbers, by providing among other things, not only easily mineralizable organic matter but other inorganic nutrients.

It has been shown in Chapter III that the soil moisture level is a controlling factor in carbon and nitrogen mineralization as well as in determining the availability of phosphorus and potassium. In this chapter, an attempt is made to show how (a) different pH levels of one soil and (b) the addition of oat straw and compost affect mineralization and availability of nutrients at different moisture levels.

(A) Effect of soil moisture levels on the mineralization of carbon and nitrogen in soil 1 (Harlington soil) brought to different pH levels and incubated.

Materials.

Soil 1, a sandy loam soil whose chemical and physical properties are shown in Tables 3 and 4 and Fig. 1 was collected from the top 6", air-dried and ground to pass a 2 mm. sieve. Four portions of it were brought to different pH levels by the addition of aluminium chloride or calcium carbonate as described in Chapter II, giving soils of pH 4.72, pH 5.80, pH 6.94 and pH 7.72.

Experimental method.

10 g. samples of the soil were weighed into test-tubes 6" x 1" (internal diameter) and wetted to 20%, 50%, 75%, 100% and 133% (water-logged) of the maximum water holding capacity by the addition of 0.8, 2.1, 3.1, 4.2 and 5.6 ml. of distilled water respectively.

The soil and added water were mixed thoroughly by means of a thin glass rod and the end of the rod in contact with the soil was broken off and left in the soil sample. A vial containing a suspension of barium peroxide in water was placed in each test-tube for carbon dioxide determination (as described in Chapter II) and the test-tube closed with a rubber bung. For each pH x moisture level treatment there were eight replicates giving a total of 160 samples.

The samples were incubated at 28°C and after 3, 6, 12 and 18 weeks the carbon dioxide and mineral nitrogen (NO_3- and NH_4-N) were determined on Morgan's extract of duplicate samples.

In what follows whenever a percentage of water is given this indicates a percentage of the maximum water holding capacity, thus 50% = 50% of the maximum water holding capacity.

1. Carbon Mineralization.

(i) Results.

The mineralized carbon (mg. CO_2/10g. soil) produced at different soil pH and moisture levels after different periods of incubation is shown in Table 17 and in Fig. 27. All increases and decreases in mineralized carbon mentioned below are significant at 5% level.

At pH 4.72: after three and six weeks, the mineralized carbon increased with increasing soil moisture level from 20% to 50% and remained constant with further increases in soil moisture levels.

After 12 and 18 weeks, mineralized carbon increased with increasing soil moisture level from 20% to 50%, remained constant to 75%, then decreased to 100% and remained constant to 133%.

At pH 5.80: after 3 and 6 weeks, the mineralized carbon increased with increasing moisture levels to an optimum at 75% and then decreased with further increases in soil moisture levels.

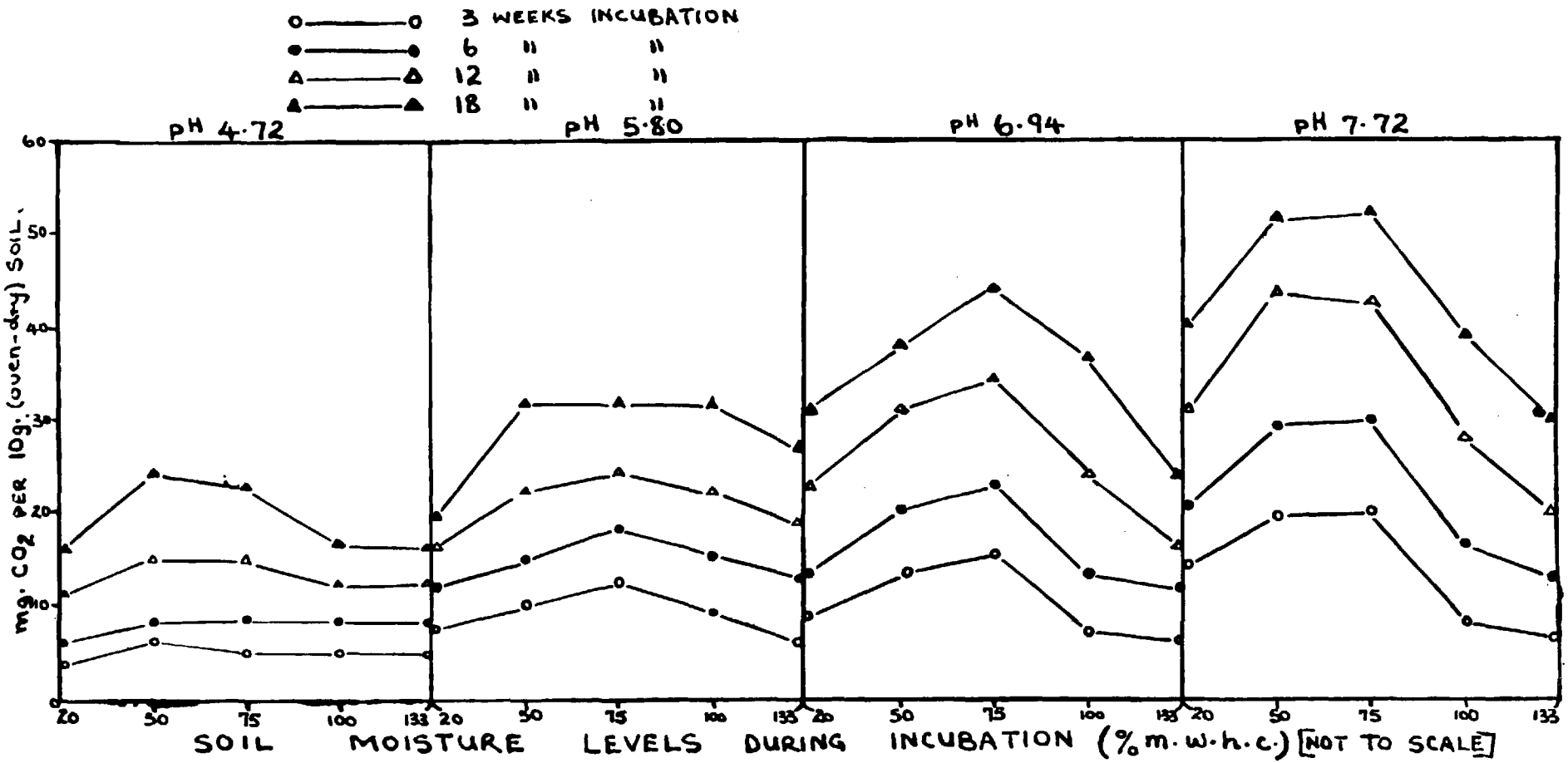
TABLE 17.

Carbon mineralization (mg. CO_2 per 10 g. (oven-dry) soil) in soil 1 brought to different pH levels and incubated at different moisture levels for 18 weeks.

Soil pH	Weeks Incubation	Soil moisture levels(% m.w.h.c.)				
		20	50	75	100	133
4.72	3	3.7	6.2	5.1	5.0	4.8
	6	5.9	8.4	8.7	8.7	8.4
	12	11.6	15.2	15.2	12.5	12.8
	18	16.7	24.5	22.9	16.6	16.1
5.80	3	7.7	9.9	12.5	9.0	6.1
	6	11.5	14.7	18.0	15.4	12.5
	12	16.3	21.1	24.2	22.4	18.7
	18	19.3	31.2	31.7	31.3	27.6
6.94	3	8.9	13.6	14.9	7.0	6.4
	6	13.5	20.6	23.2	13.4	11.9
	12	22.9	31.1	34.1	23.9	16.7
	18	31.3	38.2	43.5	36.6	23.7
7.72	3	14.3	19.3	20.2	8.6	6.5
	6	21.1	29.2	30.1	16.6	13.0
	12	31.6	44.3	42.6	28.2	19.9
	18	40.1	51.8	52.3	39.2	29.9

L.S.D. = 2.1 at 5% and 2.8 at 1% levels.

Fig. 27: CARBON MINERALIZATION IN SOIL 1 BROUGHT TO DIFFERENT pH LEVELS AND INCUBATED AT DIFFERENT MOISTURE LEVELS.



After 12 and 18 weeks, mineralized carbon increased with increasing soil moisture level from 20% to 50%, remained constant to 100% and then decreased to water-logging.

At pH 6.94: after 3 weeks the mineralized carbon increased with increasing moisture level from 20% to 50%, remained constant to 75% and then decreased to constant values at 100% and 133%.

After 6, 12 and 18 weeks, carbon mineralization increased with increasing moisture level from 20% to 75% and then decreased with further increases in moisture levels except after 6 weeks where it was constant between 100% and 133%.

At pH 7.72: throughout the incubation the mineralized carbon increased with increasing moisture level from 20% to 50%, remained constant to 75% and then decreased with further increases in moisture level.

Thus at all pH levels at all times there was always an increase in carbon mineralization with increase in moisture level from 20% to 50%; there was an optimum moisture level for carbon mineralization (except at pH 4.72 in the first six weeks) which lay between 50% and 75%.

For moisture levels 20% to 75% there was always an increase in carbon mineralization with increasing pH (highly significant at 1% level) except between pH 5.80 and pH 6.94, after 6 weeks at 20% and after 3 weeks at 75%, where it was significant at 5% level and after 3 weeks at 20% where it was non-significant.

For moisture levels 100% and 133%, the differences in carbon mineralization at the different pH levels are summarised below. The pH value represents the relevant mineralized carbon in descending order of magnitudes. All figures above the same horizontal line are not significantly (5%) different from each other but are different from all others.

After 3 weeks at 100%:	pH 5.80	pH 7.72	pH 6.94	pH 4.72
After 6 weeks at 100%:	pH 7.72	pH 5.80	pH 6.94	pH 4.72
After 12 weeks at 100%:	pH 7.72	pH 6.94,	pH 5.80	pH 4.72
After 18 weeks at 100%:	pH 7.72	pH 6.94	pH 5.80	pH 4.72
After 3 weeks at 133%:	pH 7.72	pH 6.94	pH 5.80	pH 4.72
After 6 weeks at 133%:	pH 7.72	pH 5.80	pH 6.94	pH 4.72
After 12 weeks at 133%:	pH 7.72	pH 5.80	pH 6.94	pH 4.72
After 18 weeks at 133%:	pH 7.72	pH 5.80	pH 6.94	pH 4.72

(ii) Discussion.

At all soil pH levels, the carbon dioxide produced at 20% was lower than that produced at 50%, indicating that at low moisture levels (below 50%) soil moisture, by limiting microbial numbers, limits organic carbon decomposition. This limiting effect of soil moisture level occurs at all soil pH levels.

A high moisture level (80-95%) favours anaerobic bacteria but is injurious to fungi and most actinomycetes while medium moisture levels (up to 80%) favour filamentous

fungi, aerobic bacteria and actinomycetes (Waksman (1952) and (Stover (1953).

Russell (1950) found that there was a preponderance of fungi at lower pH levels and a preponderance of bacteria and actinomycetes at higher pH levels.

The results of carbon mineralization here show that at pH levels 5.80, 6.94 and 7.72 there is a general tendency for an optimum range of soil moisture levels for carbon mineralization lying between 50% and 70%. This might be explained in the light of the facts presented above that at these pH levels there is a preponderance of bacteria and actinomycetes.

At the low pH (4.72) the absence of any optimum soil moisture levels in the early parts of incubation may be due to the fact that the fungi which predominate are not sensitive to excess soil moisture or that anaerobic bacteria able to thrive at very high moisture levels caused enough organic matter decomposition to produce amounts of carbon dioxide at 100% and 133% similar to those produced at 50% and 75% by fungi, (especially if the anaerobic bacteria are not sensitive to low pH). Alternatively, since water-logging causes an increase in soil pH (Kapp (1933)), it is also possible that at 100% and 133% moisture levels, the pH increased to levels within which bacteria become active. The significant increases in carbon mineralization with increasing pH at moisture levels up to 75% emphasize the importance of liming as a method of

stimulating organic matter decomposition with consequent nutrient release in the soil. Under these conditions, the proportion of actinomyces and aerobic bacteria would increase with increasing soil pH, thus promoting greater organic matter decomposition at higher pH levels.

At moisture levels 100% and 133%, carbon mineralization seems to be independent of soil pH during the early period of incubation. This may support the idea that the anaerobic bacteria at these high moisture levels may not be as sensitive to pH as the aerobic bacteria, hence their activity at all pH levels is more or less similar. As the incubation period advances through 6 to 18 weeks differences in carbon mineralization at the different pH levels become significant and this may be due to the larger amounts of total carbon dioxide produced which increase the accumulated differences.

2. Nitrogen Mineralization.

(i) Results.

The accumulation of NO_3-N and NH_4-N in the soil of different pH values during incubation at different moisture levels is shown in Table 18 and Fig. 28. The negative NO_3-N values which occur sometimes are because the original soil nitrate content (i.e. before incubation) has been subtracted from the NO_5-N determined after incubation.

TABLE 18.

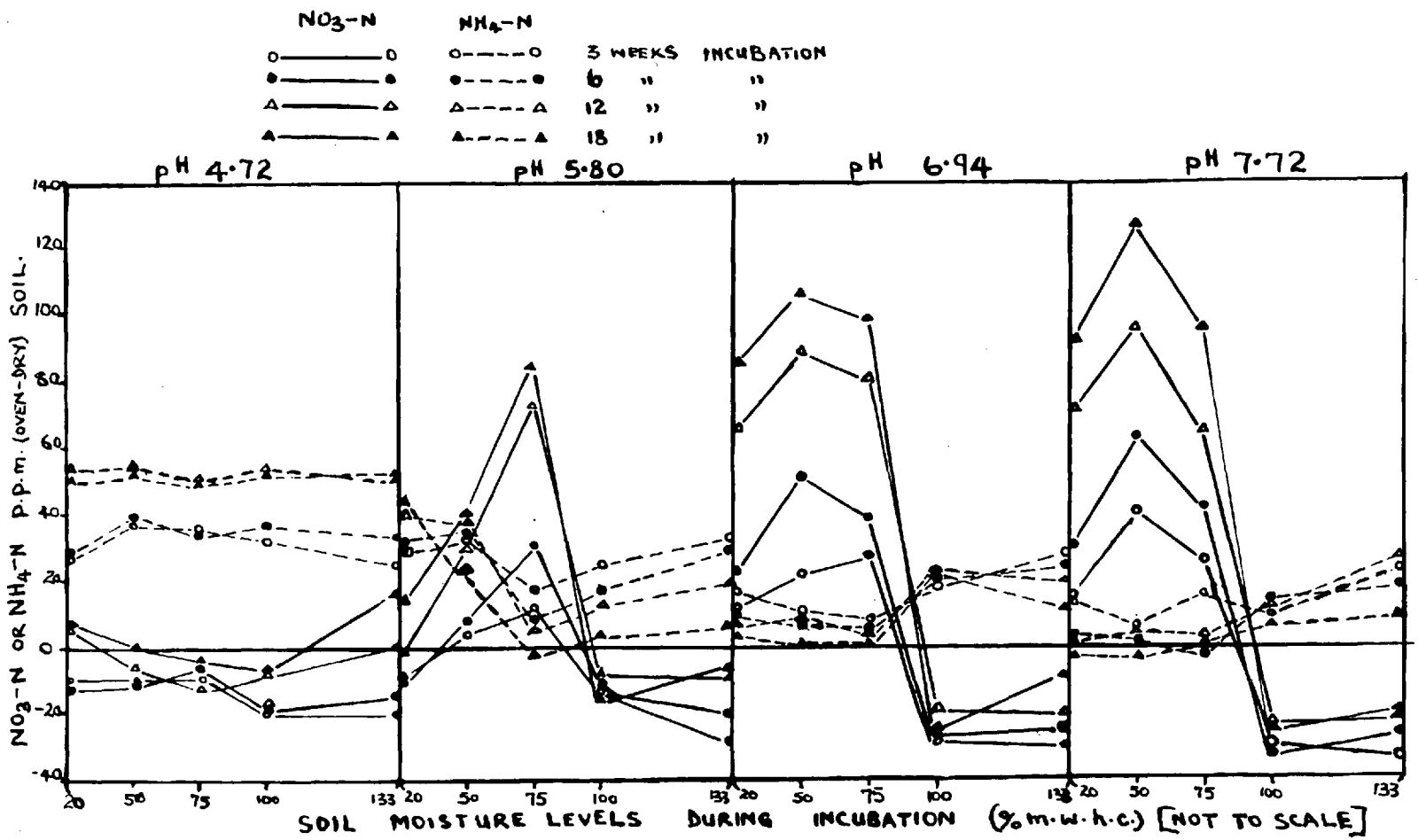
NO_3-N and NH_4-N (p.p.m. oven-dry soil) accumulation in soil 1 brought to different pH levels and incubated at different moisture levels for 18 weeks.

Incubation		Soil moisture levels (% m.w.h.c.)									
		20		50		75		100		133	
pH	Weeks	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N
4.72	3	-9.4	27.8	-9.2	37.0	-8.6	36.2	-19.9	31.7	-19.9	24.8
	6	-11.5	28.6	-9.3	39.6	-5.9	34.5	-19.9	37.0	-15.2	32.8
	12	6.0	53.7	-5.2	55.1	-12.2	48.8	-8.0	53.7	0.3	50.3
	18	8.1	50.9	0.0	53.7	-3.8	48.1	-8.0	53.0	15.8	52.3
5.80	3	-7.9	28.5	4.9	31.9	12.4	16.8	-12.9	25.0	-27.7	31.6
	6	-9.5	32.3	9.1	30.0	31.0	10.3	-11.4	17.5	-20.0	30.8
	12	-0.5	41.0	30.3	38.9	73.0	8.1	-8.9	14.4	-9.5	20.0
	18	14.9	45.2	41.5	24.2	85.4	-2.4	-11.7	3.9	-5.9	6.0
6.94	3	10.8	16.9	21.2	10.1	26.7	7.8	-30.3	18.2	-30.9	27.6
	6	22.0	10.7	50.0	7.9	38.2	6.0	-28.9	19.0	-25.8	24.4
	12	64.6	5.6	87.7	8.4	80.0	5.6	-20.8	21.0	-21.5	18.9
	18	84.2	2.8	104.5	0.0	97.5	0.0	-29.9	20.3	-9.6	10.5
7.72	3	17.1	13.2	39.7	5.7	25.3	15.3	-30.4	8.5	-33.9	23.4
	6	29.7	3.1	62.2	1.5	41.4	-1.9	-33.6	14.1	-27.4	18.5
	12	70.1	2.6	95.4	5.4	65.9	2.6	-23.7	13.8	-22.3	26.4
	18	91.1	-3.0	126.1	-3.0	94.6	1.2	-25.1	6.1	-20.9	8.2

L.S.D. NO_3-N = 14.5 at 5% and 19.3 at 1% levels.

L.S.D. NH_4-N = 5.1 at 5% and 6.7 at 1% levels.

Fig. 28: NO_3-N AND NH_4-N ACCUMULATION IN SOIL 1 BROUGHT TO DIFFERENT pH LEVELS AND INCUBATED AT DIFFERENT MOISTURE LEVELS.



Increases and decreases in NO_3-N and NH_4-N mentioned below are significant at 5% level.

NO_3-N.

At pH 4.72: there were decreases in NO_3-N compared with that originally present in the soil only in the first 6 weeks incubation at 100% and 133% and the increases at 12 and 18 weeks incubation compared with the nitrate-N content at 3 and 6 weeks only at 20%, 100% and 133%. Only at 133% was there an increase in NO_3-N after 18 weeks compared with the NO_3-N originally present in the soil.

At pH 5.80: there were decreases in NO_3-N compared with that originally present in the soil in the first six weeks incubation only at 133% while increases occurred after 18 weeks at 20%, 12 weeks at 50% and 6 weeks at 75%. Between the different moisture levels, starting only from 6 weeks incubation, the NO_3-N increased with increasing soil moisture levels from 20% to 75% and then decreased to similar levels at 100% and 133%.

At pH 6.94 and pH 7.72: the NO_3-N decreased during the whole period of incubation to similar levels at 100% and 133% compared with that originally present in the soil while at 20%, 50% and 75% it increased except in the first three weeks at pH 6.94 and 20% moisture levels.

Between the moisture levels 20% to 75%, the NO_3-N increased with increasing moisture level 20% to 50% but

whereas it remained constant from 50% to 75% at pH 6.94 it decreased at pH 7.72 with increasing moisture from 50% to 75%. Thus, there was no optimum moisture level for NO_3-N accumulation at pH 4.72. There was an optimum at 75% at pH 5.80 but only after 6 weeks incubation. There was an optimum range of 50% to 75% at pH 6.94 and an optimum at 50% at pH 7.72.

Between the soil pH levels after each incubation period NO_3-N was constant at pH 4.72 and pH 5.80, at 20% moisture, increased with increasing pH up to pH 6.94 and again remained constant with increase in pH to 7.72. At 50% moisture, however, it increased with increasing pH from 4.72 to 6.94 and then remained constant with further pH increase to 7.72. At 75%, it increased with increasing pH from 4.72 to 5.80 and thereafter remained constant as the pH increased to 7.72. At 100% it remained constant at pH 4.72 and 5.80 and decreased to similar levels at higher pH levels. At 133%, it was about the same at all pH levels except for pH 4.72, 5.80 and 6.94 at the 18 week analysis, in which the NO_3-N was lower than the corresponding amount at pH 7.72.

NH_4-N.

At pH 4.72: the NH_4-N generally increased in the first 6 weeks incubation with increasing moisture level from 20% to 50% and remained more or less constant with further increases in moisture levels. After 12 and 18 weeks, the NH_4-N increased highly significantly compared with that in

the first 6 weeks to similar levels for all moisture treatments.

At pH 5.80: NH_4-N was constant to 3 and 6 weeks, increased to 12 weeks and, while remaining constant at 20% it decreased at 50% after 18 weeks incubation. At 75%, 100% and 133%, the NH_4-N increased after three weeks and thereafter decreased as incubation progressed, to near zero levels. At the same time it was always at similar levels at 20% and 50%, decreased at 75% and increased with further increases in moisture levels.

At pH 6.94: the NH_4-N increased to 3 weeks and decreased with increasing time at all moisture levels except 100% where it remained constant. Between the moisture levels, it was constant from 20% to 75% at each period of incubation except at three weeks when it decreased with increasing moisture level from 20% to 50% and remained constant to 75%. NH_4-N increased as the moisture level increased from 75% to 100% and further increased in the first 6 weeks, remained constant to 12 weeks and decreased to 18 weeks as the moisture level increased to 133%.

At pH 7.72: the NH_4-N accumulated in the first three weeks, disappeared during the rest of incubation period at 20%, 50% and 75%. At higher moisture levels, some of the NH_4-N accumulated during earlier parts of incubation, also disappeared at the later part but on the whole the accumulated NH_4-N was higher at 133% than at 100% which in turn was higher than at lower moisture levels.

Between the pH levels, there was a general decrease in NH_4-N with increasing pH except at 100% and 133% where this general tendency was less marked.

On the whole, as the NO_3-N accumulation increased the NH_4-N decreased. Whereas there were optimum moisture levels for NO_3-N accumulation at the three higher pH levels, there were no such optima for NH_4-N accumulation.

(ii) Discussion.

High moisture levels favour anaerobic bacteria but are injurious to aerobic bacteria, actinomycetes and fungi while medium moisture levels favour the latter organisms, (Waksman (1952)) and (Stover (1953)). There is a preponderance of fungi at low pH values and a preponderance of bacteria at medium to high pH values (Russell (1950)). At the low pH (4.72) in this study it was observed that there were decreases in NO_3-N only at 100% and 133% and this indicates that the most important micro-organisms here may be anaerobic bacteria which do not seem to be sensitive to low pH values, since it is bacteria and not fungi which are known to denitrify nitrates.

At the same time there were increases in NH_4-N which were similar at all moisture levels. Bacteria and fungi are capable of producing ammonia by the decomposition of organic matter (Waksman (1952)). Soil moisture levels do not control the accumulation of ammonia as they do that of nitrate

(Gerretsen (1921), Kapp (1933) and Bhuijan (1949)). Thus at the low pH (4.72) in the absence of aerobic bacterial nitrifiers and in the presence of fungi at low and medium moisture levels and of anaerobic bacteria at the high moisture levels, the conditions are equally suited to NH_4-N accumulation.

At pH levels of 5.80 and greater the nitrate accumulation attained maxima between 50% and 75% although at pH 7.72 the maximum was specific at 50%. At 20%, the numbers of nitrifiers were limited and nitrate accumulation was thus lower than that at 50%, while at 100% and 133% the anaerobic conditions stimulated denitrification and thus produced increasing negative values of accumulated NO_3-N. At the same time, the ammonia accumulation was decreasing as the nitrate accumulation was increasing showing that ammonia accumulated during the earlier period of incubation was nitrified during the later period. This behaviour was noticeable at the higher pH levels and at moisture levels up to 75%, which have been shown to be the ideal conditions for the development of aerobic nitrifying bacteria.

The decrease in NH_4-N at 133% at pH up to 6.94, with increase in the values of NO_3-N may be due to the oxidation of the NH_4-N to NO_2-N (nitrite-N) which has been included here in the nitrate value. The decrease in NH_4-N at 100% and 133% with increase in time of incubation at pH 7.72 without any relative increase in nitrate may be due to volatilization

since Wahhab et. al. (1960) and Volk (1959) have shown that ammonia may be lost through volatilization at high moisture and pH levels.

On the whole therefore, the NO_3-N accumulation increased at moisture levels up to 50% with increasing soil pH indicating that as pH increases the numbers of bacteria increase and that nitrifying bacteria have optimum moisture levels at 50% at about neutral pH and at 75% at pH 5.80, but may be virtually inactive in pH 4.72.

At the same time NH_4-N accumulation generally decreased with increasing pH in a more pronounced fashion at moisture levels 20% to 75% than at moisture levels 100% and water-logging.

General Discussion.

Since carbon and nitrogen are intimately related in the soil organic matter, it may be expected that factors which affect carbon mineralization will affect nitrogen mineralization similarly, at least as far as the low to medium soil moisture conditions are concerned. Table 19 shows total mineral nitrogen accumulation (i.e. NO_3-N plus NH_4-N) for the various treatments and a comparison of this with Table 17 (showing carbon mineralization) shows that for moisture levels up to 75%, the course of mineralization ~~of mineralization~~ of both elements is similar. Thus both processes are carried out in the soil by organisms which are affected similarly by soil pH and moisture.

TABLE 19.

Total mineral nitrogen (NO_3-N + NO_3-N) accumulation in soil 1 brought to different pH levels and incubated at different moisture levels.

Incubation		Soil moisture levels (% m.w.h.c.)				
pH	Weeks	20	50	75	100	133
4.72	3	18.4	27.8	27.6	11.8	4.9
	6	17.1	30.3	28.6	17.1	17.6
	12	59.7	49.9	36.6	45.7	50.6
	18	59.0	53.7	44.3	45.0	68.1
5.80	3	20.6	36.8	29.2	12.1	3.9
	6	22.8	39.1	41.3	6.1	10.8
	12	40.5	69.2	81.1	5.5	10.5
	18	60.1	65.7	83.0	-7.8	0.1
6.94	3	27.7	31.3	34.5	-12.1	-3.3
	6	32.7	57.9	44.2	-9.9	-1.4
	12	70.2	96.1	85.6	0.2	-2.6
	18	87.0	104.5	97.5	-9.6	0.9
7.72	3	30.3	45.4	40.6	-21.9	-10.5
	6	32.8	63.7	39.5	-19.5	-8.9
	12	72.7	100.8	68.5	-9.9	4.1
	18	88.1	123.1	95.8	-19.0	-12.7

At moisture levels greater than 75% carbon mineralization paralleled nitrogen mineralization only at the lower pH levels. At the higher pH levels carbon mineralization still proceeded but negative nitrogen accumulation values were obtained. This indicates that even though at high moisture levels nitrogen mineralization may proceed with concommitant carbon mineralization, because of losses of mineralized nitrogen by denitrification and/or ammonia volatilization all the mineralized nitrogen may be lost.

(B) Effects of soil moisture levels on carbon and nitrogen mineralization and availability of phosphorus and potassium when straw and compost are added to the soil during incubation.

Materials.

Oat straw and composted oat straw were ground in a mill and were analysed for organic carbon (Walkley-Black) and total nitrogen, phosphorus and potassium by means of wet-digestion with sulphuric acid and hydrogen peroxide as described in Chapter II and the moisture characteristic curves of their 2% mixture with soil 1 determined and shown in Fig. 1 and Fig. 2.

Moisture and chemical characteristics of oat-straw and compost.

Material	%C	%N	%P_2O_5	%K_2O	100% m.w.h.c.*
Straw	40	0.89	0.25	0.78	55% actual moisture
Compost	35	2.61	0.63	1.38	50% actual moisture

* Added to soil 1 at the rate of 2%.

Soil 1, a sandy loam soil whose chemical and physical properties are shown in Tables 3 and 4 and in Fig. 1 was collected from the top 6", air-dried and ground to pass a 2 mm.-sieve.

Experimental Method.

10 g. samples of the soil were weighed into glazed paper, and given the following treatments: soil alone, + 2% straw, + 2% compost. They were well mixed and placed in test-tubes 6"x1" (internal diameter). They were then brought to 20%, 50%, and 133% of the maximum water holding capacity by adding to soil alone 0.8, 2.1 and 5.6 ml.; to soil + straw 1.0, 2.6 and 7.2 ml.; and to soil + compost 0.9, 2.4 and 6.6 ml. of distilled water respectively.

The soil and added water were mixed with a thin glass rod and the part of the rod which was in contact with the soil was broken off and left in the soil. A vial containing a suspension of barium peroxide was placed in each tube and the tube closed with a rubber bung. For each organic matter x moisture treatment there were eight replicates giving a total of 72 samples. For each organic matter treatment, duplicates were prepared and analysed at the beginning of the incubation, thus giving the original mineral-N, P_2O_5 and K_2O levels.

The other 72 samples were incubated at 28°C and the carbon dioxide determined every three weeks over 18 weeks the mineral-N, phosphate and potassium, were determined in the

Morgan's extract of duplicate samples after 3, 6, 12 and 18 weeks.

N.B. The percent maximum water holding capacity is, in this experiment, expressed only as percent (e.g. 50% m.w.h.c. = 50%).

1. Carbon Mineralization.

(i) Results.

The carbon dioxide produced (mg. CO_2/10 g. soil) in the untreated soil and in that treated with straw and compost and incubated at three moisture levels is shown in Table 20 and Fig. 29. In the following results and discussion, any increases or decreases in carbon mineralization mentioned are significant at 5% level.

In the soil alone there were no significant differences in carbon mineralized due to moisture level.

In the presence of 2% straw, the mineralized carbon increased compared with soil alone from 6 weeks incubation onwards for moisture levels 20% and 50% but at 133%, there was no such increase. Also from 6 weeks incubation the mineralized carbon always increased with increasing soil moisture level from 20% to 50% and then decreased to 133%.

In the presence of 2% compost, there were no increases in the mineralized carbon compared with corresponding values in the soil alone excpet from 15 weeks at 20%. There were no

[illegible] incubated alone or with 2% compost.

increases compared with the corresponding values in the soil + straw at 133%, the carbon mineralization in soil + straw increased compared with that in soil + compost from 9 weeks onwards at 20% and from 6 weeks at 50%. Between the moisture levels, there was no significant difference between carbon mineralized at 20% and that at 50% but the differences between the carbon mineralized at 50% and that at 133% became significant only at the end of incubation.

Thus, generally, at 133% there were no differences in the mineralization of carbon whether the soil was incubated alone, with straw or with compost. There were no differences in carbon mineralized at 20% and 50% in soil alone or in soil + compost. It was only when straw was added that significant differences appeared between the carbon mineralized at the different moisture levels and this happened only after six weeks incubation.

(ii) Discussion.

During the composting of oat straw the easily mineralizable carbohydrates, cellulose and hemicellulose decrease greatly while the less easily decomposable constituents increase in proportions and this tends to make the composition of the organic fraction of the compost similar to that of soil humus, (Waksman (1952)). Thus, it is understandable that the mineralization of carbon was similar at each moisture level whether the soil was incubated alone or with 2% compost.

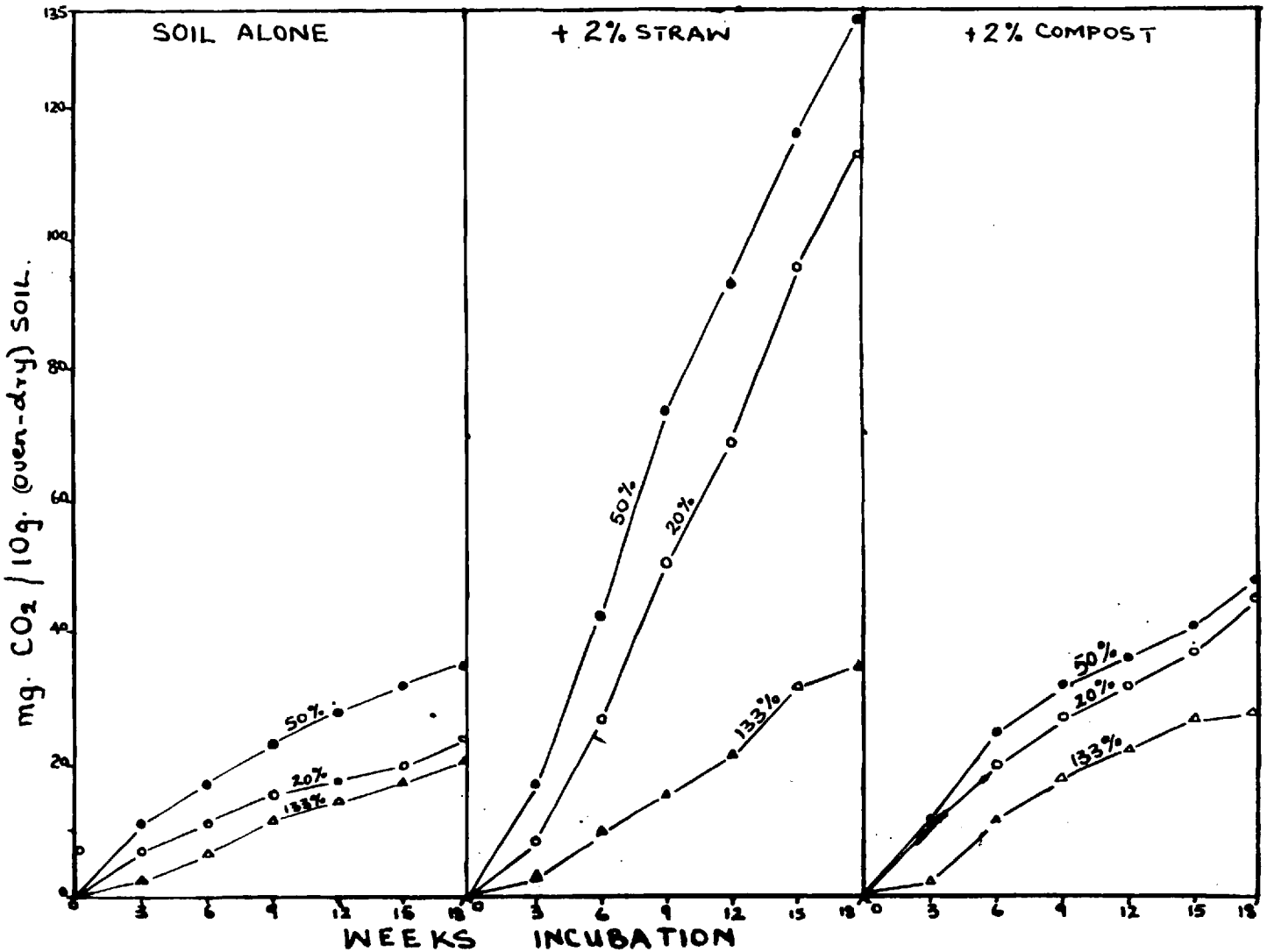
TABLE 20.

Carbon mineralization (mg.CO_2/10 g. oven-dry soil) in soil 1 treated with straw and compost and incubated at at three moisture levels.

Organic matter treatment	Weeks incubation	Soil moisture levels (% m.w.h.c.)		
		20	50	133
Soil alone	3	6.9	10.8	2.5
	6	10.9	16.8	6.4
	9	15.7	23.0	11.6
	12	17.5	27.8	14.3
	15	19.9	31.6	17.2
	18	23.9	35.2	20.6
+ 2% straw	3	8.4	17.0	2.9
	6	26.9	42.5	10.3
	9	50.8	74.1	15.8
	12	69.5	93.5	21.7
	15	95.7	116.0	31.9
	18	113.3	133.7	35.2
+2% compost	3	11.0	11.0	2.5
	6	19.8	24.8	11.8
	9	27.2	31.7	18.4
	12	31.6	36.1	22.1
	15	37.1	41.4	26.2
	18	45.3	47.8	28.1

L.S.D. = 15.5 at 5% and 20.7 at 1% levels.
Carbon content of soil = 1.32%
Carbon content of straw = 40%, added to soil = 293.4 mg.CO_2/10 g. soil.
Carbon content of compost = 35%, added to soil = 256.6 mg.CO_2/10 g. soil.

Fig. 29: CARBON MINERALIZATION IN SOIL 1 TREATED WITH ORGANIC MATTER AND INCUBATED AT DIFFERENT MOISTURE LEVELS.



It also is not surprising that highly significant increases in the mineralization of carbon occurred when uncomposted straw was added to the soil incubated at 20% and 50% compared with the mineralization of carbon when straw was absent.

It may further explain the significant differences between the carbon mineralizations with straw at the different moisture levels. Since the easily mineralizable organic fraction was abundant and microbiological numbers and activities increased with increasing moisture levels up to an optimum around 50% to 80% (Waksman (1952)), the carbon dioxide evolution from soil treated with straw has therefore increased with increasing soil moisture from 20% to 50% and then decreased at water-logging.

At 133% (water-logging), the lack of differences between the carbon mineralization irrespective of the organic matter treatment may be explained by examining the process of anaerobic carbohydrate decomposition. Anaerobic bacteria decompose cellulose mainly with the formation of various organic acids, such as lactic and acetic acids and alcohol and methane, and decompose the sugars and sugar acids, resulting from hemicellulose break down, to alcohols and lower acids (Waksman (1952)). It seems therefore that only little extra carbon dioxide evolution may be expected when straw, containing high proportions of cellulose and hemicellulose, is decomposed under water-logged (anaerobic) conditions in soil.

2. Nitrogen Mineralization.

(i) Results.

The NO_3-N and NH_4-N accumulated when the soils treated with straw and compost were incubated for 18 weeks are shown in Table 21 and Fig. 30.

N.B. All increases and decreases mentioned in these results and in the following discussion are significant at 5% level.

NO_3-N.

In the soil alone, the NO_3-N always increased with incubation at 20% and 50% anddecreased at 133% compared with the original soil content. At 133% the original NO_3-N was never completely depleted. The NO_3-N also increased with increasing moisture levels from 20% to 50% and then decreased sharply at 133%.

In the soil + 2% straw, the NO_3-N decreased at all moisture levels compared with the original NO_3-N of 40 p.p.m. and there was complete depletion of the original NO_3-N at all moisture levels in 6 weeks incubation. After that, there were increases as time went on but never enough to reach the original NO_3-N except at 50% where it exceeded the original NO_3-N at 12 weeks but decreased again at 18 weeks.

TABLE 21.

NO_3-N and NH_4-N (p.p.m. oven-dry soil) accumulation in soil 1 treated with 2% straw and 2% compost and incubated at three moisture levels.

Organic matter treatment	Original* mineral nitrogen		Weeks incubation	Soil moisture levels (% m.w.h.c.)					
				20		50		133	
	NO_3-N	NH_4-N		NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N
Soil alone	29.4	-	3	16.9	0.0	27.8	12.6	-16.2	41.0
			6	33.0	0.0	63.3	0.0	-25.6	36.4
			12	45.1	19.3	72.8	22.4	-18.4	59.5
			18	56.3	17.2	98.3	17.0	-8.8	57.4
+2% straw	40.0	-	3	-17.1	0.0	-19.2	23.8	-40.0	0.0
			6	-38.9	4.6	-40.0	0.0	-40.0	0.0
			12	-27.8	21.0	27.6	19.6	-28.5	64.1
			18	-32.9	72.4	-15.4	73.9	-22.1	65.1
+2% compost	124.4	-	3	-11.5	19.1	-101.5	48.9	-105.9	62.7
			6	-107.8	36.0	-110.6	41.5	-124.4	81.3
			12	-41.2	14.9	57.0	15.0	-112.4	84.2
			18	2.2	17.7	133.0	2.8	-124.4	59.7

L.S.D. NO_3-N = 6.2 at 5% and 8.3 at 1% levels.

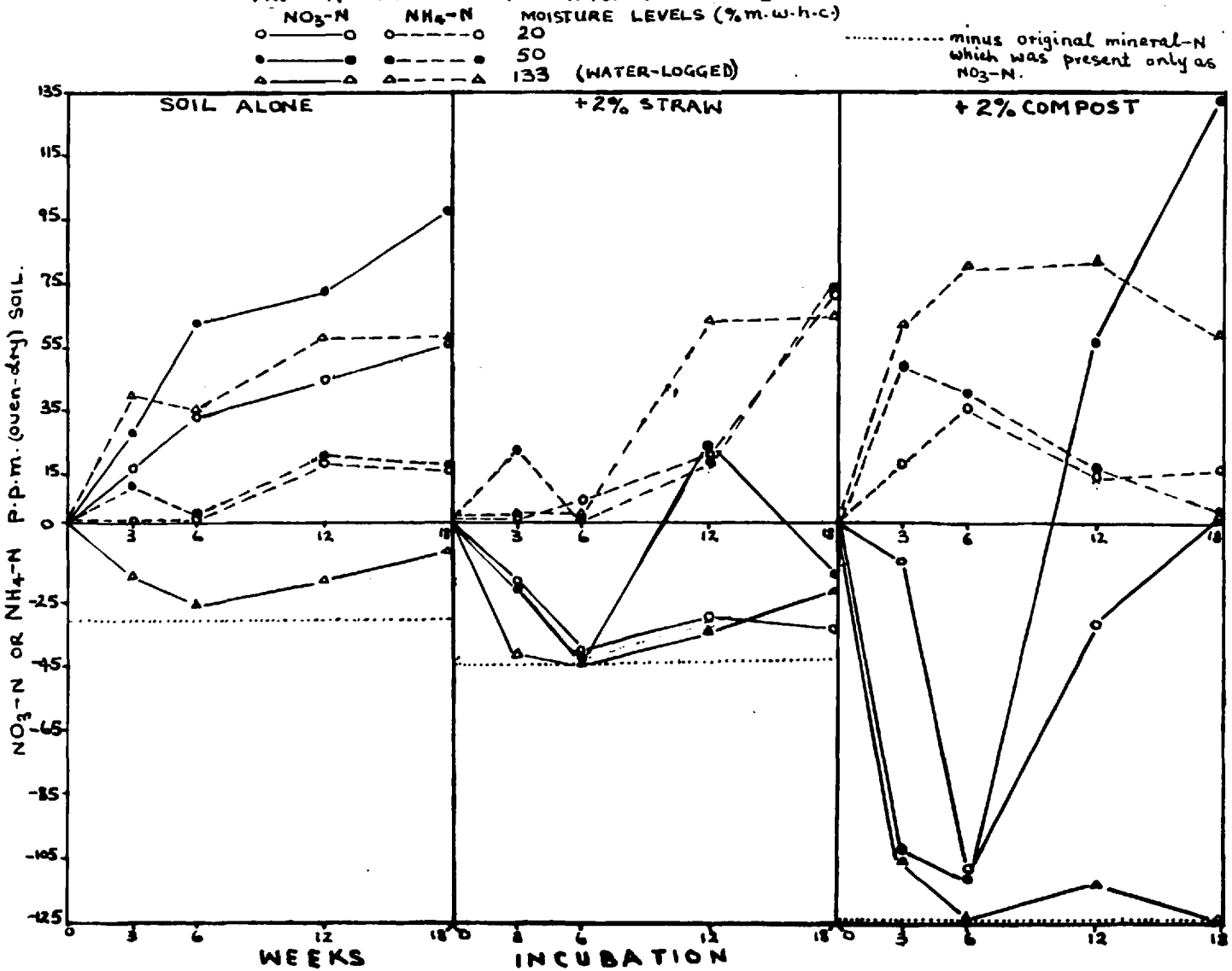
L.S.D. NH_4-N = 5.4 at 5% and 7.3 at 1% levels.

Total nitrogen content of soil = 0.15%; total nitrogen content of straw = 0.89%; added to soil through straw = 178 p.p.m. soil.

total nitrogen content of compost = 2.61%, added to soil through compost = 522 p.p.m. soil.

* subtracted from the determined values to give the values shown in the table.

Fig. 30: NO_3-N AND NH_4-N ACCUMULATION IN SOIL 1 TREATED WITH ORGANIC MATTER AND INCUBATED AT DIFFERENT MOISTURE LEVELS.



In the soil + 2% compost, the NO_3-N decreased within 6 weeks at all moisture levels compared with the original NO_3-N of 124.4 p.p.m. and there was almost complete depletion of the original NO_3-N at this time. After that, NO_3-N remained completely depleted at 133%, increased at 18 weeks to the original NO_3-N at 20% and greatly exceeded the original NO_3-N at 50% from 12 weeks.

NH_4-N.

In the soil alone, the NH_4-N remained at zero levels within 6 weeks at 20% and 50% but increased at 133%. At 12 and 18 weeks, it increased compared with the original soil NH_4-N of 0 p.p.m. and remained constant at 20% and 50% but during this time it increased further to constant levels at 133%.

In soil + straw, the NH_4-N was at near zero levels during 6 weeks incubation at all moisture levels and thus was not different from the original NH_4-N which was 0 p.p.m. At 12 and 18 weeks it increased to constant levels at 133%, and increased with time at 20% and 50% so that it was higher in 12 weeks and lower in 18 weeks at 133% than at 20% and 50%.

In soil + compost, the NH_4-N increased above the original NH_4-N of 0 p.p.m. For the first six weeks it increased with increasing time of incubation at 20% and 133%; but decreased with increasing time of incubation at 50% from 3 weeks to 6 weeks. Within this time it also increased

with increasing moisture levels. Thereafter the NH_4-N decreased with increasing time of incubation at 20% and 50%. At 133% it remained constant until 12 weeks and then decreased to 18 weeks.

Thus in soil alone and soil + straw ammonia increased simulataneously with nitrate in the last 12 weeks of incubation at all moisture levels while in soil + compost NH_4-N increased whilst NO_3-N decreased initially, whilst the reverse held during the later part of the incubation.

(ii) Discussion.

Harmsen and van Schreven (1955) after reviewing work on nitrogen mineralization from organic matter added to soils came to the conclusion that when organic matter was added to the soil there was a rapid increase in the numbers of micro-organisms which decomposed the easily mineralizable fractions of the added organic matter. The micro-organisms first immobilizedany mineral nitrogen initially present in the soil, but later, as a result of the decompositon of the cell substances of the early generations of the micro-organisms, not only was the immobilised nitrogen released but mineral nitrogen resulting from the decomposition of the organic matter accumulated.

The initial immobilization of mineral nitrogen may be regarded as a lag period in mineral nitrogen accumulation as a result of the addition of organic matter to the soil. In the soil where no organic matter was added, the results in this experiment show no such lag in nitrate-N accumulation if the

soil moisture level was 20% or 50%. The losses of the original soil NO_3-N observed at 133% was probably due to denitrification rather than any effect of organic matter, and this is confirmed by the fact that at this moisture level, ammonia accumulation was high throughout incubation and showed no lag period.

In the presence of 2% straw this lag period was clearly shown at all moisture levels, all the original soil nitrate having disappeared and no ammonia accumulated at the end of six weeks incubation. From then on the nitrate increased slightly at 20% and 133% while it increased sharply and then decreased at 50% so that at the end of 18 weeks, the nitrate accumulation at all moisture levels still did not attain the original soil level within this period, the ammonia increased with time at all moisture levels, initially more rapidly at 133% than at 20% and 50%, so that at the end of 18 weeks similar amounts of ammonia were accumulated at all moisture levels. It would seem that after the initial lag in both nitrate and ammonia accumulation, the soil moisture level did not affect the final ammonia or nitrate status of the soil treated with straw. Waksman (1952) found that with straw, irrespective of soil moisture level, ammonia accumulated while nitrate remained at low levels after the initial lag period. This might indicate either that micro-organisms active after the lag period prefer nitrate to ammonia for cell substance synthesis or that nitrifying organisms have been suppressed. The latter

alternative is likely to obtain at 133% (water-logging) while the former may obtain at 20% and 50%.

In the presence of compost, the lag in nitrate accumulation was prominent also at the end of six weeks incubation at all moisture levels but no such lag occurred in ammonia accumulation, in fact ammonia accumulation was highest at all moisture levels at this time. Thereafter nitrate accumulated rapidly at 20% and 50% while the accumulated ammonia disappeared. At 133%, however, ammonia accumulation remained high and the nitrate remained completely absent. It might be suggested that micro-organisms similar to those operating after the lag period at 20% and 50% in the soil treated with straw were operating during the initial stages of incubation of the soil treated with compost because they seemed to assimilate the original soil nitrate while allowing ammonia accumulation to proceed. Later generations seemed not only to have decomposed the cell substances of these earlier generations but were actively oxidizing any ammonia produced, to nitrates. This process seemed more marked at 50% than at 20%. This is understandable since nitrifiers are very sensitive to the effects of low moisture levels (Hwang and Frank (1938).

At 133%, the losses of original soil nitrate which persisted from 6 weeks incubation, were probably due to denitrification, since the conditions were anaerobic, while

the accumulation of ammonia is characteristic of water-logged soil conditions (Kapp (1933), Bhuijan (1949)).

3. Availability of Phosphorus.

(i) Results.

The available (Morgan extractable) phosphorus in the soil treated with straw and compost and incubated at three moisture levels is shown in Table 22 and Fig. 31.

N.B. All increases and decreases mentioned in the results and the following discussion are significant at 5% level.

In the soil alone, the available phosphorus remained at constant levels similar to that in the original soil when the moisture levels at incubation were 20% and 50%. With water-logging (133%) available phosphorus increased greatly during the first three weeks and then continued to increase slowly thereafter.

In the soil + 2% straw, the original soil available phosphorus was increased by the addition of straw from 47 p.p.m. to 60 p.p.m. soil. During incubation, the available phosphorus decreased in the first three weeks at 20% and 50%, decreased further after six weeks at 50%, and finally increased slightly to constant levels after 12 and 18 weeks. After the initial decrease at 20%, it increased to constant levels after 6 and 12 weeks and again decreased at 18 weeks. With water-logging

(133%) available phosphorus increased greatly to 3 weeks, decreased to six weeks and then increased with increasing time.

In the soil + 2% compost, the addition of compost increased the original soil phosphorus from 47 p.p.m. to 69 p.p.m. During incubation at 20% and 50% the available phosphorus decreased with increasing time of incubation to similar values for both moisture levels. At 133% available phosphorus greatly increased to three weeks, increased further to 6 weeks, remained constant to 12 weeks and then increased again to 18 weeks. As a result of the increase in the original soil phosphorus due to the addition of straw and compost the differences between corresponding values of available phosphorus in the soil with and without straw, and compost were significant at 5% during the early part of incubation period when it was incubated at 20% and 50%. At the end of incubation, the differences were small. At water-logging, the available phosphorus decreased in the order soil + compost > soil + straw > soil alone, except before the first 6 weeks when it was similar for soil alone and soil + straw but was higher for soil + compost.

(ii) Discussion.

The results show that at aerobic moisture levels when no organic matter was added to soil the available phosphorus was unaffected in this soil after 18 weeks incubation. In the presence of straw the initial decrease at three weeks might be

TABLE 22.

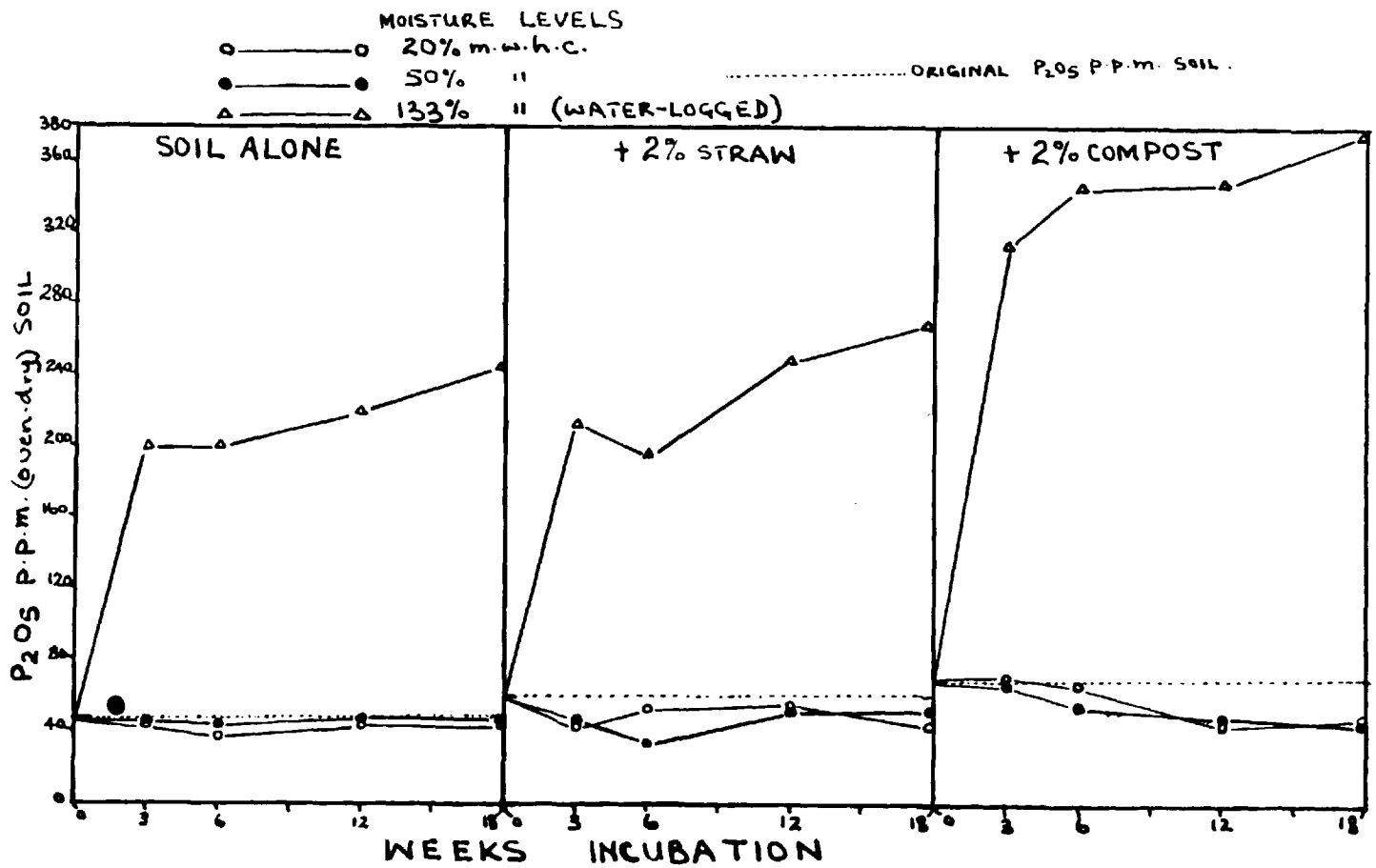
Available phosphorus (P_2O_5 p.p.m. oven-dry) in soil 1 treated with straw and compost and incubated at three moisture levels.

Organic matter treatment	Original available phosphorus	Weeks incubation	Soil moisture levels(%m.w.h.c.)		
			20	50	133
Soil alone	47	3	44	44	206
		6	39	43	208
		12	44	44	220
		18	44	45	245
+ 2% straw	60	3	43	46	214
		6	54	35	198
		12	56	54	250
		18	45	54	270
+ 2% compost	69	3	72	69	317
		6	69	58	347
		12	48	50	357
		18	50	49	377

L.S.D. (20% and 50%) = 4 at 5% and 5 at 1%.
L.S.D. (water-logged or 133%) = 12 at 5% and 16 at 1%.

Total P_2O_5 content of straw = 0.25%, added to soil through straw = 50 p.p.m. soil.
Total P_2O_5 content of compost = 0.625%, added to soil through compost = 125 p.p.m. soil.

Fig. 31: AVAILABLE P_2O_5 IN SOIL 1 TREATED WITH ORGANIC MATTER AND INCUBATED AT DIFFERENT MOISTURE LEVELS.



due to the decomposition of the earlier generations of micro-organisms similar to the process which brings about mineral-nitrogen accumulation after an initial lag period. Alternatively, this might be due to the release of organic phosphorus in the straw since only 13 p.p.m. of the 50 p.p.m. of total P_2O_5 (soil basis) added through the straw was extracted before incubation.

In the presence of compost under aerobic conditions the available phosphorus was unchanged during the early part of incubation but decreased later. It would seem therefore that the rate of mineralization of added organic phosphorus was off-set by assimilation of inorganic phosphorus by micro-organisms during the first three weeks. Later, any phosphorus released from the organic form was probably fixed in the soil, since Tendille (1959) and several other workers have shown that the addition of phosphates favours the fixation of phosphorus in the soil.

Under water-logged conditions phosphorus was greatly mobilized whether or not organic matter was added to the soil. This agrees with results obtained by Gasser and Bloomfield (1955), Bromfield (1954) and several other workers. The greater mobilization observed with straw and compost addition compared with soil alone may be explained by the fact that organic acids produced as a result of the fermentation of the added organic matter may exhibit a solubilizing effect on soil phosphorus compounds (Gasser and Bloomfield (1955), Shapiro (1958a).

The greater mobilization of phosphorus in the presence of compost than in the presence of straw may be related to observations made by Gasser and Bloomfield (1955) that the more organic matter added to the soil, the more rapid the change from oxidizing to reducing conditions on water-logging, except if the C : N ratio was greater than 20. Here the original C : N ratio of the added straw was 45
and that of the added compost was 13.4 and it would seem that partly because of this and probably as a result of the greater total phosphorus content of the compost there was a greater mobilization of phosphorus with compost than with straw during water-logging of the soil.

4. Availability of Potassium.

(i) Results.

The available (Morgan extractable) potassium in the soil treated with straw and compost and incubated at three moisture levels is shown in Table 23 and Fig. 32.

N.B. All increases and decreases in the available potassium mentioned in these results and in the following discussion are significant at 5% level.

In the soil alone there were no significant changes in available potassium during the incubation at all moisture levels compared with the original soil available potassium except for a decrease in the first three weeks at water-logging.

As a result of adding 2% straw, the original soil available potassium was increased by 100 p.p.m. During three weeks incubation the available potassium decreased at all moisture levels to similar amounts. Later while it decreased further and finally increased at 50% and 133%, it remained constant at 20%, so that at the end of incubation it was at similar values at all moisture levels but still significantly (5%) less than the original potassium status.

As a result of adding 2% compost, the original soil available potassium was increased by 87 p.p.m. Within three weeks, decreases were observed only at 50% and 133% but there were further decreases to 12 weeks at all moisture levels to similar amounts. Thereafter there were increases at all moisture levels. The final values were significantly lower than the original available potassium values at 20% and 50% but was similar to the original value at 133%.

On the whole, allowing for differences in the original potassium status, straw and compost fixed similar amounts of potassium at corresponding moisture levels and times of incubation.

(ii) Discussion.

Bray and De Turk (1939), Damsgaard-Sorensen (1942) and Ayres (1949) reported lack of change in the available potassium when the soil was stored moist, and the results obtained here when no organic matter was added to the soil agrees with these reports.

These results also show that soil moisture levels 20% to 133% had no effect on the availability of potassium in this soil, except for a temporary decrease with water-logging. With the added materials 60% of the total potassium (156 p.p.m.) added through the straw and 31% of the total potassium (276 p.p.m.) added through the compost was extractable before incubation. This is probably due to differences in the exchange capacity and hence the potassium retaining ability of straw and compost.

Hurwitz and Batchelor (1943) found the fixation of potassium added through mixtures of oat straw and clover plant up to 14% after 89 days incubation while Aleksandrov (1950) attributed the major portion of potassium fixation in sierozem and chernozem soils to microbiological processes. Contrary results have however been reported by Vandecaveye (1924) and York et. al. (1953). Since Waksman (1952) has stated that the ash of bacterial cells may contain 1% to 25% potassium and that of fungi 8% to 40%, it must be expected that some of the fixation of potassium in the soil must be due to microbial assimilation.

In the light of these facts, it would seem that part of the fixation of the potassium added in straw and compost was due to microbial immobilization. This is confirmed by the fact that at the end of incubation the available potassium tended to approach the original status, increasing from the low levels to which it had fallen at 12 weeks. This may coincide with the

TABLE 23.

Available potassium (K_2O p.p.m. oven-dry soil) in soil 1 treated with straw and compost and incubated at three moisture levels.

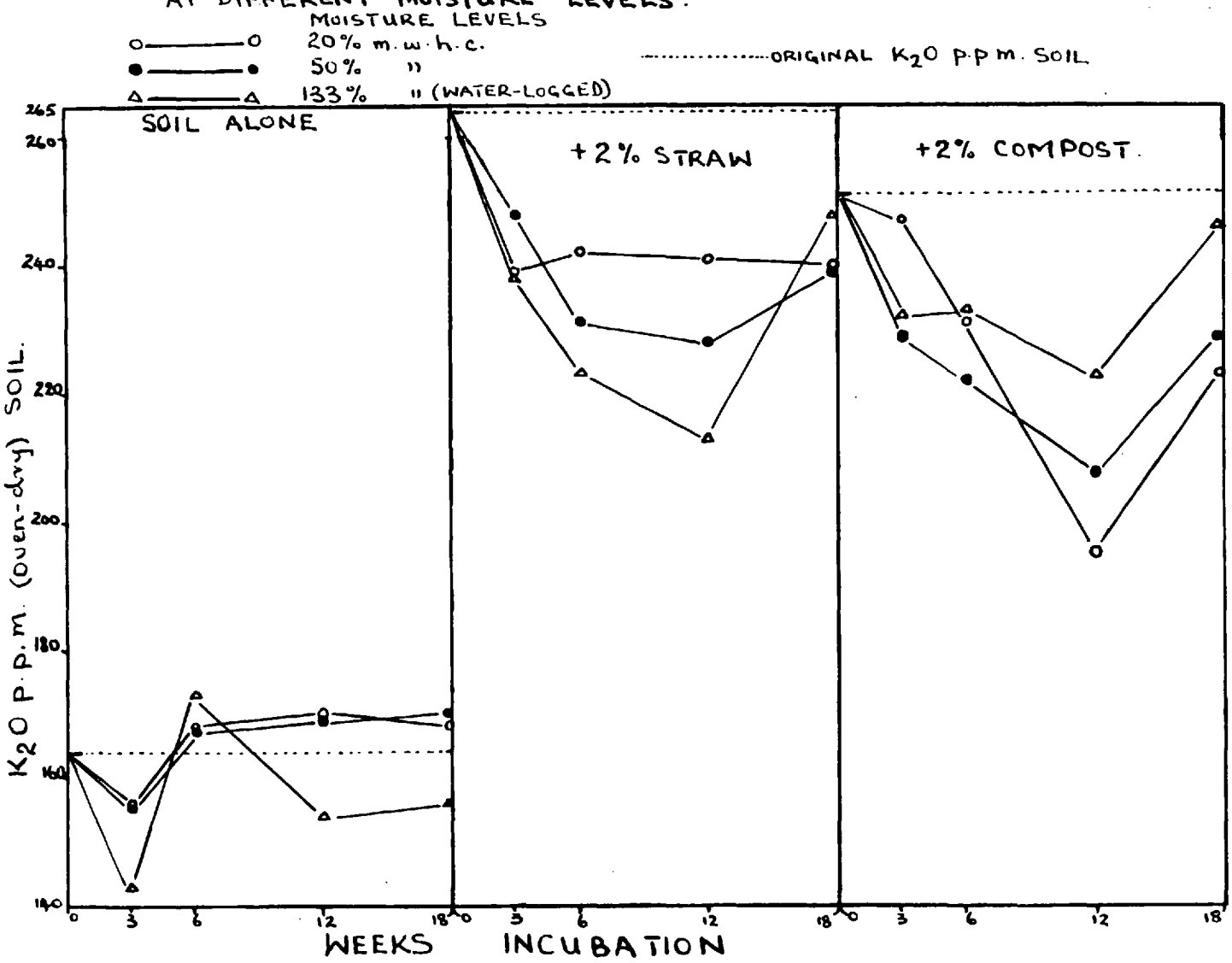
Organic matter treatment	Original available phosphorus	Weeks incubation	Soil moisture levels (% m.w.h.c.)		
			20	50	133
Soil alone	164	3	155	155	143
		6	168	168	173
		12	170	169	154
		18	168	170	156
+ 2% straw	264	3	239	248	239
		6	242	231	223
		12	241	228	213
		18	240	239	248
+ 2% compost	251	3	247	229	232
		6	231	222	233
		12	195	213	218
		18	223	229	246

L.S.D. = 15 at 5% and 21 at 1%.

Total K_2O content of straw = 0.78%, added to soil through straw = 156 p.p.m. soil.

Total K_2O content of compost = 1.38%, added to soil through compost = 276 p.p.m. soil.

Fig. 32: AVAILABLE K_2O IN SOIL 1 TREATED WITH ORGANIC MATTER AND INCUBATED AT DIFFERENT MOISTURE LEVELS.



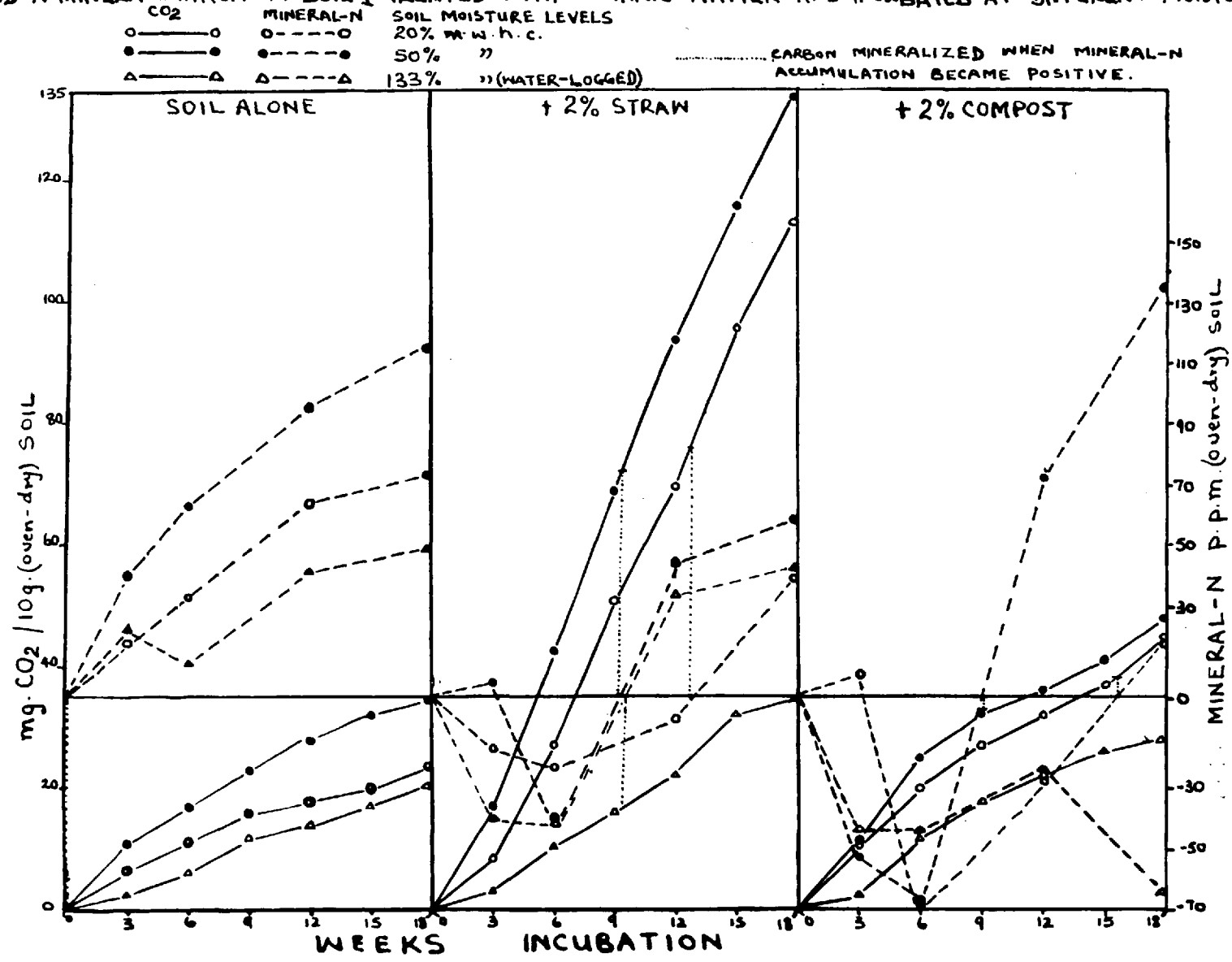
decomposition of the cells of earlier generations of micro-organisms.

Bray and De Turk (1939) and De Turk et. al. (1943) stated that soils have different equilibrium levels to which their exchangeable potassium status tended to approach from lower or higher levels, and this tendency held whether the soil was stored wet or dry. Thus on addition of potassium through straw or compost it was possible that this tendency of the soil potassium status to approach the equilibrium level led to some of the observed fixations. This effect might be important since the fixation did not seem to adhere strictly to a pattern similar to that of microbial activity. In fact similar amounts and patterns of fixation occurred at all moisture levels and in the presence of straw and compost where as carbon mineralization as a measure of microbial activity was most pronounced in the presence of straw and at moisture levels 20% and 50%.

General Discussion.

Harmsen and van Schreven (1955) in their review of work on nitrogen mineralization emphasized the importance of the C : N ratio of the added material as a factor controlling the accumulation of mineral nitrogen in the soil. They concluded that a nitrogen content of 1.5-2.0% (dry basis) in the added organic matter (corresponding to a C : N ratio of 20 to 25) was the limiting value. Materials containing less than this

Fig. 33: C AND N MINERALIZATION IN SOIL 1 TREATED WITH ORGANIC MATTER AND INCUBATED AT DIFFERENT MOISTURE LEVELS



amount of nitrogen would prevent accumulation of mineral nitrogen when added to the soil.

To test how far this conclusion may apply in this study, Fig. 33 has been prepared. In Fig. 33, the carbon and nitrogen mineralization at corresponding soil moisture levels have been plotted against the time of incubation and from it the carbon mineralized at the time mineral nitrogen accumulation started after recovering from the lag period of original mineral nitrogen microbial assimilation was determined.

It was obvious that irrespective of the C : N ratio of the added organic matter, (straw, 45.0 and compost, 13.4), there was mineral nitrogen accumulation (except for compost at 133%) after an initial lag period . This result seems to contradict the conclusions of Harmsen and van Schreven (1955), but agrees with some recent work by Cornfield (1959), that this lag phase occurred with the addition of compost having a C : N ratio of 21 and to an even greater extent with the addition of farmyard manure having a C : N ratio of 15.6.

What seemed more important was the rapidity, as affected by moisture levels 20% to 50%, with which the easily mineralizable fraction of the added organic matter was decomposed. Thus with added straw and compost, the easily mineralizable organic fraction was more rapidly mineralized at 50% than at 20% and in each case, the lag period was shorter at 50% than at 20%. At water-logging where carbon mineralization was

similar irrespective of the type of organic matter added there was a lag period followed by mineral nitrogen accumulation with straw, but an indefinite lag period i.e. no accumulation of mineral nitrogen even up to 18 weeks, with compost. It would seem that at this moisture level (133%), the rapidity (similar for straw and compost) with which decomposition of organic matter took place was not as important as the amount of original mineral nitrogen in determining the course of mineral nitrogen accumulation during incubation. With straw where the original mineral nitrogen was low, accumulation of mineral nitrogen above the original amounts was more rapid than with compost were possibly due to the high original mineral nitrogen, no accumulation above this original level could take place.

It is also interesting to note that although the lag period was shorter at 50% than at 20% similar amounts (73 mg. CO_2/10 g. soil for 50% and 76 mg. for 20% with straw, and 33 mg. for 50% and 38 mg. for 20% with compost) of carbon were mineralized at both moisture levels before the accumulation of mineral nitrogen reached amounts higher than the original mineral nitrogen.

At 50% and 20%, the fixation of phosphorus and potassium, due to straw and compost additions followed the trends of carbon mineralization and mineral nitrogen accumulation. In the early period of incubation, where the rates of carbon mineralization and nitrogen immobilization were highest, the

fixation of phosphorus and potassium were correspondingly high. As the rate of carbon mineralization decreased and the mineral nitrogen accumulation increased towards the end of the incubation, decreases in the extent of fixation of phosphorus and potassium took place. Under these conditions, the temporary fixation of both phosphorus and potassium must have been due to microbial assimilation.

At water-logging, trends in the availability of potassium were similar to those at 50% and 20% with both straw and compost addition and while microbial assimilation and release might be of some importance, other mechanisms of soil potassium fixation might play some part.

Conclusions.

Carbon and nitrogen mineralization during incubation were studied at different soil moisture levels (from 20% to 133% of the maximum water holding capacity) (a) at different soil pH levels (4.72, 5.80, 6.94, 7.72) and (b) when the soil was treated with oat-straw and compost. In addition, the availability of phosphorus and potassium was studied with the straw and compost treatments.

(A) 1. When the soil pH was low (4.72), carbon and nitrogen mineralization was independent of soil moisture level. This is probably due to the fact that the activity of micro-organisms which predominate at low pH, viz. fungi, is not affected by moisture level.

2. Carbon mineralization and NO_3-N accumulation increased with increasing soil pH up to 7.72 with maximum levels occurring at moisture contents between 50% and 75% of the maximum water holding capacity. At the same time ammonia accumulation decreased with increasing soil pH at low and medium soil moisture levels. It was supposed that these effects were due to the activities of micro-organisms which were sensitive to both moisture and soil pH, very likely aerobic bacteria to which nitrifiers belong.

3. Under saturated and water-logged conditions carbon mineralization and nitrate accumulation were low while ammonia accumulation was high at all pH levels. Under these conditions, anaerobic bacteria which are presumably not sensitive to pH are predominant.

(B) 1. When the soil was treated with compost, carbon mineralization was similar at all moisture levels to that occurring in untreated soil. This might be due to the similarity in the composition of soil humus and the organic fraction of compost. When straw was added, there was a considerable increase in carbon mineralization under aerobic conditions, but not under water-logged conditions. Carbon mineralization was greater at 50% than at 20% of the maximum water holding capacity. A high proportion of easily mineralizable organic fraction in straw and the limiting effect of low moisture levels on microbial activity and numbers are suggested.

2. Carbon mineralization was similar with all organic matter treatments under water-logging. This might be related to the type of decomposition which took place under water-logged conditions by which organic carbon is converted mainly to organic acids with little carbon dioxide evolution.

3. With the addition of straw and compost there was an initial lag period before the accumulation of mineral nitrogen at 20% and 50% of the maximum water holding capacity. This is explained by the assimilation of mineral nitrogen by the first generations of micro-organisms in the presence of much energy material. The subsequent accumulations are likely to be due to the decomposition of the cell substances of these first generations by later generations.

4. With water-logging, a similar lag followed by accumulation of mineral nitrogen was observed with straw addition but no mineral nitrogen accumulation occurred with compost. It is supposed that losses of mineral nitrogen under anaerobic conditions might be as important as assimilation by micro-organisms.

5. At low and medium moisture levels, the fixation of phosphorus and potassium added through the straw and compost followed a trend similar to that of mineral nitrogen accumulation, being pronounced during the lag period of mineral nitrogen accumulation. Fixation was probably by microbial assimilation.

6. At water-logging, trends of potassium fixation were similar to those at lower moisture levels but since microbial activity (as determined by carbon dioxide evolution) was lower, other mechanisms of moist potassium fixation e.g. fixation by clay might have played a part in the process.

7. Phosphorus was greatly mobilized, under water-logging more so with straw and compost additions than in their absence. The solubilizing effects of fermentation products (organic acids) on soil phosphorus under anaerobic conditions have been suggested.

Generally, the importance of liming acid soils and the provision of optimum soil moisture levels as methods of increasing microbial activity and nitrification which are important factors in determining the performance of crops in upland field conditions, have been emphasized.

It seems also that the addition of straw and compost to a soil may stimulate a temporary immobilization of nutrients by micro-organisms and this may possibly affect the performance of crops during the initial stages of growth.

CHAPTER V

THE EFFECT OF SOIL MOISTURE LEVEL ON THE TOTAL NITROGEN BALANCE IN THE SOIL (A) DURING INCUBATION AT DIFFERENT pH LEVELS AND WITH ADDED NH_4-N OR NO_3-N AND OAT STRAW OR COMPOST (B) UNDER RYE-GRASS AND RICE WITH ADDED NH_4-N OR NO_3-N IN POT TESTS

Introduction.

In recent times, the use of inorganic nitrogen fertilizer in improving crop performance has become increasingly important in many countries. The soils receiving such fertilizer applications have varying pH values and organic matter contents. These soil characteristics not only affect the crop performance but also may determine the proportion of the added fertilizer nitrogen which is available to the crop.

The soil moisture level during crop growth and the form of inorganic nitrogen may also determine the amount of applied nitrogen that is available to the crop.

That amount of applied inorganic nitrogen which is not available to the crop may have been assimilated by micro-organisms, or lost by leaching, erosion, denitrification, or volatilization of ammonia.

At the same time, the nitrogen-fixing micro-organisms may mitigate any nitrogen losses. The activities of these micro-organism, symbiotic and non-symbiotic, are also controlled by the soil pH, the amount of energy material in the soil, the soil moisture level and the amount of inorganic nitrogen present in the soil.

One way of evaluating the magnitude of the balance between the nitrogen added as fertilizers and by microbial fixation and that lost by the various channels is the balance of the total nitrogen obtained at two different times between which the soil is subjected to various treatments.

It has been found in Chapter III that mineral nitrogen accumulation increased with increasing moisture level up to 40-50% maximum water-holding and then decreased rapidly with further increases in soil moisture level and denitrification or ammonia volatilization was suggested as one of the agents keeping the accumulation of mineral nitrogen low at high soil moisture levels.

In Chapter IV, similar low mineral nitrogen accumulation was observed at high soil moisture levels, at different pH levels and with different added organic materials. The low mineral nitrogen contents were thought to arise from mineral nitrogen losses through denitrification. There were also temporary decreases in the accumulation of mineral nitrogen at all moisture levels when straw and compost were added, and these were probably due to microbial immobilization.

In order to confirm or refute the suppositions made about the mineral nitrogen accumulations studied in Chapter III and Chapter IV and to evaluate the soil nitrogen balance during incubation and in pot tests with crops, nitrogen balances were determined in this chapter (a) during the incubation at different moisture levels of the soil (which had been brought to different pH levels) receiving oat straw and compost treatments and different inorganic nitrogen forms, and (b) under rye-grass and rice in pot tests grown at different soil moisture levels and treated with different inorganic nitrogen forms.

(A) Effect of soil moisture level on the total nitrogen balance in the soil during incubation at different pH levels and with added NH_4-N or NO_3-N and oat straw or compost.

Materials.

Stock solutions of NH_4-N as $(NH_4)_2SO_4$ and NO_3-N as KNO_3 of concentration 12,000 p.p.m. (solution basis) each were prepared.

3 portions of soil 1 (Harlington soil) whose chemical and physical properties are shown in Tables 3 and 4 and Fig. 1 were brought to pH levels 4.72, 6.41 and 8.00 by the addition of aluminium chloride or calcium carbonate as described in Chapter II.

The oat straw and compost had the following characteristi

Organic matter	%C	%N	C:N ratio	*m.w.h.c.
Straw	40	0.89	45	55% actual moisture
Compost	35	2.61	13.4	50% actual moisture

* with straw and compost added to soil at the rate of 2%.

Experimental method.

10 g. samples of the soil were weighed into polythene sheets 6" square (polythene has been shown by Eno (1960) to be permeable to oxygen and carbon dioxide but impermeable to ions). The soil at each pH level was factorially treated with three organic matter treatments viz. soil alone, soil + 2% oat straw and soil + 2% composted oat straw and all well mixed.

They were then given three nitrogen treatments, no nitrogen, + NH_4-N 600 p.p.m. soil and +NO_3-N 600 p.p.m. soil by adding, 0.5 ml. of distilled water, 0.5 ml. of the NH_4-N stock solution and 0.5 ml. of the NO_3-N stock solution respectively.

After wrapping them up with the polythene sheets, they were finally brought to three moisture levels, 20%, 50% and 133% (water-logging) of the maximum water holding capacity by the further addition of 0.3, 1.6 and 5.1 ml. (for soil alone) 0.5, 2.1 and 6.7 ml. (for soil + 2% straw) and 0.4, 1.9 and 6.1 ml. (for soil + compost) of distilled water respectively, through the open end of the bag formed by the polythene sheet.

All samples were mixed with a thin glass rod and the end of the rod which had been in contact with the soil was broken off and left in the soil sample.

The samples thus wrapped in the polythene sheet were placed in dry test-tubes 6" x 1" (internal diameter) so that the open end of the bag faced the mouth of the tube.

Glass vials containing a suspension of barium peroxide in water were placed in the tubes so that they rested on the rim of the polythene bag and did not come in contact with the soil. This prevented any loss of soil during the replacement of the vial.

The 81 treatments, 3 pH levels x 3 organic matter treatments x 3 nitrogen treatments x 3 moisture treatments, were duplicated to give 162 samples. All were incubated in a

warm cupboard in which the temperature varied between 25° and 30°C. The vials containing the suspension of barium peroxide were replaced with freshly charged vials every three weeks and the incubation lasted for 15 weeks.

At the end of this time, 1.0 ml. of NH_2SO_4 was added to each sample to prevent any losses by ammonia volatilization during the subsequent drying (see Chapter II) and all samples were dried in the greenhouse at a temperature varying from 30°C to 35°C.

After drying, the samples contained in the polythene wrapping were lifted out of the test-tubes, the dry soil pulverised with the fingers from the outside of the polythene bag and the soil and bag placed in a 500 ml. Kjeldahl flask and the total nitrogen determined as described in Chapter II. Blanks were done with a similar size of polythene sheet.

1. Results.

N.B. In the following results and discussion, the percentage maximum water holding capacity is expressed as percentage moisture (e.g. 50% represents 50% m.w.h.c.). All nitrogen balances mentioned in the text are significant at 5% level.

(i) Treatments without added inorganic nitrogen.

The total nitrogen balances (p.p.m. soil) obtained under different pH, organic matter and soil moisture treatments

without added inorganic nitrogen are shown in Table 24 and Fig. 34. Negative values indicate the extent of net loss of nitrogen whilst positive values indicate the extent of net gain of nitrogen.

In soil without added organic matter: there were no changes in total nitrogen at 20% at all pH levels but there were net losses at 50% and even greater losses at 133%.

In the presence of 2% straw: Although there were trends for net nitrogen to increase with both moisture level and pH in no case were these increases significant.

In the presence of 2% compost: there were net increases at 20% only at pH 4.72 and pH 6.41, and a net increase at 50% only at pH 4.72. At 133%, net losses were obtained only at pH 6.41 and 8.00. Under all other conditions, there were no changes in the total nitrogen.

Generally, the total nitrogen balance in the presence of 2% compost increased with moisture level from 20% to 50% and decreased at water-logging when the pH was 4.72. At the higher pH levels, the nitrogen balance decreased with increasing moisture level. Furthermore, the net gains of nitrogen at 20% increased with pH from 4.72 to 6.41 and then decreased with increase in pH to 8.00. At 50% and 133%, the nitrogen balance decreased with increasing pH.

TABLE 24.

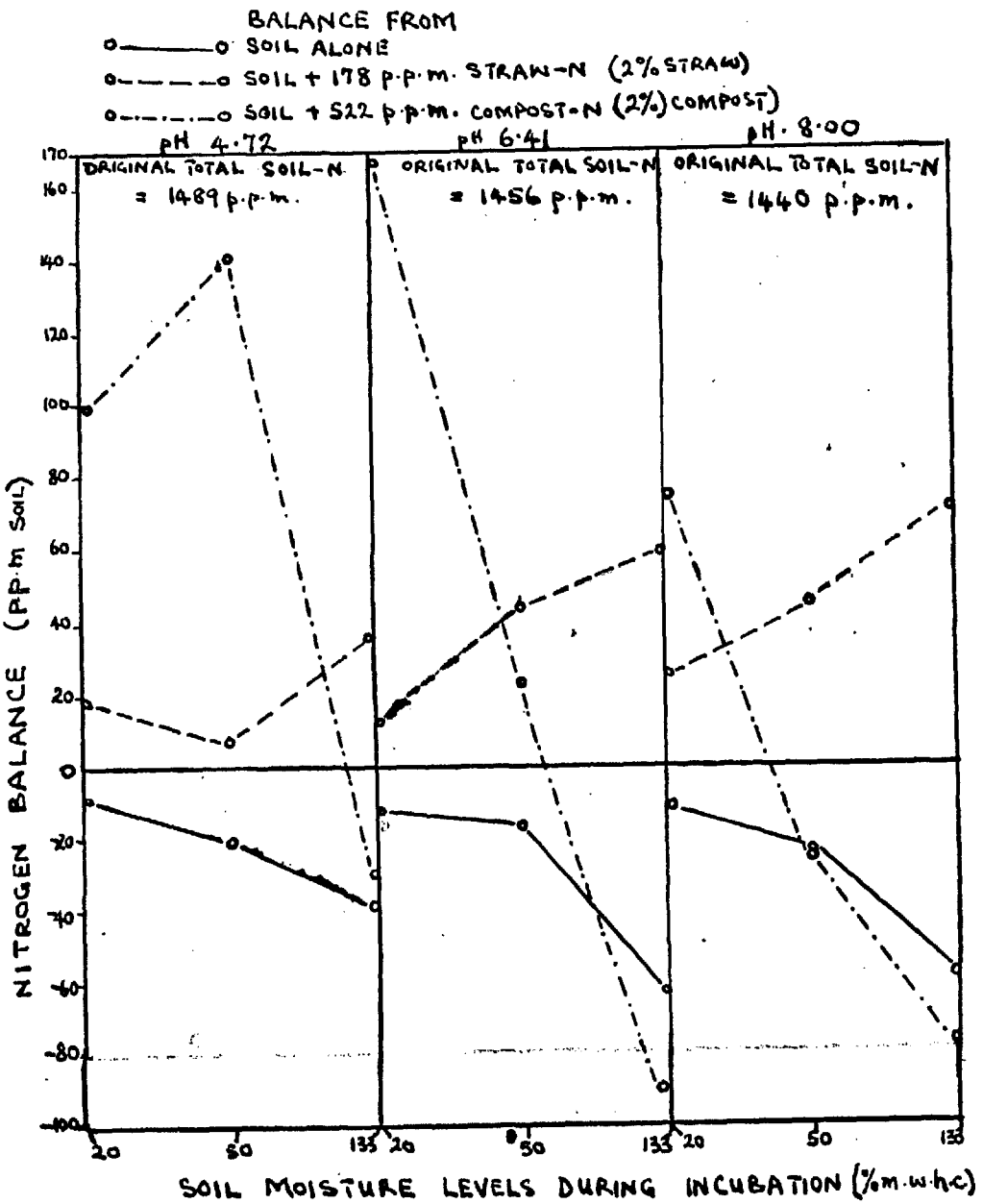
Total nitrogen balance (p.p.m.) in soil 1 incubated with added organic matter at three pH and three moisture levels.

Soil pH	4.72			6.41			8.00			L.S.D.	
Moisture levels (% m.w.h.c.)	20	50	133	20	50	133	20	50	133	at 5%	at 1%
Soil alone*	-8	-20	-38	-11	-15	-62	-10	-22	-57	15	23
+ straw**	19	8	37	13	45	60	27	46	72	79	109
+ compost**	100	142	-29	168	24	-89	75	-23	-79		

* Original soil total nitrogen = 1489, 1456 p.p.m. for low, medium and high pH levels respectively.

** 2% straw and 2% compost added to provide 178 and 522 p.p.m. N respectively.

Fig. 34: TOTAL NITROGEN BALANCES (P.P.M. SOIL BASIS) IN SOIL TREATED WITH STRAW AND COMPOST AND INCUBATED AT DIFFERENT MOISTURE LEVELS.



(ii) Treatments with added inorganic nitrogen.

The total nitrogen balances (p.p.m. soil) are shown in Table 25 and the balance as a percent of the added inorganic nitrogen is shown in Table 26 and Fig. 35. All gains and losses of nitrogen were obtained by balancing the original soil total nitrogen, the nitrogen added in the organic matter and added inorganic nitrogen against the total nitrogen determined at the end of incubation.

(1) $+NH_4$-N.

At pH 4.72: there were no changes at 20% and 50% in the total nitrogen but at 133%, there was a net loss where NH_4-N had been applied to the soil alone. When NH_4-N was applied with the addition of straw and compost, there were net gains at 20% and 50% which were higher at 20% than at 50% and higher in the presence of compost than in the presence of straw. At 133% however, straw and compost caused no change in the total nitrogen.

At pH 6.41: there were net losses in total nitrogen at all moisture levels and organic matter treatments except at 20% when the soil was treated with compost for which there was a net gain and at 20% when the soil was not treated with organic matter for which no change in total nitrogen was observed. All losses in total nitrogen increased with increasing soil moisture level. The greatest losses at 50% occurred with compost but at 133% with straw.

At pH 8.00: there were highly significant (1% level) net losses in total nitrogen at all moisture levels and with all organic matter treatments. All losses in total nitrogen increased with increasing moisture level, were highest with the addition of straw and least in the soil alone.

Thus at the low pH, gains in total nitrogen, when NH_4-N was applied, were observed under aerobic conditions in the presence of straw and compost. At the high pH, losses in total nitrogen were observed at all moisture levels and increased with increasing moisture level and in the following order of organic matter treatment: soil alone < soil + compost < soil + straw. The losses generally increased with pH while where gains occurred they increased with decreasing pH.

(2) $+NO_3$-N.

At pH 4.72: there were net losses in nitrogen at all moisture levels and with all organic matter treatments except at 20% and 50% when no organic matter was added. Losses of nitrogen increased with increasing moisture level. Losses at 20% were higher with compost than with straw, whilst at 50% and 133%, the reverse was true.

At pH 6.41: there were net losses at all moisture levels and with all organic matter treatments. Losses of nitrogen also increased with increasing moisture level. At all moisture

TABLE 25.

Total nitrogen balance (p.p.m.) in soil 1 incubated with added inorganic nitrogen and organic matter at three pH and three moisture levels.

Soil pH	4.72			6.41			8.00		
Moisture levels (% m.w.h.c.)	20	50	133	20	50	133	20	50	133
Soil+NH_4-N***	13	9	-55	5	-71	-87	-77	-193	-245
+NH_4-N+straw	112	30	14	-34	-46	-377	-176	-426	-449
+NH_4-N+compost	123	48	-27	61	-138	-314	-113	-271	-406
Soil+NO_3-N***	-15	-26	-337	-62	-130	-500	-12	-147	-479
+NO_3-N+straw	-137	-282	-570	-143	-346	-574	-261	-351	-583
+NO_3-N+compost	-187	-178	-365	-147	-288	-577	-57	-241	-533

Table: L.S.D. = 33 at 5% and 44 at 1%.

*** NH_4-N and NO_3-N added at the rate of 600 p.p.m. soil.

TABLE 26.

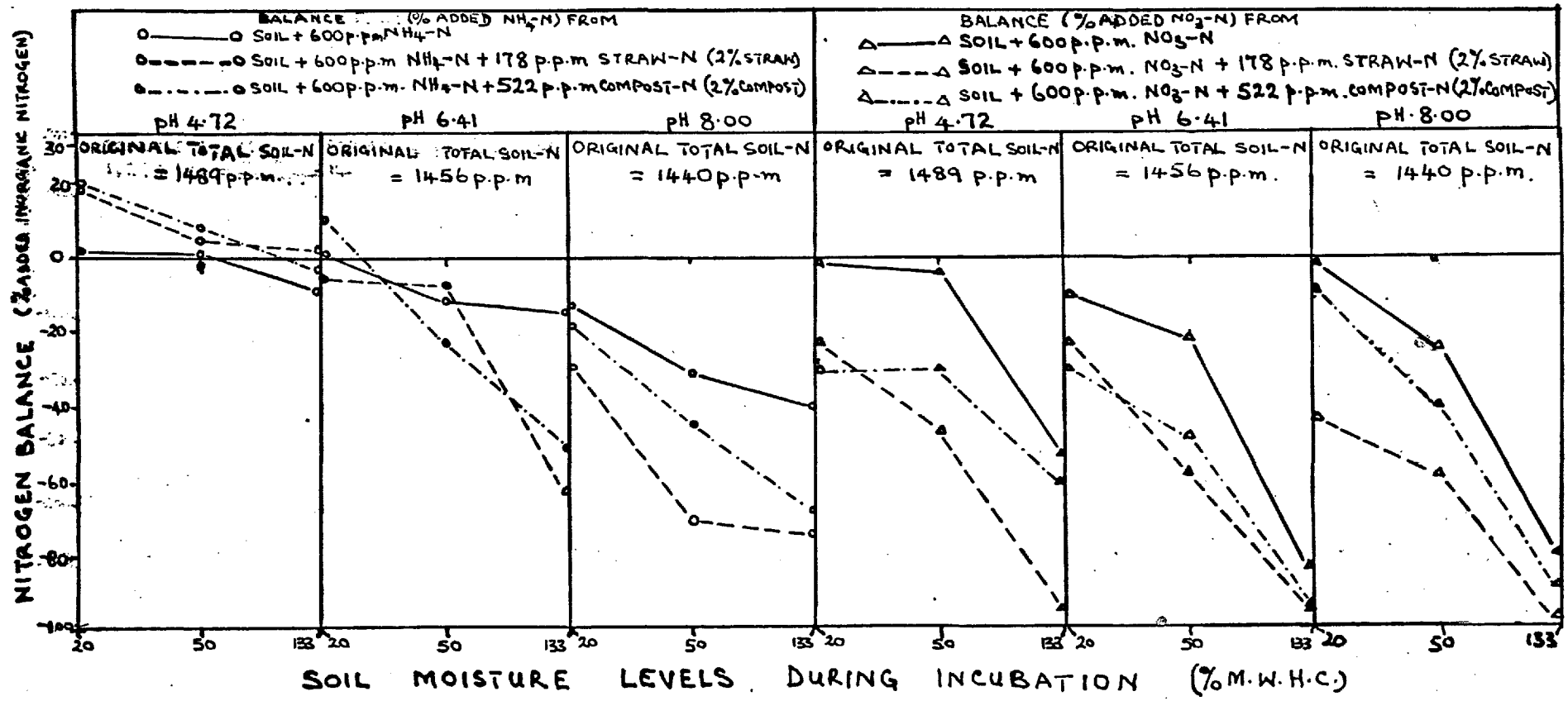
Total nitrogen balance (% of added inorganic nitrogen) in soil 1 incubated with added inorganic nitrogen and organic matter at three pH and moisture levels.

Soil pH	4.72			6.41			8.00		
Moisture levels (% m.w.h.c.)	20	50	133	20	50	133	20	50	133
Soil+NH_4-N*	2.1	1.5	-9.1	0.8	-11.2	-14.5	-12.9	-32.2	-40.8
+NH_4-N+straw	18.6	5.0	2.4	-5.7	-7.7	-62.7	-29.4	-71.0	-74.9
+NH_4-N+compost	20.4	7.9	-4.5	10.2	-22.8	-52.3	-18.9	-45.1	-67.6
Soil+NO_3-N*	-2.5	-4.4	-56.9	-10.3	-21.7	-82.4	-2.0	-24.5	-71.6
+NO_3-N+straw	-22.8	-47.0	-94.9	-23.8	-44.3	-95.7	-43.5	-58.5	-97.6
+NO_3-N+compost	-31.2	-29.7	-60.8	-24.4	-48.0	-96.1	-9.5	-40.2	-88.9

L.S.D. at 5% = 5.0 and at 1% = 6.9.

* Added at the rate of 600 p.p.m. soil.

Fig·35: TOTAL NITROGEN BALANCES (% OF ADDED INORGANIC NITROGEN) IN SOIL TREATED WITH STRAW AND COMPOST AND WITH DIFFERENT INORGANIC NITROGEN FORMS AND INCUBATED AT DIFFERENT MOISTURE LEVELS.



levels nitrogen losses were similar with straw or compost and were consistently greater than where no organic matter was added.

At pH 8.00: there were net losses at all moisture levels and with all organic matter treatments except at 20% where the soil had not received organic matter additions. All losses in nitrogen also increased with increasing moisture level. Straw resulted in greater losses of nitrogen than did compost.

Generally, at 20% the losses in nitrogen when NO_3-N was added were low at all pH levels in the soil alone, increased with pH in the presence of straw and decreased with pH in the presence of compost. At 50% the nitrogen losses increased with pH irrespective of the organic matter treatment. At 133%, the nitrogen losses were similar at all pH levels when straw was applied but increased with pH from 4.72 to 6.41 and then decreased to 8.00 when compost or no organic matter was applied. Thus at all moisture levels, straw addition caused the greatest loss in nitrogen at all pH levels.

Discussion.

In the absence of added inorganic nitrogen and organic matter: there were losses in total nitrogen which increased with increasing moisture level from 50% to 133%. The losses were also higher at the higher pH levels.

Waksman (1952), cited Winogradsky as reporting that anaerobic bacteria found conditions favourable at soil moisture levels around 40%, while Meiklejohn (1940), described two species of Pseudomonas capable of denitrification in aerated cultures as well as under anaerobic conditions. For these reasons the losses of nitrogen at 50% moisture observed here may be expected. Since denitrification is usual under water-logged conditions, the losses at 133% are not surprising.

The losses at the higher pH levels (6.41 and 8.00) agree with the results of Broadbent (1951) and Bremner and Shaw (1958) and may be due to greater nitrification at 50% at the higher pH levels (as observed in Chapter IV of this work), thus providing more nitrate for denitrification. At 133% it may be due to greater volatilization of ammonia at the higher than at the lower pH levels (Wahhab et. al. (1957)).

When 2% oat straw was added, there were appreciable, though non-significant, gains in nitrogen and these gains tended to increase with increasing moisture level and pH. These gains or at least the absence of losses in nitrogen might be due to the activities of non-symbiotic nitrogen-fixing bacteria. Since the soils were incubated in the dark fixation by algae was unlikely. The non-symbiotic nitrogen-fixing bacteria are composed of anaerobic organisms: starch-fermenting organisms, (Bacillus saccharobutyricus), non-starch-fermenting organism

(Clostridium pasteurianum) and others (Plectridium group); and the aerobic organisms: species of Azotobacter and others including Diplococcus pneumoniae, Aerobacter aerogenes and Bacillus asterosporus. The increase in the gains in nitrogen with increasing moisture levels may be due to the fact that the anaerobic organisms are more numerous than the aerobic in soils (Waksman (1952)), and that since more organic matter is decomposed at 50% than at 20% the amount of fixation of atmospheric nitrogen increases with increased decomposition of organic matter. The greater fixation of nitrogen at the higher pH levels (6.41 and 8.00) than at pH 4.72, may be connected with the sensitivity of the nitrogen-fixing bacteria to pH levels. The aerobic group are sensitive to pH and cease to function, except for one species (Azotobacter indicum) at pH less than 6.0, whilst the anaerobic group are more tolerant of pH but have an optimum pH around neutrality (Waksman (1952)).

With added compost net gains in nitrogen were observed only under aerobic conditions especially at the low and medium pH. Under water-logging net losses occurred to a greater extent at the higher pH levels than at the lower pH level.

It is probable that nitrogen fixation took place under all conditions as it did in the presence of straw but due to denitrification at 50% and 133% and possible volatilization of ammonia at the higher pH levels, the nitrogen balance decreased with both increasing moisture and pH levels. Losses of

nitrogen with compost compared with straw at 50% and 133% may be connected with the original total nitrogen (soil-N + added organic matter-N) since loss of nitrogen increases with increasing original nitrogen content in soils (Harmsen and van Schreven (1955)). Total nitrogen added to soil in straw was 178 p.p.m. and in compost 522 p.p.m.

Alternatively, the differences between the fixation of nitrogen at 20% and 50% may be due to differences in the amount of nitrogen mineralized. Greater mineral nitrogen accumulation occurs at 50% than at 20%, and the nitrogen-fixing capacity of the aerobic nitrogen fixers is suppressed in the presence of much mineral nitrogen (Waksman (1952)).

Waksman (1952), stated that humus has a beneficial effect on nitrogen fixation probably due to the inorganic constituents. This may account for the fact that positive balances with compost observed here at 20% were higher than those with straw, compost having a constitution more like humus than has straw.

In the presence of added NH_4-N (600 p.p.m. soil): there were gains in nitrogen at low pH (4.72) only when straw or compost was added and the gains decreased with increasing moisture level . At the same time when no organic matter was added there were no changes in total nitrogen at 20% and 50% but a loss at 133%. It has been mentioned earlier that low

pH levels and the presence of mineral nitrogen inhibit nitrogen fixation by aerobic non-symbiotic organisms (Waksman (1952)). This makes it difficult to see why there was fixation of nitrogen in the presence of added NH_4-N at low pH and under aerobic conditions. Since fungi predominate at low pH, it is possible that the observed nitrogen fixation is due to the activity of fungi similar to those mentioned by Waksman (1952) as capable of nitrogen fixation. The absence of a detailed knowledge of the conditions under which such fungi operate makes it difficult to assess the extent of their activity.

At higher pH levels (pH 6.41 and 8.00) there were losses of nitrogen which tended to increase with increasing pH and with increasing moisture level and which were further stimulated by the addition of organic matter, more so by straw than by compost. The increase in nitrogen loss with increasing soil pH agrees with the results of several workers including Wahhab et. al. (1957), Arnold (1954), Wahhab and Uddin (1955) and others. This may be explained by the reaction between ammonium sulphate and calcium carbonate at high pH levels. (Calcium carbonate was added to produce the soil of pH 8.00 used in this study) thus:

$$2NH_4^+ + CO_3^{2-} \longrightarrow (NH_4)_2CO_3$$

$$(NH_4)_2CO_3 \longrightarrow CO_2 + 2NH_3 + H_2O$$

The results in this study, however, contradict those of Gerretsen and de Hoop (1957) who found losses of nitrogen from $(NH_4)_2SO_4$ added to a culture solution at pH around 4.0.

The increase in nitrogen losses with increasing moisture level agrees with the results of Wahhab et. al. (1960). Martin and Chapman (1951), found that the losses of nitrogen from added ammonium sulphate increased with increasing moisture level for some soils but decreased after an initial increase for others. Others, Trickey and Smith (1955) and Volk (1959), found nitrogen losses when ammonium sulphate was added to soils to increase with decreasing moisture level. These contradictory results may be due to soil types but here where carbonate has been specially added to raise the pH, it is likely that water-logging further riased the pH (Kapp (1933))(Sreenivan and Subrahmanyan (1934)) and this may account for the increased volatilization of ammonia.

The increase in nitrogen losses due to straw and compost additions at the high pH levels agrees with the result of Trickey and Smith (1955). It may be due to the production of ammonia which was observed in Chapter IV at all moisture levels in the presence of straw which has resulted in nitrogen loss by volatilization of this extra ammonia at the high pH levels. In the case of compost, volatilization of ammonia derived from the added organic nitrogen may be the cause of greater nitrogen loss than from the soil alone.

In the presence of added NO_3-N (600 p.p.m. soil):

there were losses of nitrogen whether or not organic matter had been added, and the losses increased with increasing moisture level. Waksman (1952), cited Winogradsky as reporting that anaerobic bacteria found conditions favourable at soil moisture levels around 40% of the water holding capacity whilst Meiklejohn (1940) described two species of Pseudomonas capable of denitrification in aerated cultures as well as under anaerobic conditions. For these reasons losses of nitrogen from added NO_3-N at 50% moisture as have been observed here may be expected. Since denitrification is usual under water-logged conditions, (Bremner and Shaw (1958) (Broadbent (1951)) the losses at 133% may be said to be normal.

Losses of nitrogen at 20% became appreciable at all pH levels only when organic matter was added to the soil. This may be explained by the postulation made by Broadbent (1951) that denitrification was affected more by the quantities of nitrate and oxidizable carbon in the soil than by the partial pressure of oxygen.

Broadbent's (1951) postulation may also explain the greater losses of nitrogen at 50% and 133% when organic matter was added than when it was not. His consideration that on purely thermodynamic grounds denitrification would occur in the presence of oxidizable carbon compounds even under fully aerobic conditions where the oxygen in the nitrate radical was

utilized for the required energy-releasing reaction lends weight to the increased loss of nitrogen when nitrate is added to the soil treated with organic matter.

The greater loss of nitrogen in the presence of oat straw than in the presence of compost follows from the fact that oat straw containing more easily oxidizable organic carbon than compost causes greater nitrogen loss by denitrification. In general nitrogen losses tended to be more pronounced at pH 6.41 than at lower and higher pH levels especially in the soil alone and soil + compost. This agrees with results obtained by Broadbent (1951) that although the significance of the differences in nitrogen losses when nitrate and organic matter were added to the soil at different pH levels was questionable, losses tended to a maximum at pH 6.3.

The lack of a definite relation between nitrogen loss from added nitrate and the pH may be related to the tolerance of a wide range of pH levels by anaerobic bacteria (Waksman (1952)).

(B) <u>The effects of soil moisture level on the total nitrogen balance in the soil under rye-grass and rice crops in pot tests with added NH_4-N and NO_3-N.</u>

<u>Materials.</u>

Stock solutions of NH_4-N as $(NH_4)_2SO_4$ and NO_3-N as KNO_3 of concentration 2,500 p.p.m. (solution basis) each were prepared.

The percentage germination of rye-grass and rice seeds was determined and was over 95%.

Soil 1 (Harlington soil) whose chemical and physical properties are shown in Table 3 and 4 and in Fig. 1, was used.

Experimental method.

500 g. lots of the air-dry, 2 mm.-sieved soil were weighed into glass pots of about 0.7 litre capacity and whose drainage holes were covered with pieces of glass cloth, except for those earmarked for the water-logging treatment under rice, the holes of which were plugged with rubber bungs.

There were two lots of pots for rye-grass, each lot earmarked to receive three nitrogen and three moisture treatments replicated three times giving 27 pots per lot or a total of 54 pots. One lot was analysed after 3 and the other after 6 cuttings. There was only one lot of pots for rice which were to receive three nitrogen and two moisture treatments replicated three times, giving a total of 18 pots, which were analysed after 2 cuttings.

0.25 g. of rye-grass or rice seeds was sown in the dry soil in each pot and the pot placed in a tub of distilled water until the soil was well soaked. Each pot was left in the greenhouse and watered every morning and evening until the seedlings were 18 days old.

Rye-grass: The tops of the rye-grass seedlings were cut, steam-oven dried for 24 hours and stored. For the first lot of rye-grass pots, the following total nitrogen treatments were given: (i) no nitrogen, (ii) +300 p.p.m. NH_4-N (soil basis) and (iii) +300 p.p.m. NO_3-N (soil basis). For the second lot, the following total nitrogen treatments were given: (i) no nitrogen, (ii) + 600 p.p.m. NH_4-N (soil basis) and (iii) + 600 p.p.m. NO_3-N (soil basis).

All nitrogen treatments were given in split application at the rate of 100 p.p.m. NH_4-N and 100 p.p.m. NO_3-N at the beginning and every two weeks (after each cutting of the tops) by applying 20 ml. of the relevant stock solution. The control received distilled water.

At the same time, three moisture treatments (a) low (b) medium and (c) high, were given by adding, twice daily for (a) enough water to prevent permanent wilting, for (b) 35 ml. of distilled water, and for (c) enough water to have some standing in the saucer carrying each pot, respectively. For this high moisture treatment, the contents of the saucer were washed into the soil during each watering.

Rice: The 18-day old seedlings were thinned from about 20 to 10 per pot and the thinnings dried and stored. The following nitrogen treatments were given (i) no nitrogen (ii) + 400 p.p.m. NH_4-N (soil basis) and (iii) + 400 p.p.m. NO_3-N (soil basis) in split application as for the rye-grass

pots, except that the rice plants were thinned again from 10 to 5 plants per pot two weeks after the treatments began. The remaining 5 plants were left to the end of the experiment.

The rice pots were maintained at two moisture levels (a) medium and (b) water-logged by adding, twice daily for (a) 45 ml. of distilled water (this was not sufficient to water-log the soil) and for (b) enough water to keep the soil water-logged to a depth of about 1 cm.

Thus by the end of the experiment the first lot of rye-grass had received three nitrogen applications and the tops had been cut three times since differential treatments began, whilst the second lot had received six nitrogen applications and the tops had been cut six times since differential treatments began. The rice pots received four nitrogen applications and the plants were thinned once and cut finally. The final cutting for the first lot of rye-grass was done after 6 weeks, for the second lot after 12 weeks and for rice after 8 weeks since the treatments began. All cuttings of the tops were dried in a steam oven for 24 hours.

Immediately after each final cutting, the pots containing the soil, roots and water, were weighed. The pots and contents were air-dried in the greenhouse and weighed again and the soil moisture content of the soils as percentage of the water-holding capacity was determined.

The dried soil was pulverised to pass a 2mm.-sieve and the larger pieces of roots separated.

The three cuttings of the tops of the first lot of rye-grass were bulked, as were the first four and the last two cuttings of the second lot. All cuttings and bulked cuttings including those before the treatments began, were weighed, ground in a mill and analysed for total nitrogen, using the salicylic acid modified wet digestion method (Chapter II). The larger pieces of roots (not washed) and duplicated 20 g. samples of the soil from each pot were analysed for total nitrogen by the salicylic acid-modified Kjeldahl digestion.

From the results, the nitrogen balance sheets were prepared.

(1) Results.

Only the moisture levels and the nitrogen balances are discussed here since the yields and nitrogen uptake by the tops are discussed in Chapter VI.

N.B. Throughout the following results and discussion, the percentage of the maximum water-holding capacity is expressed as percentage moisture e.g. 50% = 50% m.w.h.c.

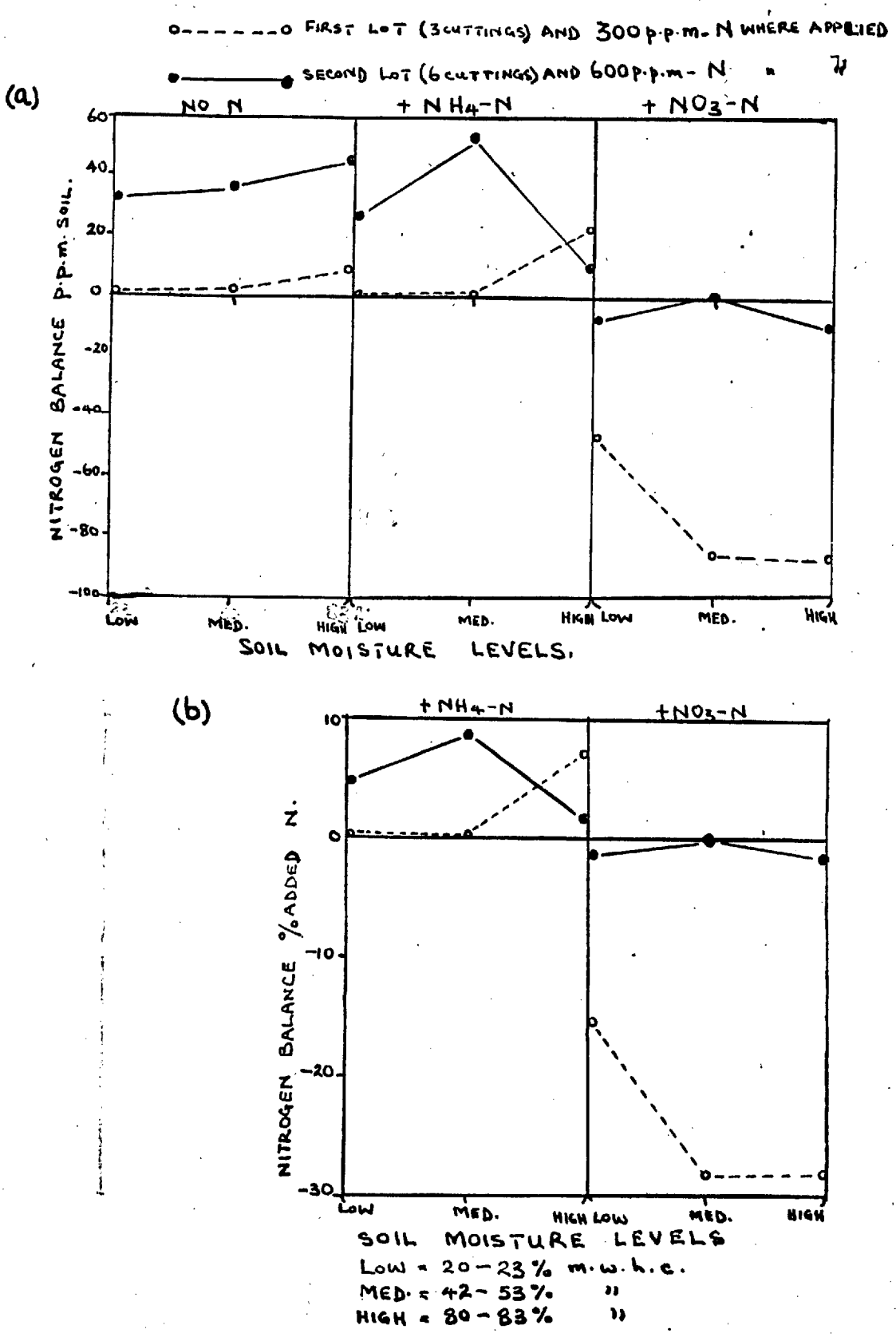
Rye-grass: The total nitrogen balance sheet for the soil under potted rye-grass treated with two inorganic nitrogen forms and three moisture levels is shown in Table 27. and the nitrogen balances are shown graphically in Fig. 36.

TABLE 27. Total nitrogen (p.p.m. soil) balance sheet for potted rye-grass treated with two inorganic nitrogen forms and three soil moisture levels. Orginal soilN = 1500 p.p.m.

Treatments		Tops			Roots	N left in soil	Total N accounted for	Balance p.p.m.	% Balance of added N
(% m.w.h.c.) Soil moisture At the end	Added nitrogen	Cutting before treatment	1st4* cuttings	Last 2 cuttings	At the end				
FIRST LOT: ANALYSED AFTER 3 CUTTINGS									
20%	0	33	28	-	5	1434	1500	0	-
50%	0	35	34	-	7	1426	1502	2	-
81%	0	33	34	-	11	1431	1509	9	-
23%	300	35	166	-	11	1588	1800	0	0.0
47%	p.p.m.	37	236	-	14	1513	1800	0	0.0
82%	NH_4-N	35	259	-	26	1503	1823	23	7.7
23%	300	36	139	-	9	1570	1754	-46	-15.3
48%	p.p.m.	36	207	-	10	1462	1715	-85	-28.3
80%	NO_3-N	32	233	-	18	1433	1716	-84	-28.0
SECOND LOT: ANALYSED AFTER 6 CUTTINGS									
22%	0	36	29	7	2	1459	1533	32	-
53%	0	34	34	13	3	1450	1536	36	-
83%	0	34	38	14	5	1454	1545	45	-
21%	600p.p.m.	36	137	56	3	1895	2127	27	4.5
42%	NH_4-N	34	354	143	21	1601	2153	53	8.8
80%		36	326	74	16	1658	2110	10	1.7
23%	600p.p.m.	36	149	87	4	1817	2093	-7	-1.2
43%	NO_3-N	33	345	193	12	1517	2100	0	0.0
80%		34	293	155	25	1576	2091	-9	-1.5

* 3 cuttings for the first lot. L.S.D. between balances p.p.m. = 43 at 5% and 57 at 1% levels.
L.S.D. between balances % = 10.9 at 5% and 14.7 at 1% levels.

Fig. 36: TOTAL NITROGEN BALANCES (a) P.P.M. (SOIL BASIS) AND (b) % OF ADDED NITROGEN, IN THE SOIL CROPPED WITH RYE-GRASS AT DIFFERENT MOISTURE LEVELS AND TREATED WITH DIFFERENT INORGANIC NITROGEN FORMS



The soil moisture levels which were determined at the end of cropping lay between 20% and 23% for the low, between 42% and 53% for the medium and between 80% and 83% for the high moisture levels.

There were non-significant net gains in nitrogen in the first lot of rye-grass when NH_4-N or no nitrogen was added and this tended to increase with increasing moisture level. There were significant (at 5% level) net losses of nitrogen in the first lot of rye-grass when NO_3-N was added and the losses were high at the medium and high moisture levels compared with that at the low moisture level. The percentage balances of the added nitrogen paralleled the total nitrogen balances (p.p.m. soil basis).

In the second lot of rye-grass, there were net nitrogen gains when NH_4-N or no nitrogen was added. These positive balances were significant (5% level) at the high moisture level when no nitrogen treatment was applied and at medium moisture level when NH_4-N was applied. When NO_3-N was applied there were no net gains or losses at any moisture level. The percentage gains or losses under all treatments in the second lot of rye-grass were non-significant.

Thus between the first and second lots of rye-grass, there was a general reduced nitrogen loss or increased gain, the increase being significant under NO_3-N treatment at the medium and high moisture levels and significant under NH_4-N at the medium moisture level.

Rice: The total nitrogen balance under the rice crop is shown in Table 28 and Fig. 37.

The soil moisture levels were about constant at 50% for the medium and at 130% for the water-logging.

The total nitrogen balances were negative and significant (5% level) under all treatments (moisture x nitrogen) except under water-logging x no nitrogen treatment. With NH_4-N and NO_3-N treatments, the loss of nitrogen was significantly (5% level) higher under water-logging than under medium moisture levels, and was more with NO_3-N than NH_4-N treatments. The percentage losses of added nitrogen paralleled the actual nitrogen losses (p.p.m. soil basis).

It was observed that in the last three weeks of the growth of the second lot of rye-grass, a mass of green (algal?) growth covered the surface of the soil and was more developed at the higher than at the medium and low moisture levels. No such growth was however observed for the first lot of rye-grass or for the rice which had been finally cut before the green growth developed in the second lot of rye-grass pots.

Discussion.

The moisture contents of the soils, determined at the end of plant growth are considered to be indicative of moisture differences during growth.

TABLE 28.

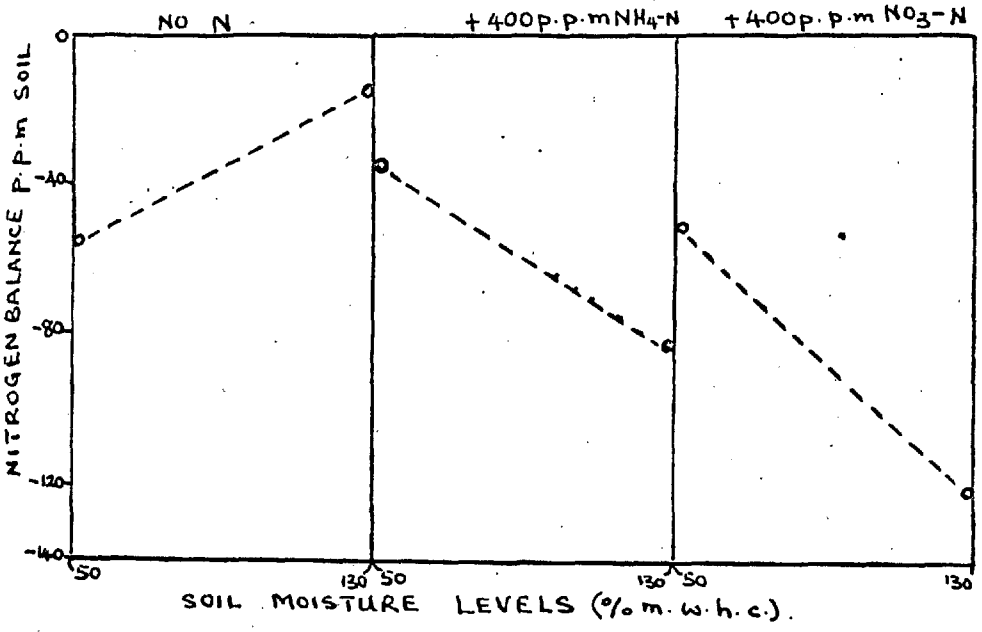
Total nitrogen (p.p.m. soil) balance sheet for potted rice treated with two inorganic nitrogen forms and two soil moisture levels. Original soil N = 1500 p.p.m.

Treatments		Tops			Roots	N left	Total N	Balance	Balance
Soil moisture % m.w.h.c.	Added N	Thinning before treatment	Thinning after treatment began	Final cutting	At the end	in soil	accounted for	p.p.m.	% of added N
50	0	22	14	21	6	1382	1445	-55	-
130	0	26	17	30	13	1397	1483	-17	-
50	400p.p.m. NH_4-N	23	60	283	50	1449	1865	-35	-8.7
130		25	53	275	41	1423	1817	-83	-20.7
50	400p.p.m. NO_3-N	20	69	286	39	1434	1848	-52	-13.0
130		22	37	231	53	1434	1777	-123	-30.7

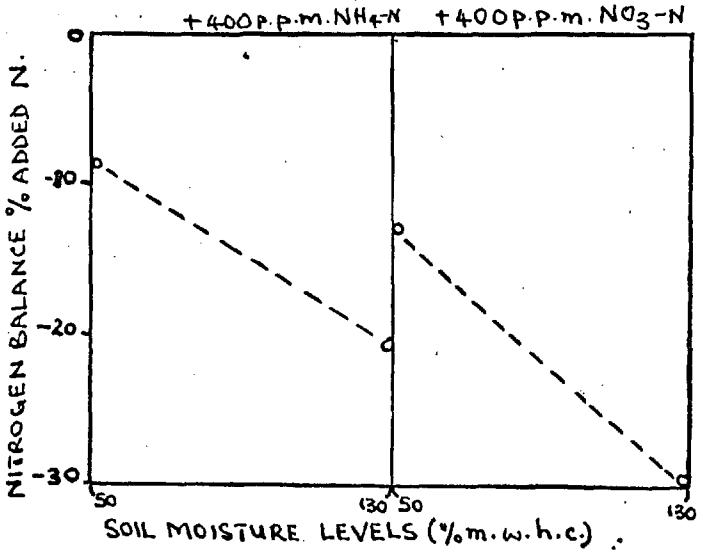
L.S.D. between balances p.p.m. = 26 at 5% and 37 at 1% levels.
L.S.D. between balances % = 6.5 at 5% and 9.5 at 1% levels.

Fig. 37: TOTAL NITROGEN BALANCES (a) P.P.M. (SOIL BASIS) AND (b) % OF ADDED NITROGEN, IN THE SOIL CROPPED WITH RICE AT DIFFERENT MOISTURE LEVELS AND TREATED WITH DIFFERENT INORGANIC NITROGEN FORMS.

(a)



(b)



133% = WATER-LOGGED.
50% ≙ FIELD CAPACITY.

The non-significant changes in total nitrogen obtained for the first lot of rye-grass at all moisture levels when NH_4-N or no nitrogen treatments was applied indicate either that there were no nitrogen losses or that any losses in nitrogen were balanced by non-symbiotic fixation. This result disagrees with that of Mann and Barnes (1951), who after treating potted barley with organic and ammonium nitrogen carriers obtained losses varying from 40% to 50% of the added nitrogen.

In the same first lot of rye-grass, there were significant (5% level) losses in nitrogen at all moisture levels where NO_3-N was applied. Losses must be by denitrification since they were higher in the more anaerobic conditions at the medium and high moisture levels than at the low moisture level. This agrees with results of several workers including Broadbent and Chapman (1950), Bizzell (1944) and Callison et. al. (1933) who reported negative nitrogen balances in long term lysimeter experiments.

The lower nitrogen losses for the second lot of rye-grass compared with those for the first lot may be brought about by two causes:

Firstly, increased non-symbiotic nitrogen fixation by bacteria due to the energy material obtained by the decomposition of the older roots of the second lot of rye-grass

in the later growth period. This is confirmed by the fact that in many cases the amount of roots (as shown by the total nitrogen value of the roots) separated on pulverising the residual soil was higher in the first lot than in the second of rye-grass.

Secondly, the development of a mass of green growth on the surface of the soil of the second lot of rye-grass might have contributed to nitrogen fixation by the algae forming the green growth. De and Sarkar (1936) and Nishigaki and Shioiri (1959) found net gains only where such algal growths occurred under plants in pot tests.

The greater gains in nitrogen at the high moisture level when no nitrogen was added and at the medium moisture level when NH_4-N was added than under all other conditions may be connected with the type of micro-organism fixing atmospheric nitrogen under the respective conditions. The greater development of roots at the high moisture level and the low amounts of inorganic nitrogen would encourage bacterial nitrogen fixation especially as anaerobic nitrogen fixers are more numerous than aerobic nitrogen fixers (Waksman (1952)). In the presence of added NH_4-N, most nitrogen fixation may be by algal fixation since the presence of inorganic N would depress bacterial nitrogen fixation. Since algal growth increased with increasing moisture level, the depression in nitrogen gain at the high moisture may be due to volatilization of ammonia.

In the case of NO_3-N treatment, all nitrogen lost from the first lot of rye-grass was "recovered" in the second lot. This "recovery" must be connected with the development of the algae that fixed nitrogen during the later part of the growth of the second lot of rye-grass.

Under rice there were net losses in nitrogen whether or not nitrogen treatments were applied. The greater losses under water-logging when NH_4-N and NO_3-N were applied than under medium moisture level indicates increased volatilization of ammonia and denitrification by water-logging. This agrees with the incubation results. Greater losses when NO_3-N than when NH_4-N was applied reflects the greater importance of denitrification than of ammonia volatilization as a mechanism of loss under water-logged conditions.

Comparing the nitrogen balances for both lots of rye-grass with those for rice, there were greater losses of nitrogen under rice than under rye-grass. This may be due to the differences in soil moisture levels at which they were grown. At the medium moisture level, especially when nitrate was added, the rice soil was continuously at 50% m.w.h.c. while the rye-grass soil was invariably below 50%. Greater losses under rice than under rye-grass may be connected with the degree of anaerobiosis of the soil conditions (Greenwood (1961)), (Korsakova (1941)), Martin and Cox (1956).

The differences between nitrogen losses under rye-grass and under rice may also be related to the conclusion reached by Wilson (1943) that graminae have the same effect as bacteria, as far as the reduction of nitrate is concerned. They may not produce gaseous nitrogen from nitrate but may reduce nitrate to nitrite in the process of assimilation. Some of this nitrite may appear as nitrous acid and react chemically with other substances in the plant or its exudates and result to nitrogen loss.

How far this reaction is important is not known but Wilson's (1943) report of the presence of nitrite in the exudates of blue grass roots may give weight to his theory. It is therefore possible that rice is more prone to produce nitrite from nitrate and thus stimulate nitrogen loss than does rye-grass especially as the respiration of rice roots seems more complex than that of rye-grass roots.

General Discussion.

It has been shown that during incubation of the soil of pH 6.41, with nitrate- and ammonia-nitrogen treatments, there were always losses in nitrogen at all moisture levels even when no organic matter was added. The soil with this pH (6.41) was the soil employed for nitrogen balance experiments under potted crops. For both incubation and pot tests there was a tendency for nitrogen losses, when they occurred, to

increase with increasing moisture level. The loss was most pronounced when NO_3-N was added and the crop had not been growing so long that nitrogen fixing processes had apparently "recovered" all the lost nitrogen.

There was a tendency for nitrogen balances under rice receiving NH_4-N or NO_3-N to follow trends similar to those in soil under incubation with added NH_4-N and NO_3-N.

Addition of organic matter to the soil when no inorganic nitrogen had been added caused net nitrogen gains after 15 weeks incubation. This obtained similarly under the second lot of rye-grass after about 15 weeks growth (from beginning of germination). This strengthens the supposition that the provision of decomposable root material stimulated nitrogen fixation under the second lot of rye-grass and caused net nitrogen gains.

In the presence of added inorganic nitrogen during incubation, addition of organic matter increased the net nitrogen losses since algae did not develop during incubation. This may strengthen the supposition that under the second lot of rye-grass which had received NH_4-N and NO_3-N increase in net nitrogen gain and reduction in net nitrogen loss compared with that obtained under the first lot may be due more to nitrogen fixation by algae than by nitrogen-fixing bacteria.

It therefore looks as if studies of nitrogen balances during incubation of soils may give some clue as to what may be expected in cropped soil.

Conclusions.

Total nitrogen balance studies were done under (a) different soil pH levels, different organic matter treatments (straw and compost), different inorganic nitrogen treatments (NH_4-N and NO_3-N), and different soil moisture levels during incubation;

(b) different inorganic nitrogen treatments (NH_4-N and NO_3-N) and different soil moisture level with rye-grass and rice in pot tests.

(A) 1. In the absence of added inorganic nitrogen, addition of oat straw and compost caused net nitrogen gains under aerobic conditions and net nitrogen losses, except in the case of straw addition, under anaerobic conditions. Net gains of nitrogen were probably due to non-symbiotic nitrogen fixation exceeding any losses.

2. The net gains were higher with compost treatment than with straw treatment. This is probably due to the similarity in the composition of compost and soil humus, so that compost provided more inorganic nutrients than straw for the metabolism of the nitrogen-fixing bacteria.

3. When NH_4-N was added to the soil, net nitrogen losses increased with increasing pH, with increasing moisture level, and at the medium and high pH (6.41 and 8.00), nitrogen losses were further stimulated by the addition of organic matter (straw and compost). Losses were probably due to volatization of ammonia.

4. In the presence of added NH_4-N at the low pH (4.72), there were net gains in nitrogen especially at the low moisture level when straw and compost were added. This may be due to the ability of certain fungi to fix nitrogen.

5. When NO_3-N was added, net nitrogen losses increased with increasing moisture level and with organic matter treatment. Losses were greater with straw than with compost. The provision of more easily mineralizable organic carbon by straw than by compost or by soil alone with subsequent increased denitrification may account for this. The increase in net nitrogen losses with increasing moisture level was probably due to the increased degree of anaerobiosis which tended to increase denitrification.

(B) 1. Although nitrogen losses occurred during the early period of cropping of rye-grass with NO_3-N, longer cropping resulted in apparent "recovery" of the lost nitrogen. Longer cropping also increased the net nitrogen gains with NH_4-N and no nitrogen treatments. These were due presumably to the activities of nitrogen-fixing bacteria as energy material became available from decaying roots and of nitrogen-fixing algae which developed in the late period of growth.

2. Under rice, however, net losses in nitrogen were obtained under all conditions. This might have been due to insufficient time for algae growth to have developed or to the possible greater reduction of nitrate to nitrite by rice than by rye-grass during nitrate assimilation.

The difference between the two crop species may be connected with their root respiration mechanisms.

In general, the conclusion was reached that the phenomenon of denitrification was of great importance in the presence of large amounts of organic matter and nitrate and when the soil was very moist.

It was also concluded that loss of nitrogen by ammonia volatilization was of importance only when the pH was high and under these conditions it was stimulated by the addition of organic matter or by high soil moisture level.

The atmospheric nitrogen fixation by non-symbiotic bacteria might be of some importance only when organic materials have been added to the soil in the absence of large amounts of mineral nitrogen. On the other hand, fixation of nitrogen by algae might proceed in a cropped soil under all conditions, but was usually stimulated by increasing moisture level.

CHAPTER VI

THE EFFECT OF SOIL MOISTURE LEVEL ON THE PERFORMANCE OF (A) RYE-GRASS (B) RICE CROPS GROWN IN POTS AND GIVEN DIFFERENT NITROGEN TREATMENTS

Introduction.

In all rainfall areas of the world plants of the grass family (Graminae) are found thriving; grass crops and cereals find little competition in the world's great grasslands where rainfall is not heavy enough for forest trees. In tropical and subtropical countries rice is cultivated in swamps where there is little competition from "upland" crops.

Grass leys and mixed swards for animal feeding are invariably drained or irrigated when necessary to improve yields and it is expected therefore that maximum productivity would be obtained at a particular level of soil moisture. Rye-grass is one of the most important grasses included in swards or permanent grasslands in providing animal feeds in England and the effects of the soil moisture on its performance is an important aspect of a study of its productivity. This includes a study of the yields, soil fertility and the quality of the crop.

As far as rice is concerned, there are two types, the "upland" rice and the swamp rice (or paddy) thriving in drained and swampy conditions respectively. These two conditions provide two different soil environments where nutrient metabolic process and availability are generally different. However any type of rice can be grown under both drained and swampy conditions. Thus rice is a particularly suitable crop for studying soil nutrient availability at all moisture levels, including water-logging.

Thus, in the present chapter of this work, the yields and nitrogen, phosphorus and potassium uptake by rye-grass and rice under different nitrogen and soil moisture treatments are studied. The percentage utilization of the added nitrogen by the crops, the percentage content of nutrients in the crop tissues and the effects of the different nitrogen treatments on the reaction of the residual soil are also determined.

Materials and Experimental Methods.

The materials and experimental methods of Chapter 5(B) were used, the only extra work involved being the analysis of the tops for phosphorus and potassium in addition to nitrogen. From these the percentage content of the nutrients in the tops and the percentage utilization of the added nitrogen were calculated.

After drying the soil and pulverising it, duplicate 20 g. samples were taken for pH determination.

Only the second lot of rye-grass which had six cuttings and received 600 p.p.m. NH_4-N, and NO_3-N or no nitrogen treatments and the rice which had received 400 p.p.m. NH_4-N and NO_3-N or no nitrogen treatments are reported and discussed in the present Chapter.

N.B. All increases or decreases in dry-matter yields and nutrient uptake mentioned in the following results and discussions are significant at 5% level.

(A) Rye-grass.

(i) Results.

The dry matter yields and total nitrogen, phosphorus and potassium uptake by rye-grass tops grown with different nitrogen and soil moisture treatments are shown in Table 29 and graphically in Fig. 38 (dry-matter yields), Fig. 39 (nitrogen uptake), Fig. 40 (phosphorus uptake) and Fig. 41 (potassium uptake).

Dry-matter yields: (Fig. 38) There were no significant differences between the dry-matter yields at all moisture levels when the soil received no nitrogen treatment. There were highly significant responses to NH_4-N and NO_3-N treatments at all moisture levels.

In the first four cuttings, with NH_4-N and NO_3-N treatments, there was a great increase in dry-matter yields with increase in moisture level from low to medium and while remaining constant with a further increase in moisture level with NH_4-N, the dry-matter yields increased further with increasing moisture level with NO_3-N. Thus differences in dry-matter yields between NH_4-N and NO_3-N treatments were significant only at the high moisture level, NO_3-N giving greater yields than NH_4-N treatments.

In the last two cuttings, and in the total yields (all cuttings) with NH_4-N and NO_3-N treatments, there was also a

great increase in dry-matter yields with increase in moisture level from low to medium. With a further increase in moisture level, under NH_4-N treatment, dry-matter yields decreased but under NO_3-N treatment, dry-matter yields remained constant in the last two cuttings but increased in the total cuttings. Thus comparing NH_4-N and NO_3-N treatments, rye-grass yielded better under the latter than under the former.

Comparing the dry-matter yields at the high moisture levels when no nitrogen was applied with the yields at the low moisture level when NH_4-N or NO_3-N was applied, NO_3-N treatment increased the dry-matter yields in all cuttings while NH_4-N treatment did so only in the first four cuttings.

Nitrogen uptake: In all cuttings, there were no significant differences in the total nitrogen uptake at all moisture levels when no nitrogen treatment was given. NH_4-N and NO_3-N treatments greatly increased the total nitrogen uptake over that obtained when no nitrogen was applied.

Under NH_4-N and NO_3-N there was a highly significant increase in total nitrogen uptake with increasing moisture level from low to medium followed by a decrease with a further increase in moisture level from medium to high. The decrease in nitrogen uptake with the further increase in moisture level was however non-significant in the first four cuttings with NH_4-N and in the last two cuttings with NO_3-N treatments.

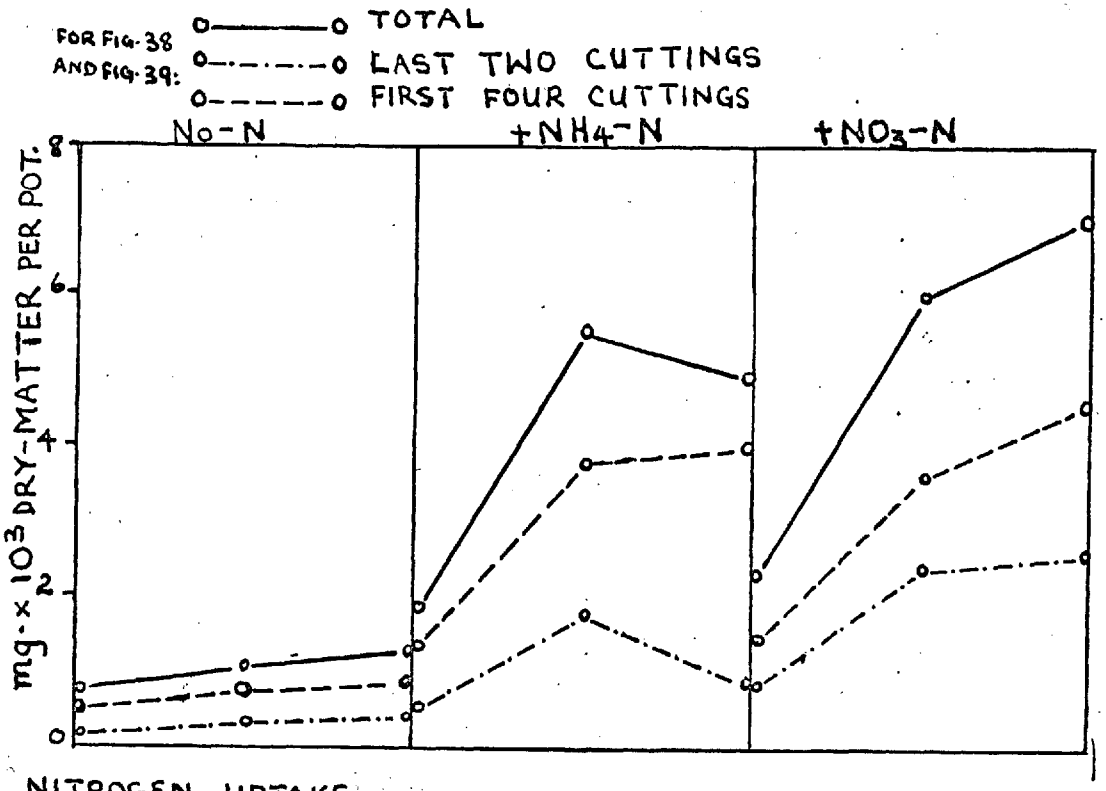
TABLE 29.

Dry-matter yields and nitrogen, phosphorus and potassium uptake (mg./pot) by rye-grass tops grown with different nitrogen and soil moisture treatments.

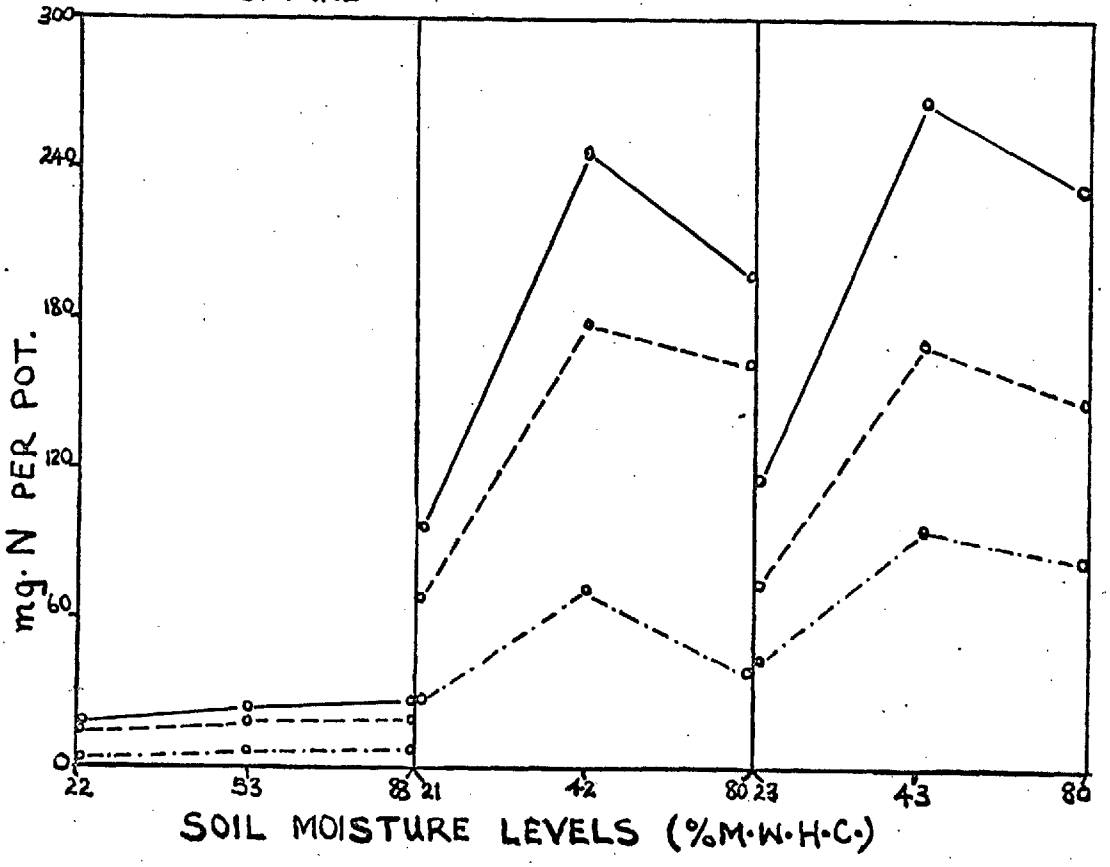
	Yields										
N treatments	+NO N			+NH_4-N			+NO_3-N			L.S.D.	
Moisture treatments (%m.w.h.c.)	22.0	53.0	82.0	21.0	42.0	80.0	23.0	43.0	80.0	At 5%	At 1%
1st 4 cuttings	569	767	889	1350	3817	4064	1484	3604	4549	416	570
Last 2 cuttings	181	310	390	516	1795	887	845	2407	2578	313	428
TOTAL	750	1077	1279	1866	5612	4951	2329	6011	7127	631	864
	Nitrogen (N)										
1st 4 cuttings	14.5	17.2	18.9	68.6	176.9	163.1	74.3	170.6	147.2	23.4	32.0
Last 2 cuttings	3.2	6.6	7.9	28.1	71.0	39.1	43.7	96.3	85.4	12.1	16.6
TOTAL	17.7	23.8	26.8	96.7	247.9	202.2	118.0	266.9	232.6	17.9	24.6
	Phosphorus (P_2O_5)										
1st 4 cuttings	13.9	19.2	18.1	17.7	61.7	75.4	16.1	40.9	60.8	2.8	3.8
Last 2 cuttings	3.1	5.4	5.9	5.2	30.4	13.6	5.5	21.2	28.9	5.6	7.6
TOTAL	17.0	24.6	24.0	22.9	92.1	89.0	21.6	62.1	89.7	8.6	11.9
	Potassium (K_2O)										
1st 4 cuttings	25.9	31.6	36.9	70.7	152.6	151.2	98.5	219.2	284.0	25.0	34.3
Last 2 cuttings	5.2	9.9	7.1	19.4	28.0	9.0	83.5	174.3	148.8	10.6	14.5
TOTAL	31.1	41.5	44.0	90.1	180.6	160.2	182.0	393.5	432.8	32.2	44.1

DRY-MATTER YIELDS AND NITROGEN UPTAKE BY RYE-GRASS TOPS GROWN UNDER DIFFERENT NITROGEN AND SOIL MOISTURE TREATMENTS IN POTS:

Fig·38: DRY-MATTER YIELDS.



Fig·39: NITROGEN UPTAKE.



PHOSPHORUS AND POTASSIUM UPTAKE BY RYE-GRASS TOPS GROWN UNDER DIFFERENT NITROGEN AND SOIL MOISTURE TREATMENTS IN POTS.

Fig.40: PHOSPHORUS UPTAKE.

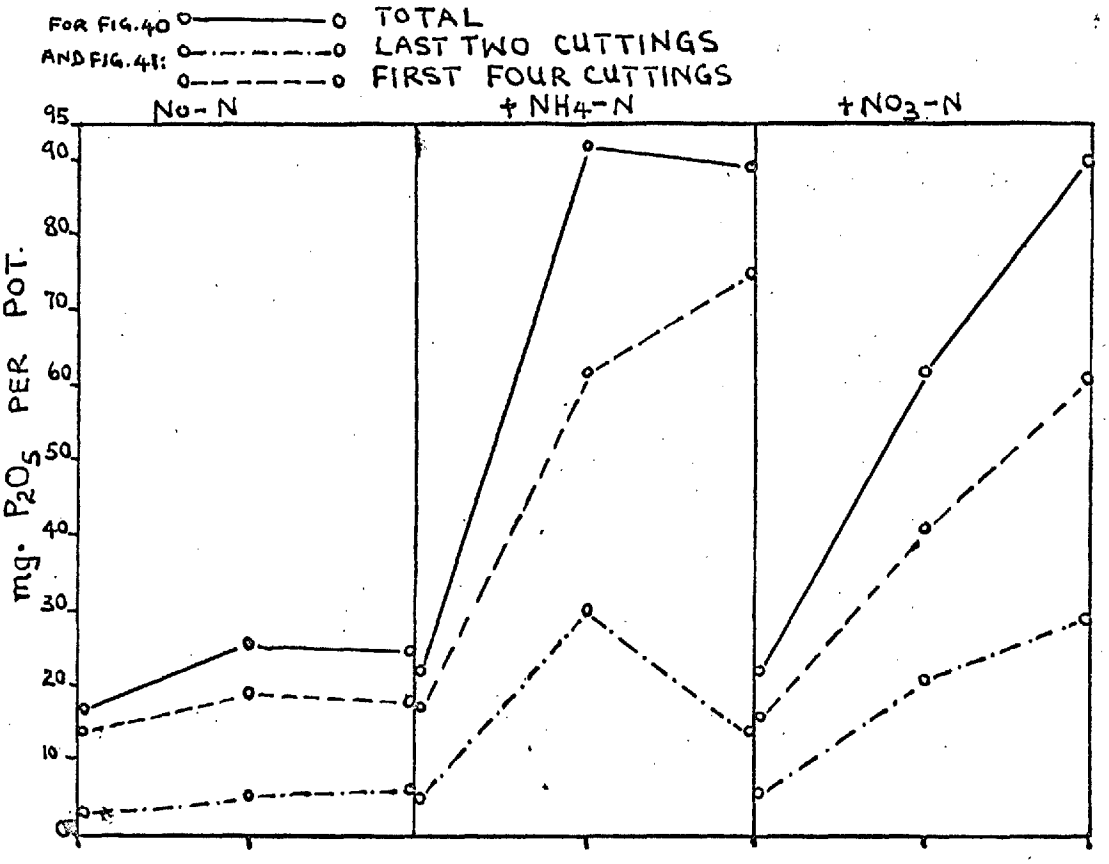
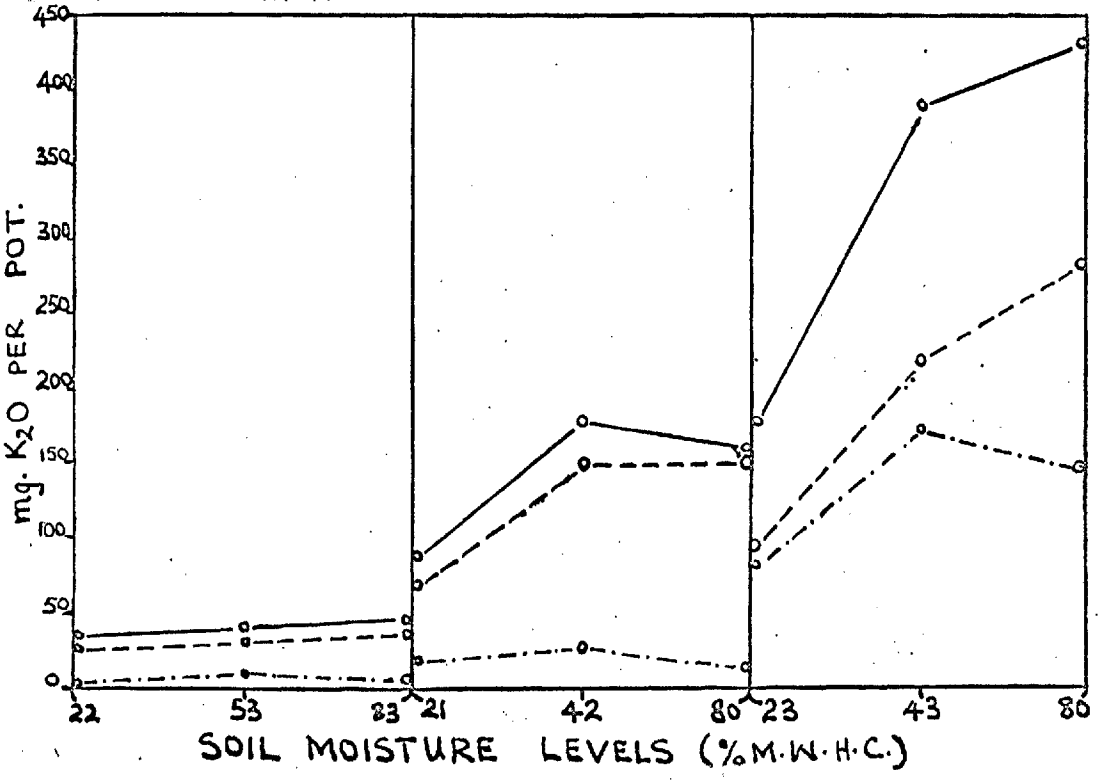


Fig.41: POTASSIUM UPTAKE.



Comparing NH_4-N and NO_3-N treatments in the first four cuttings nitrogen uptake was similar at low and medium moisture levels but higher with NH_4-N than with NO_3-N at the high moisture level. In the last two and total cuttings, however, nitrogen uptake was higher with NO_3-N than with NH_4-N at corresponding moisture levels.

Phosphorus uptake: Without nitrogen treatment, there were no significant differences between the total phosphorus uptake except in the first four cuttings where the phosphorus uptake was higher at the medium and high than at the low moisture levels.

Furthermore, there were no significant differences between the phosphorus uptake at the low moisture levels whether or not nitrogen treatments were given except that NH_4-N treatment caused greater uptake than no nitrogen treatment in the first four cuttings.

With NO_3-N treatment, the phosphorus uptake in all cuttings increased with increasing soil moisture level. When NH_4-N treatment was given the total phosphorus uptake increased with increasing moisture level from low to medium. Thereafter, the total phosphorus uptake increased in the first four cuttings but decreased in the last two and total cuttings with a further increase in moisture level.

Comparing NH_4-N and NO_3-N treatments, in all cuttings, phosphorus uptake with NH_4-N was greater than that with NO_3-N at the medium moisture level. At the high moisture level, phosphorus uptake with NH_4-N was greater in the first four

cuttings, lower in the last two cuttings and similar in the total cuttings when compared with the phosphorus uptake with NO_3-N.

Thus nitrogen treatments increased total phosphorus uptake compared with no nitrogen treatment only when the moisture levels were medium and high.

Potassium uptake: It is to be noted that NO_3-N was added as KNO_3 and thus only NO_3-N treatment received extra potassium.

There were no significant differences between the total potassium uptake at all moisture levels when no nitrogen treatment was given, whilst NH_4-N treatment increased potassium uptake compared with no nitrogen treatment. With the NH_4-N treatment, in the first four and total cuttings, the potassium uptake increased with increasing moisture level from low to medium and then remained constant with a further increase in soil moisture level. In the last two cuttings, potassium uptake was about constant at low and medium and decreased at high moisture levels.

With the NO_3-N treatment, in the first four and total cuttings, the potassium uptake increased with increasing moisture level. In the last two cuttings, the potassium uptake increased with increasing moisture level from low to medium and then decreased with a further increase in moisture level.

Generally, there was a response in dry-matter yields and nitrogen, phosphorus and potassium uptake to nitrogen treatments, the responses being greater at the medium and high than at the low moisture levels.

(ii) Discussion.

Dry-matter yields: As shown in Table 3 and Fig. 1, the soil 1 (Harlington soil) used for this study has its permanent wilting percentage (15 atmosphere percentage tension) at an actual moisture content of 5.62%. The low moisture level determined at the end of crop growth under the present study was 20% of the maximum water-holding capacity which had been maintained during crop growth by adding just enough water periodically when necessary to prevent wilting. This low moisture level is equivalent to 8.6% actual moisture and thus just above the permanent wilting percentage.

The lack of significant between the dry-matter yields at all moisture levels when no nitrogen treatment was given and the large responses of the crop to nitrogen fertilization indicate that the limiting effect of nitrogen was more important than that of soil moisture level. This observation coupled with the fact that differences in yields of dry-matter appeared between the different moisture levels only when nitrogen applications were made strengthens the confirmation made by Williams (1954) of the hypothesis that growth may not be limited directly by soil

moisture until the wilting point, but soil moisture above the wilting point may affect the availability of nutrients.

The general increase in dry-matter yields with increasing moisture level from low to medium when nitrogen treatments were given and the further increase with moisture level when NO_3-N was applied may be due to the suggestion made by Finn et. al. (1961) that grasses tend to respond negatively to increased oxygen availability.

Since the availability of oxygen increases as the amount of water decreases, the increases in yields with increasing moisture levels observed here may be justified especially as they agree with the results of Finn et. al. (1961), Jenne et. al. (1958), Schumaker and Davis (1961) and Low and Piper (1960).

The greater yields of dry-matter obtained with NO_3-N than with NH_4-N in the last two cuttings and hence in the total cuttings may be related to the mode of inorganic nitrogen utilization by grass plants. Dormaar and Ketcheson (1960) in studying this problem with maize plants in pots concluded that at low rates of nitrogen application NH_4-N stimulated more production of dry-matter than did NO_3-N but at higher rates the reverse was the case. Thus in this study, in the first four cuttings there were no significant differences between dry-matter yields with NH_4-N and NO_3-N and this may correspond with a period when the amounts of nitrogen applied were low. Later as the amount of nitrogen applied increased, NO_3-N stimulated

more dry-matter yields than did NH_4-N. This is confirmed by similar results obtained by Bizzell (1943) in lysimeter experiments.

Generally, dry-matter yields with NH_4-N at low moisture level were similar to those with no nitrogen treatment at high moisture level but those with NO_3-N at low moisture level were higher than both. The greater dry-matter yields with NO_3-N than with NH_4-N particularly at the low moisture level agree with the results of Widdowson and Shaw (1960) who explained them by the fact that NO_3-N and urea were better than NH_4-N when there was not enough rain for full yields.

Shalvet and Zwerman (1958) demonstrated that deficits in maize yields caused by excessive soil moisture could be mitigated by the addition of nitrate. In a similar manner here, the deficit in yield caused by the low moisture level compared with the yield at the high moisture level when no nitrogen treatment was given, was mitigated by both NH_4-N and NO_3-N additions, NO_3-N being much more effective than NH_4-N. Thus if there is a choice between irrigation and nitrogen treatment as a method of increasing rye-grass yields at low soil moisture contents, irrigation to 80% of the maximum water-holding capacity or NH_4-N treatment would be equally effective, but NO_3-N treatment would be superior to both.

Nitrogen uptake: There were no significant differences in the total nitrogen uptake at all moisture levels when no nitrogen was added. This tends to follow from the proposal made in the Review of Literature (Chapter 1) of this work that if nutrients are in limited availability, the total uptake may be independent of the soil moisture. It is confirmed by Doneen (1942) who observed that variations in soil moisture level did not affect the total nitrogen obtained by crops as long as there was some available water present.

When, however, NH_4-N and NO_3-N were applied, the increase in nitrogen uptake with increasing moisture level from low to medium may be due to increased growth of the crop. With further increase in moisture level the total nitrogen uptake tended to decrease. This is definitely not connected with plant growth since in fact the dry-matter yields inceased at this point when NO_3-N was applied. The decrease in nitrogen uptake at the high moisture level may arise from the unavailability of the added nitrogen either due to losses by volatilization of ammonia and denitrification or due to immobilization in the roots and soil micro-organisms. In chapter V, it was shown that favourable nitrogen balances obtained when NH_4-N and NO_3-N were applied might have been due to nitrogen fixation by algae which developed towards the end of plant growth, so the possibility of nitrogen losses cannot be overlooked.

In the nitrogen balance sheet in chapter V, the total nitrogen contained in the separated roots was highest at the high moisture levels. This is confirmed by the results of Shalhevet and Zwerman (1958) that the root weight of maize was a function of NO_3-N supply under poor drainage conditions.

The contention made by Shalhevet and Zwerman (1958) that NO_3-N added to the soil raised the redox potential at a high water-table and thus served not only as a nitrogen source but also as an oxidising agent may account for the greater uptake with NO_3-N than with NH_4-N treatments. This is confirmed by the fact that with NH_4-N dry-matter yields were greatly reduced especially in the last two cuttings at high moisture level, hence nitrogen uptake was adversely affected.

Phosphorus uptake: It has been shown in earlier chapters of this work that phosphorus was greatly mobilized at high soil moisture levels. In the first four cuttings of the rye-grass tops when no nitrogen was applied, the greater uptake of phosphorus at the medium and high moisture levels than at the low level may be due to this.

The non-significant differences in the phosphorus uptake, when no nitrogen was applied in the last two and hence in the total cuttings may be due to reduced transference of phosphorus from the roots to the shoots. This has been shown to happen by Foster and Russell (1958) suggesting that indirect

interaction of iron with phosphate due to the formation in plant roots of complexes between the phosphate and the iron bound to an organic substrate. This reaction is likely to become more important after a greater amount of root material has been developed than earlier.

Conversely, Kereszteny (1953) suggested that phosphate mobilized under high moisture levels was not all available to the plant. This may be so but the fact that nitrogen seemed to limit dry-matter production in this study more than did moisture treatment may be more important in limiting the extent of uptake of the mobilized phosphorus. This concept is supported by the fact that when nitrogen was applied, phosphorus uptake increased with dry-matter yield which also increased with soil moisture level. It also agrees with the results of Low and Piper (1960) who found phosphorus uptake by Italian rye-grass to increase with increasing moisture level when nitrogen, phosphorus and potassium fertilizers were applied to soils of low fertility.

When all the nitrogen treatments are considered, the similarity in phosphorus uptake at the low moisture level irrespective of nitrogen treatments and dry-matter yields agrees with the results of Fawcett and Quirk (1960) that phosphorus uptake was greatly reduced when wheat plants were watered to low soil moisture level after temperorary wilting compared with plants grown at field capacity. It may be explained by the reduced solubility of phosphorus compounds in soil

solution when the proportion of "unfree water" (Wadleigh and Richards (1951)) in the soil is high.

The greater uptake of phosphorus when NH_4-N than NO_3-N was applied at the medium moisture level agrees with the results of Dormaar and Ketcheson (1960) who found this happening at nitrogen applications above 100 p.p.m. It also confirms reports by Yuen and Pollard (1957) using the same soil as used in this study and accounting for the result by the influence which the different nitrogen forms had on the pH of the soil, which is slightly below neutrality. They suggested that the uptake of phosphorus was favoured by the NH_4-N which increased soil acidity.

At the high moisture level, NH_4-N was also more effective in stimulating phosphorus uptake than was NO_3-N in the first four cuttings but in the last two NO_3-N was more effective, thus resulting in similar total phosphorus uptake by the total cuttings. It may be thought that at the earlier period of growth, the increase of anaerobiosis at this high moisture level was small and the acidifying effect of NH_4-N on phosphorus uptake was predominant. As time went on, due to greater degree of anaerobiosis developed in the soil, the tendency to oxidize NH_4-N to NO_3-N decreased and hence the acidifying effect decreased. This, coupled with the counter effect of increasing soil pH through excessive soil moisture level (Dennett (1932), and the decreased dry-matter production

due to possible hydrogen sulphide toxicity, tended to eliminate the disparity in the phosphorus uptake as stimulated by the two nitrogen forms.

Potassium uptake: The non-significant differences in potassium uptake at the different moisture levels when no nitrogen was applied may also be due to limitation of growth by nitrogen deficiency rather than by soil moisture treatments. Thus when NH_4-N was added there were increases in potassium uptake resulting in total potassium uptake that was higher at the medium and high moisture levels than at the low. The pattern of potassium uptake with NH_4-N closely paralleled that of dry-matter yields and it might seem that at the high moisture level decreased amounts of potassium uptake were mainly due to the low dry-matter production as a result of the possible toxic effects of hydrogen sulphide in the last two cuttings.

With NO_3-N, a lot of potassium had been added to the soil as KNO_3 and the increase in potassium uptake with increasing soil moisture level for the first four and total cuttings may be attributed to increased production of dry-matter which also increased with increasing moisture level (Jenne et. al. (1958). The decrease in potassium uptake in the last two cuttings at the high moisture level after an increase with moisture level from low to medium agrees with results obtained by Wilamis and Davis (1944) in which barley took up less potassium in poorly

drained than in well drained soils. This is likely to become more pronounced in the later than in the earlier growth period as the degree of anaerobiosis increased. Thus potassium uptake was higher in the first four cuttings and lower in the last two cuttings at the high than at the medium moisture levels.

There is no doubt that, in view of the great difference in total potassium uptake and the relatively smaller differences in total dry-matter yields between NH_4-N and NO_3-N treatments, there is a luxury consumption of the potassium when added as KNO_3. Furthermore, while other factors mentioned above may determine differences in yields of dry-matter and in nitrogen and phosphorus uptake between the different nitrogen treatments, some of the differences may have arisen as a result of the presence of the extra potassium.

(B) RICE.

(i) Results.

The dry-matter yields and total nitrogen, phosphorus and potassium uptake by rice plant tops under different nitrogen and soil moisture treatments are shown in Table 30 and graphically in Fig. 42 (Dry-matter yields), Fig. 43 (Nitrogen uptake), Fig. 44, (Phosphorus uptake) and Fig. 45 (Potassium uptake).

Dry-matter yields: (Fig. 42).

There were no significant differences in the dry-matter yields at the two moisture levels, "upland" and water-logged, when no nitrogen treatment was given, but there was a great response to nitrogen treatments.

In the initial thinning, dry-matter yields under water-logging was greater than those at "upland" moisture level when NH_4-N was applied but with NO_3-N there was no difference in dry-matter yields between the two moisture levels. In the final cutting and in total cuttings water-logging increased dry-matter yields more than did "upland" moisture level with NO_3-N, but just failed to do so with NH_4-N.

Between NH_4-N and NO_3-N treatments, dry-matter yield differences werenonsignificant at the "upland" moisture level in all cuttings. Under water-logging, however, the dry-matter yields with NH_4-N were higher than those with NO_3-N in the initial thinning, but in the final cutting and hence in the total cuttings, dry-matter yields were higher with NO_3-N than with NH_4-N.

Thus, generally, the response to nitrogen treatment was high and similar for both forms of nitrogen at the "upland" moisture level. At water-logging the response was greater in the earlier and less in the later period of growth with NH_4-N than with NO_3-N.

Nitrogen uptake: (Fig. 43).

There was no significant difference in the nitrogen uptake at the two moisture levels when no nitrogen treatment was given but there were increases in nitrogen uptake to similar amounts at "upland" moisture level when both NH_4-N and NO_3-N treatments were given.

At water-logging, the nitrogen uptake was lower than at the "upland" moisture level irrespective of nitrogen treatment or cutting and the nitrogen uptake with NH_4-N was higher than that with NO_3-N.

Phosphorus uptake: (Fig. 44).

There were no significant differences in the phosphorus uptake at the two moisture levels when no nitrogen was applied. Nitrogen treatments significantly increased phosphorus uptake.

With NH_4-N, the differences in phosphorus uptake, between water-logging and "upland" moisture level were significant only in the initial thinning but with NO_3-N, the phosphorus uptake was always higher at water-logging than at the medium moisture level.

Phosphorus uptake was higher with NH_4-N than NO_3-N under all conditions except in the final cutting at water-logging where the differences were non significant.

TABLE 30.

Dry-matter yields and total nitrogen, phosphorus and potassium uptake (mg./pot) by rice plant tops under different nitrogen and soil moisture treatments.

	DRY-MATTER						L.S.D.	
N-treatment	Control		$+NH_4$-N		$+NO_3$-N		at5%	at1%
Moisture treatment	Medium	Water-logged	Medium	Water-logged	Medium	Water-logged		
Initial thinning	436	436	790	1127	827	901	94	132
Final cutting	1173	1279	5843	6168	6448	7910	704	987
TOTAL	1609	1715	6633	7295	7275	8811	682	956
	NITROGEN (N)							
Initial thinning	7.24	8.13	33.48	26.40	34.28	18.31	3.66	5.13
Final cutting	10.53	14.83	141.70	137.53	143.03	115.22	11.00	15.43
TOTAL	17.77	22.96	175.18	163.93	177.31	133.53	11.50	16.13
	PHOSPHORUS (P_2O_5)							
Initial thinning	8.15	8.37	15.71	21.07	12.09	15.36	2.88	4.03
Final cutting	15.84	13.85	61.82	59.52	33.61	55.90	5.53	7.76
TOTAL	23.99	22.22	77.53	80.59	45.70	71.26	6.21	8.71
	POTASSIUM (K_2O)							
Initial thinning	16.91	18.52	32.64	43.71	39.45	43.30	5.14	7.20
Final cutting	33.82	39.12	99.32	128.25	246.38	245.52	25.92	36.34
TOTAL	50.73	57.64	131.96	171.96	285.83	288.82	27.04	37.91

DRY-MATTER YIELDS AND NITROGEN UPTAKE BY RICE TOPS GROWN UNDER DIFFERENT NITROGEN AND SOIL MOISTURE TREATMENTS IN POTS.

Fig. 42: DRY-MATTER YIELDS.

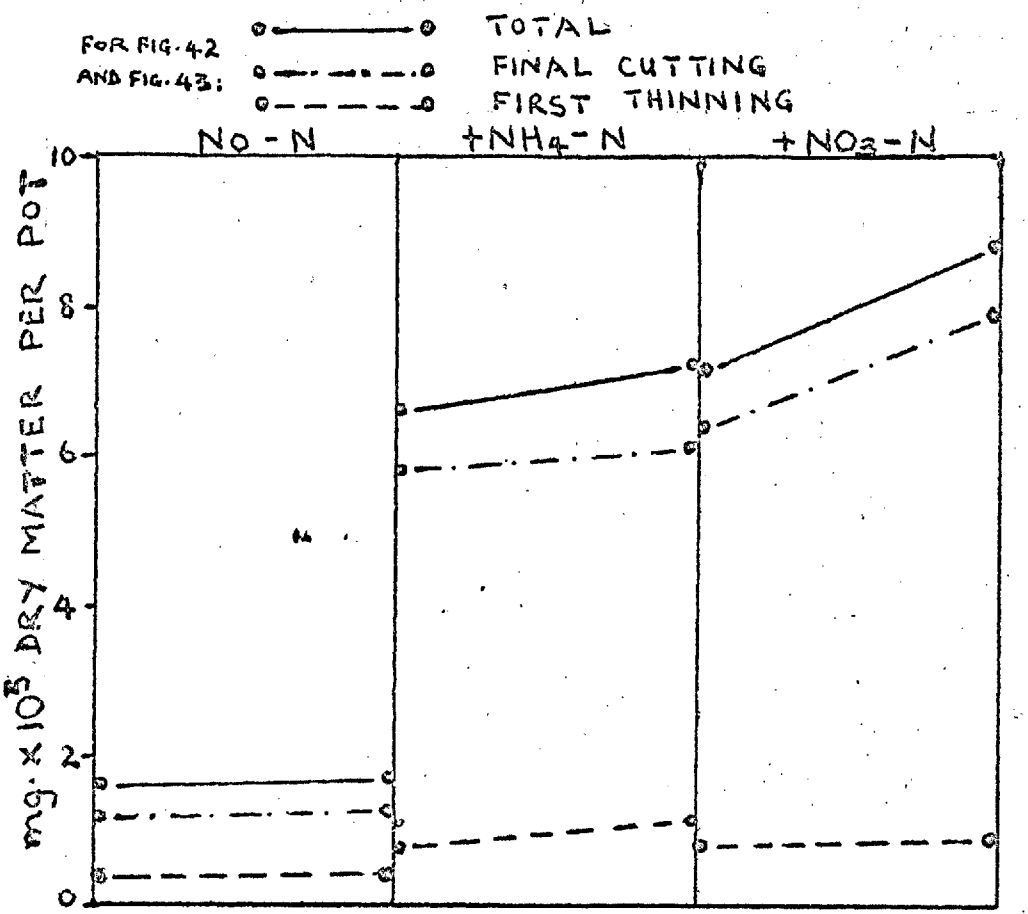
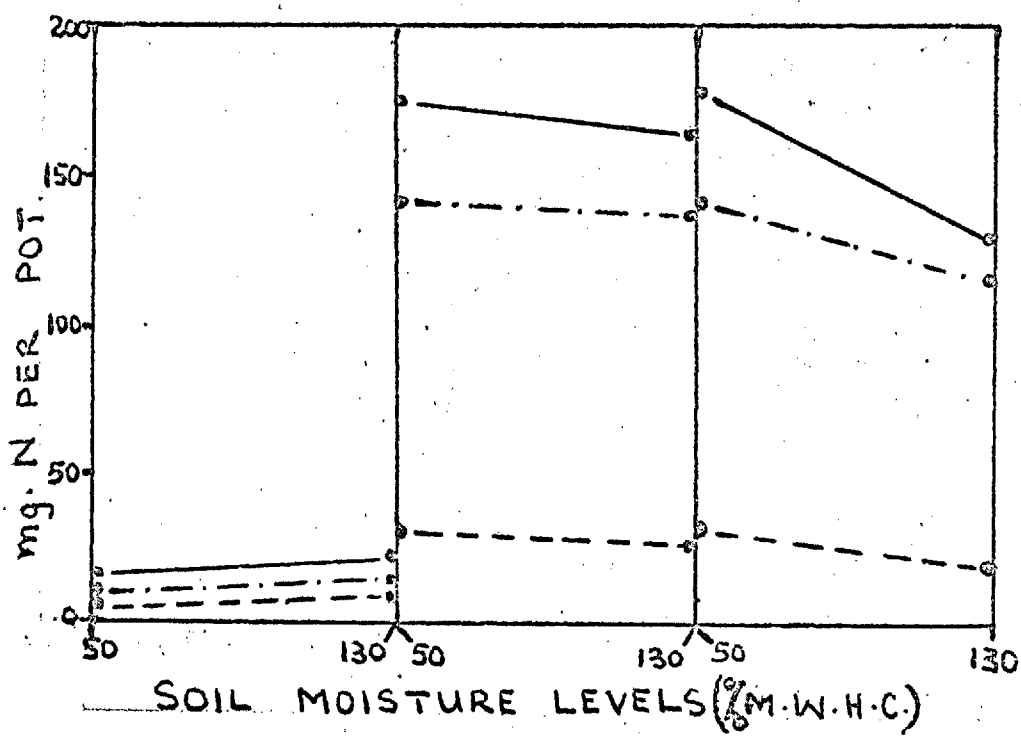


Fig. 43: NITROGEN UPTAKE.



PHOSPHORUS AND POTASSIUM UPTAKE BY RICE TOPS GROWN UNDER DIFFERENT NITROGEN AND SOIL MOISTURE TREATMENTS IN POTS.

Fig. 44: PHOSPHORUS UPTAKE.

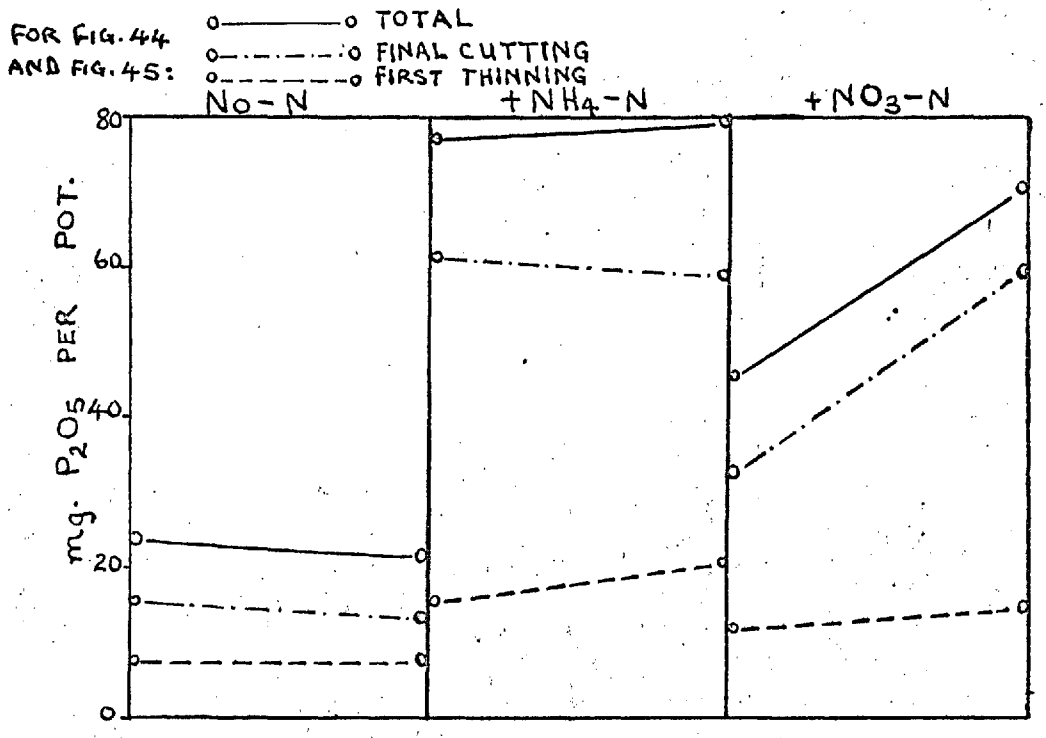
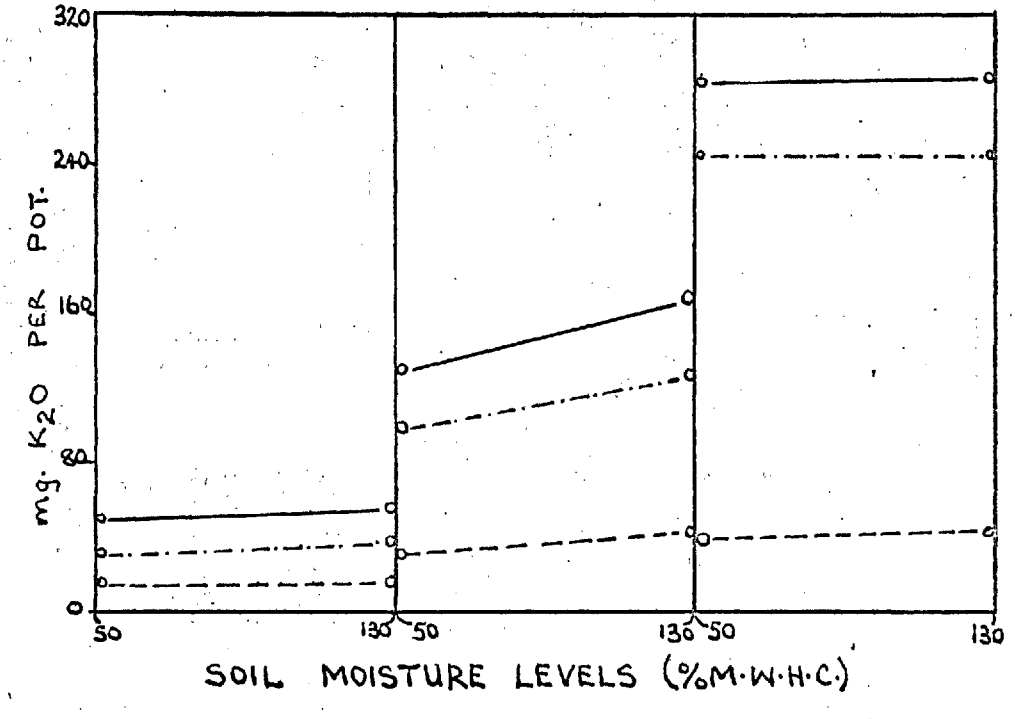


Fig. 45: POTASSIUM UPTAKE.



Potassium uptake: (Fig. 45).

There were no significant differences in the potassium uptake at the two moisture levels when no nitrogen was added. Nitrogen treatments increased potassium uptake.

With NH_4-N, potassium uptake was always higher under water-logging than at the "upland" moisture level.

With NO_3-N, it must be noted that potassium had been added in the KNO_3 when the treatment was applied and no potassium was added to the other nitrogen treatments. There were no significant differences in potassium uptake between the two moisture levels.

(ii) Discussion.

Dry-matter yields: The lack of differences in yields of dry-matter by rice grown at "upland" moisture level and water-logging without nitrogen treatment may be due to the fact that some factor other than moisture level was limiting growth. It has been suggested for rye-grass that inadequacy of nitrogen may be more important in limiting growth than effects of soil moisture level. This may also apply to rice since there was a great response in dry-matter yields to nitrogen treatments. Shapiro and Armiger (1958) obtained similar results and concluded that flooding might increase rice growth only when the general nutrient status of the soil was high.

When nitrogen treatments were applied, dry-matter yields responded to moisture treatments, tending to be higher

at water-logging than at the "upland" moisture level. This agrees with the results of Shapiro and Armiger (1958) and Shapiro (1958).

Shibuya et. al. (1935) reported that rice was an "ammophile" plant, reacting better to NH_4-N than to NO_3-N, while Kapp (1934) found that NH_4-N increased yields more than did NO_3-N (as $NaNO_3$) under water-logged conditions only when applications were over 500 p.p.m. N (soil basis). In the present study NH_4-N produced more dry-matter than did NO_3-N at water-logging only in the early part of growth, when only 100 p.p.m. of nitrogen had been added. This agrees with the result of Patrick and Sturgis (1955).

Later, NO_3-N out-yielded NH_4-N at water-logging and this agrees with reports by Kapp (1933). The disparity in dry-matter yields between NH_4-N and NO_3-N treatments may be due to the toxic effects of hydrogen sulphide which has been shown by Greene (1960) to accumulate and harm the roots of rice plants when high amounts of ammonium sulphate were applied to rice under water-logged conditions. The toxic effects of hydrogen sulphide will become more important in the later than in the earlier stages of growth since the NH_4-N treatment was given in split applications.

This disparity in yields may also be due to the presence of added potassium with the NO_3-N treatment which may maintain the general nutrient status at a high level

while a depletion of soil available potassium with NH_4-N treatment proceeds.

When, however, it is considered that Kapp (1933) obtained greater yields with NO_3-N added as $NaNO_3$ than with NH_4-N added as $(NH_4)_2SO_4$ at rates below 400 p.p.m., the toxic effects of accumulated hydrogen sulphide may be more important than the extra potassium addition in creating the observed disparity in dry-matter yields between NH_4-N and NO_3-N treatments.

Nitrogen uptake.

Addition of nitrogen to the soil resulted in a larger nitrogen uptake by rice than no nitrogen addition (Kapp 1934). The results obtained in this study agree with this. The lack of significance in the differences in nitrogen uptake at "upland" moisture level and water-logging when no nitrogen was added may be due to the fact that nitrogen deficiency limited growth (and hence nitrogen uptake) more than did the effects of moisture levels since Kapp (1934) reported that the nitrogen removed by rice was proportional to the growth and dry-matter produced.

This report by Kapp (1934) held for nitrogen uptake when no nitrogen was added in this study but when NH_4-N and NO_3-N were applied, the nitrogen uptake was inversely related to the dry-matter yields as stimulated by differences in moisture levels. Thus the greater uptake of nitrogen at the "upland"

moisture level than at water-logging contradicts this report and that of Shapiro (1958) that total nitrogen uptake by nitrogen-fertilized rice increased on flooding. The results obtained in this study were due primarily to losses of nitrogen which were greater at water-logging than at the medium moisture level (chapter V). The greater uptake of nitrogen with NH_4-N than with NO_3-N under both moisture levels was due to greater losses of nitrogen from NO_3-N than from NH_4-N treatments.

Phosphorus uptake.

Flooding may increase rice growth and phosphate uptake only when the general nutrient status of the soil is high (Shapiro and Armiger (1958). Thus the lack of significance in the differences in phosphorus uptake between the "upland" moisture level and water-logging when no nitrogen was added may be due to the low nitrogen level. When nitrogen (especially NO_3-N) was added, water-logging stimulated more phosphorus uptake than did "upland" moisture level. This is understandable since under water-logged conditions phosphorus was greatly mobilized as shown in the earlier chapters of this work while Shapiro (1958) stated that phosphorus was still mobilized on flooding in the presence of actively growing plants.

The lack of significance in the differences between phosphorus uptake at "upland" moisture level and that at water-logging when NH_4-N was applied especially in the later part of

the growth period may be due to the toxic effects of hydrogen sulphide on the root uptake of phosphorus under water-logging. Greene (1960) has suggested that H_2S derived from $(NH_4)_2SO_4$ under water-logging inhibited uptake of nutrients by the roots.

It may be argued that this effect should also apply to other nutrients but when it is considered that Greene (1960) also suggested that if iron was present in the soil solution (as was the case under water-logging, Shapiro (1958)) the young roots acquired a yellowish brown coating of ferric hydroxide gel which protected them against damage by moderate amounts of H_2S. If this was the case then some phosphate ions tending to pass into the root may be precipitated as ferric compounds in the ferric hydroxide coating. Thus such a coating devised for protection against H_2S damage will be more detrimental to phosphorus translocation to the tops than to the uptake of other nutrients.

It would, therefore, seem that due to general root degeneration and protective coatings of ferric iron on young roots stimulated by H_2S toxic effects, the uptake of phosphorus by rice tops under prolonged water-logging and increased $(NH_4)_2SO_4$ application would be hampered and would tend to levels similar to the phosphorus uptake at the "upland" moisture level.

The greater uptake of phosphorus with NH_4-N than with NO_3-N under both moisture levels agrees with the results obtained by Shibuya and Saeki (1939) with rice and by

Yuen and Pollard (1957) with Italian rye-grass in the same soil as used in this study. The latter workers assigned the result to the influence of the respective nitrogen forms on the slightly acid reaction of the soil. Since uptake of phosphorus by oats was maximum at pH 5.8 to 6.0, the addition of $(NH_4)_2SO_4$ which tended to lower the soil pH from 6.50 increased phosphorus uptake while the addition of KNO_3 which tended to increase the soil pH stimulated less phosphorus uptake.

Potassium uptake.

The lack of significance in the differences in potassium uptake at "upland" moisture level and water-logging when no nitrogen was applied was possibly due to the deficiency of nitrogen in producing similar amounts of growth at both moisture levels. This is strengthened by the fact that in Chapter IV there were no differences in the availability of potassium in the same soil when incubated at moisture levels similar to those at which the rice was grown.

With NH_4-N, the greater potassium uptake at water-logging than at the "upland" moisture level may be due partly to the greater (though non-significant) dry-matter yields. Since, however, the potassium uptake was significantly higher at water-logging than at the "upland" moisture levels while the differences in dry-matter yields were non-significant, it would seem that water-logging actually increased potassium availability. This may be a result of the solubilizing effects of organic acids produced in anaerobic carbon metabolism on potassium minerals.

This proposition is strengthened by the fact that the total potassium uptake at both moisture levels, (132 mg./pot at "upland" moisture level and 172 mg./pot at water-logging) was higher than the original soil available (Morgan extractable) potassium (164 p.p.m. soil or 82 mg./pot). Thus at both moisture levels, originally unavailable potassium was released to the plant and the solubilizing effects of organic acids mentioned above might have released more at water-logging than at the medium moisture level.

There was a super abundance of potassium when NO_3-N was added to the soil and the equal potassium uptake at both moisture levels despite the fact that water-logging stimulated greater dry-matter yields than did "upland" moisture level shows a greater luxury consumption of potassium at the "upland" moisture level than at water-logging.

Comparing the yields and potassium uptake with NH_4-N on the one hand and yields and potassium uptake with NO_3-N on the other, it is seen that the potassium added with NO_3-N was subject to luxury consumption.

Percentage content of nitrogen, phosphorus and potassium in the total plant tops.

(i) Results.

(A) Rye-grass.

The percentage contents of nitrogen, phosphorus and potassium of the rye-grass tops grown at low, medium and high moisture levels with different nitrogen treatments are shown in Table 31 and Fig. 46.

There were no significant differences in the nitrogen % at all moisture levels when no nitrogen was applied. When NH_4-N and NO_3-N were applied, the nitrogen % decreased with increasing moisture level.

The phosphorus % was similar at low and medium and decreased at the high moisture levels, when no nitrogen was applied. When nitrogen was applied, the phosphorus % increased with increasing moisture level.

The potassium % decreased with increasing moisture level when no nitrogen or NO_3-N was applied but decreased with increasing moisture level from low to medium and remained constant with a further increase in moisture level to high when NH_4-N was applied.

Between the nitrogen treatments, nitrogen addition significantly increased nitrogen % to similar levels for NH_4-N and NO_3-N except at the high moisture level where the nitrogen % with NH_4-N was significantly higher than that with NO_3-N.

Nitrogen addition significantly decreased phosphorus % to amounts significantly higher with NH_4-N than with NO_3-N. NH_4-N treatment significantly increased potassium % at the low moisture level and decreased it to similar amounts at the medium and high moisture levels. NO_3-N treatment (where potassium had been added in the KNO_3) increased highly the potassium % compared with NH_4-N and no nitrogen treatments.

(B) Rice.

The percentage contents of nitrogen, phosphorus and potassium of the rice tops grown at "upland" moisture level and water-logging with different nitrogen treatments are shown in Table 32 and Fig. 47.

TABLE 31.

Percentage nitrogen, phosphorus and potassium in Rye-grass tops grown with different nitrogen and soil moisture treatments.

Nutrient	NO N			+600p.p.m.NH_4-N			+600p.p.m.NO_3-N			L.S.D.	
	*22	53	83	21	42	80	23	43	80	at 5%	at 1%
%N	2.36	2.17	2.11	5.18	4.41	4.12	5.07	4.47	3.27	0.31	0.42
%P_2O_5	2.30	2.22	1.87	1.23	1.64	1.81	0.93	1.03	1.26	0.16	0.23
%K_2O	4.15	3.85	3.44	4.83	3.22	3.25	7.81	6.54	6.07	0.28	0.38

* % maximum water-holding capacity
NH_4-N added as Ammonium sulphate ($(NH_4)_2SO_4$).
NO_3-N added as Potassium nitrate (KNO_3).

TABLE 32.

Percentage nitrogen, phosphorus and potassium in Rice tops grown with different nitrogen and soil moisture treatments.

Nutrient	NO N		+400p.p.m.NH_4-N		+400p.p.m.NO_3-N		L.S.D.	
	*50	Water-logged	50	Water-logged	50	Water-logged	at 5%	at 1%
%N	1.11	1.34	2.53	2.25	2.44	1.52	0.56	0.79
%P_2O_5	1.49	1.30	1.17	1.11	0.63	0.81	0.11	0.16
%K_2O	3.16	3.33	1.99	2.36	3.93	3.27	0.21	0.29

* % maximum water-holding capacity. Water-logged = 130% m.w.h.c.
NH_4-N added as Ammonium sulphate ($(NH_4)_2SO_4$)
NO_3-N added as Potassium nitrate (KNO_3).

Fig. 46: PERCENTAGE NUTRIENTS IN RYE-GRASS TOPS GROWN UNDER DIFFERENT NITROGEN AND SOIL MOISTURE TREATMENTS.

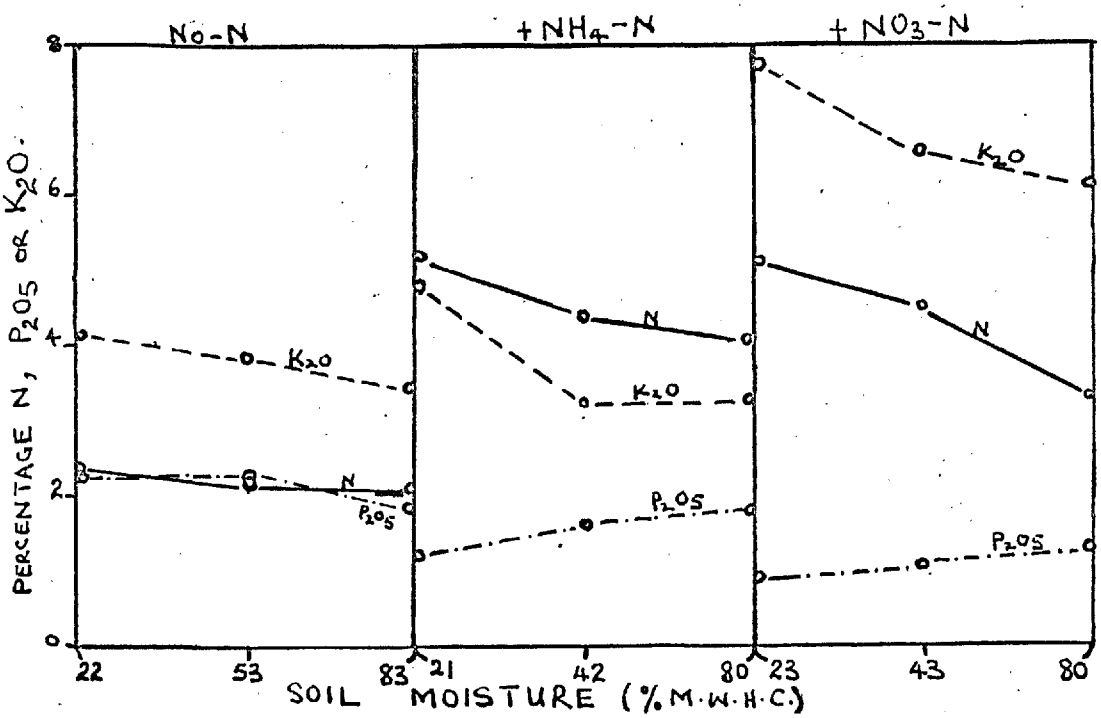
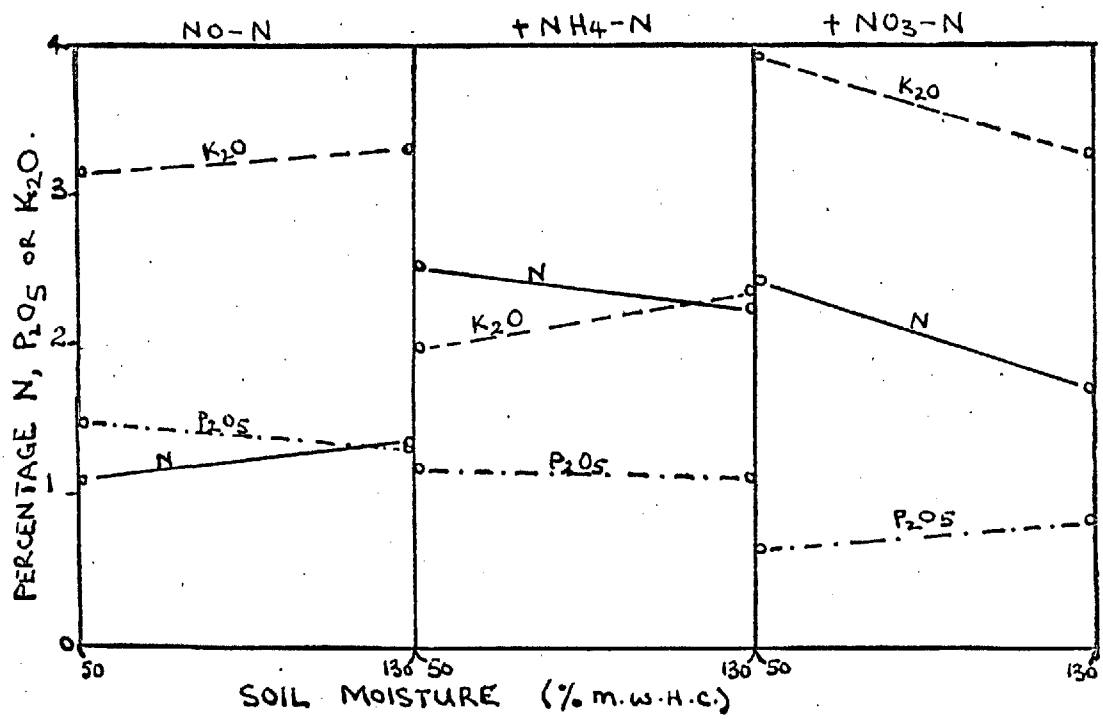


Fig. 47: PERCENTAGE NUTRIENTS IN RICE TOPS GROWN UNDER DIFFERENT NITROGEN AND SOIL MOISTURE TREATMENTS.



The nitrogen % was similar at both moisture levels when no nitrogen or NH_4-N was applied but was higher at the "upland" moisture level than at water-logging when NO_3-N was applied.

The phosphorus % was higher at the "upland" moisture level than at water-logging when no nitrogen was applied and higher at water-logging than at the "upland" moisture level when NO_3-N was applied.

The potassium % was similar at both moisture levels when no nitrogen was applied, higher at water-logging than at the "upland" moisture level when NH_4-N was applied, similar at both moisture levels when NH_4-N was applied and higher at water-logging than at the "upland moisture level when NO_3-N was applied.

Nitrogen % was increased by NH_4-N at both moisture levels and by NO_3-N at "upland" moisture level compared with the no nitrogen treatment. The difference in nitrogen % between NH_4-N and NO_3-N was significant only at water-logging, nitrogen % with NH_4-N being higher than that with NO_3-N. Phosphorus % decreased in the order: no nitrogen > NH_4-N > NO_3-N, while potassium % decreased in the order NO_3-N > no nitrogen > NH_4-N except that under water-logging, the potassium % was similar when NO_3-N and no nitrogen were applied.

(ii) Discussion.

(A) Rye-grass.

It was postulated in Chapter I of this work that if the availability of nutrients in the soil was unlimited, the

nutrient content of the plant would be independent of the soil moisture. If the availability of nutrients was limited, the nutrient content would decrease with increasing moisture level due to dilution by greater dry-matter production at the higher than at the lower moisture levels.

The nutrient content of the rye-grass grown at three soil moisture levels and with different nitrogen treatments did not follow this theory due to the independent effects of soil moisture on nutrient availability and on plant growth.

Thus the increase in nitrogen % when nitrogen was applied compared with when no nitrogen treatment was given agrees with the results obtained by several workers including Schumaker and Davis (1961) and Kapp (1934). The general decrease in nitrogen % with increasing moisture level when nitrogen was added and was presumably in unlimited availability also agrees with the results of Schumaker and Davis (1961) and Lawton (1945a) and may be due to the dilution of absorbed nitrogen by the increased dry-matter yields.

The lower nitrogen % only at the high moisture level when NO_3-N was applied than when NH_4-N was applied may be due to lower amounts of available nitrogen, more nitrogen having been lost by denitrification with NO_3-N than by ammonia volatilization with NH_4-N. The lack of difference in nitrogen % between the two nitrogen forms at the medium and low moisture levels agrees with the result of Bizzell (1943) although Morgan and Jacobson (1942) found the nitrogen % of tobacco grown in lysimeters

higher with NO_3-N than with NH_4-N.

The decrease in the phosphorus % with nitrogen compared with no nitrogen treatment might be due to dilution by the increased organic matter production. The increase in phosphorus % with increasing moisture level when nitrogen treatments have been applied was probably due to the greater availability of phosphorus at the higher moisture than at lower levels. This agrees with results obtained by Low and Piper (1960) using rye-grass and by Jenne et. al. (1958) using maize. Lawton (1945a) however found slight decreases in phosphorus % of maize leaves at the higher compared with the lower moisture levels. Similar results were obtained in this study where no nitrogen had been added.

The phosphorus % with NH_4-N was higher than that with NO_3-N probably because of the greater availability of phosphorus with NH_4-N than with NO_3-N especially as the total phosphorus uptake followed a similar trend, (Yuen and Pollard (1957)).

The potassium % generally decreased with increasing moisture level and seemed to follow the trends suggested in the proposition that when a nutrient was in unlimited availability, if increasing moisture levels increased dry-matter yields, the nutrient content would decrease with increasing moisture level. It would seem that potassium was in unlimited availability both in the presence or absence of nitrogen treatments. Lawton (1945a) and Jenne et. al. (1958) obtained similar results.

The very highly increased potassium % when potassium was added in the KNO_3 treatment confirms the luxury consumption of the added potassium already mentioned for NO_3-N treatment.

(B) Rice.

Addition of nitrogen generally increased the nitrogen % in the rice tops, This agrees with the results obtained by Kapp (1934) and Shapiro (1958), and was due to the greater available nitrogen present in the soil treated with nitrogen than in that not so treated. The similarity in the nitrogen % at the "upland" moisture level and at water-logging when no nitrogen or NH_4-N was applied disagrees with the results of Shapiro (1958) who reported that flooding increased nitrogen % of rice tops.

The decrease in nitrogen % at water-logging compared with that at the "upland" moisture level when NO_3-N was added was probably due to the decreased available nitrogen as a result of denitrification under water-logging, especially as total nitrogen uptake followed a similar trend. This might account for the lower nitrogen % at water-logging with NO_3-N than with NH_4-N which has also been observed by Patrick and Sturgis (1955) during the early period of rice growth.

As observed for rye-grass, the phosphorus % of rice tops also decreased with nitrogen application and this may similarly be due to dilution by the greater dry-matter yields.

The increase at water-logging of phosphorus % compared with the phosphorus % at the "upland" moisture level when NO_3-N was applied agrees with the results of Shapiro (1958). This may be due to the greater utilization of available phosphorus at water-logging only when NO_3-N was applied since in the soil where no nitrogen was applied, phosphorus % was lower at water-logging than at the "upland" moisture level. In the latter case it was probable that deficiency of nitrogen which limited the general nutrient uptake interacted with the slight increase in dry-matter yield at water-logging resulting in lowered phosphorus %. The greater phosphorus % with NH_4-N than with NO_3-N may be due to the greater availability of soil phosphorus with NH_4-N than with NO_3-N (Yuen and Pollard (1957)).

The potassium % when NH_4-N was applied was lower than that when no nitrogen was applied. This may be due to dilution as a result of increased dry-matter yields and agrees with results obtained by Kapp (1934) that as the growth of rice plant increased by addition of nitrogen, the percentage potassium in the entire plant decreased. The higher potassium % at water-logging than at the "upland" moisture level may be due to the increased supply of potassium from its minerals dissolved by organic acids produced from anaerobic organic matter decomposition.

Where potassium was added (in the NO_3-N treatment) potassium was presumably in unlimited availability and the

TABLE 33.

Efficiency of utilization of added inorganic nitrogen by rye-grass and rice tops grown at different soil moisture levels.

Crop	$+NH_4$-N			$+NO_3$-N			L.S.D.	
Rye-grass	Soil moisture levels (% m.w.h.c.)			Soil moisture levels (% m.w.h.c.)			At 5%	At 1%
	Low (21)	Medium (42)	High (80)	Low (23)	Medium (43)	High (80)		
	32.2	82.1	66.7	39.3	89.6	75.4	7.5	10.5
Rice	Medium (50)	Water-logged (130)		Medium (50)	Water-logged (130)			
	86.0	82.0		88.7	66.9		7.2	10.4

For rye-grass: added NH_4-N and NO_3-N at 600 p.p.m. soil.
For rice: added NH_4-N and NO_3-N at 400 p.p.m. soil.

NH_4-N as ammonium sulphate, $((NH_4)_2SO_4)$

NO_3-N as potassium nitrate, (KNO_3).

TABLE 34.

Changes in soil pH after cropping rye-grass and rice under different nitrogen and soil moisture treatments.

Crop	NO N			$+NH_4$-N			$+NO_3$-N			L.S.D.	
	Moisture levels (% m.w.h.c.)			Moisture levels (% m.w.h.c.)			Moisture levels (% m.w.h.c.)			at 5%	at 1%
Rye-grass	22	53	83	21	42	80	23	43	80		
	6.25	6.20	6.44	5.31	4.76	5.33	6.14	7.20	7.12	0.09	0.12
Rice	50	130		50	130		50	130			
	5.61	6.12		4.66	5.30		6.44	6.57		0.10	0.14

For rye-grass: added NH_4-N and NO_3-N at 600 p.p.m. soil.
For rice: added NH_4-N and NO_3-N at 400 p.p.m. soil.

NH_4-N as Ammonium sulphate, $((NH_4)_2SO_4)$
NO_3-N as Potassium nitrate, (KNO_3).

Fig. 48: EFFICIENCY (%) OF ADDED NITROGEN UTILIZATION BY RYE-GRASS AND RICE TOPS GROWN AT DIFFERENT SOIL MOISTURE LEVELS IN POTS.

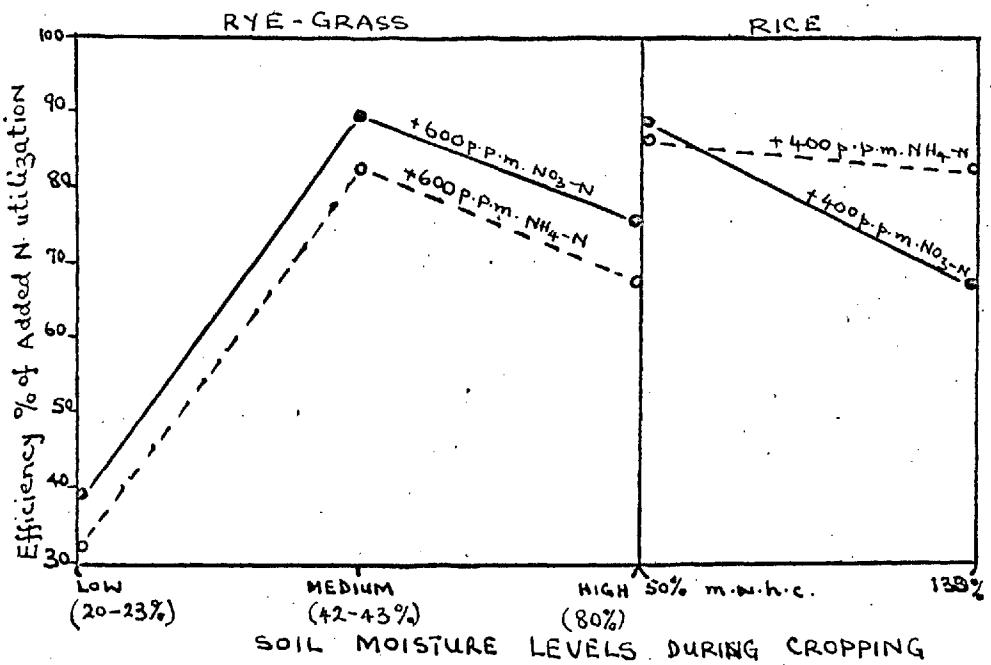
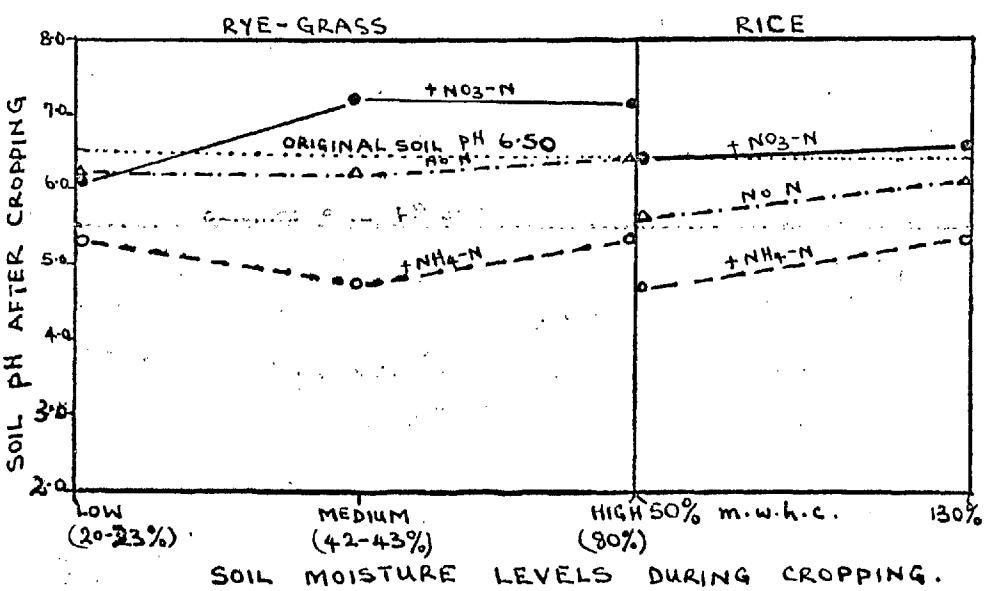


Fig. 49: CHANGES IN THE SOIL pH AFTER CROPPING WITH RYE-GRASS AND RICE UNDER DIFFERENT NITROGEN AND SOIL MOISTURE TREATMENTS.



decrease in potassium % at water-logging compared with the potassium % at the medium moisture level was probably due to dilution by the increased dry-matter yields.

Efficiency of added nitrogen utilization.

Results.

The efficiency of utilization of added inorganic nitrogen by rye-grass and rice tops grown at different soil moisture levels is shown in Table 33 and Fig. 48. The nitrogen uptake when no nitrogen was added has not been taken into account.

For rye-grass, the efficiency of nitrogen utilization increased with increasing moisture level from low to medium and then decreased. This held for both forms of added nitrogen (NH_4-N and NO_3-N). At the high and medium moisture levels, added NO_3-N was more efficiently utilized than NH_4-N while at the low moisture level, the difference in utilization between NO_3-N and NH_4-N just failed to reach significance (5% level).

For rice, water-logging significantly reduced added NO_3-N utilization compared with the "upland" moisture level. There were no significant differences in the efficiency of nitrogen utilization between both moisture levels when NH_4-N was added and between NH_4-N and NO_3-N at the "upland" moisture level. At water-logging, NH_4-N was much better utilized than NO_3-N.

Discussion.

The increase in added nitrogen utilization with increasing moisture level from low to medium and a decrease with further increase in moisture level to high, agrees with the result of Schumaker and Davis (1961) who found for Western wheat-grass a maximum utilization at moisture levels between 50% and 75% of the maximum water-holding capacity when applications of nitrogen were above 200 p.p.m. soil. This may be due to the lower availability of nitrogen at the high moisture level due to nitrogen losses to the atmosphere, and to the reduced growth and dry-matter yields at the low moisture level.

The better utilization of NO_3-N than NH_4-N may be due to the preference for nitrate to ammonia by rye-grass. This agrees with the results obtained by Morgan and Jacobson (1942) and Bizzell (1943) who obtained 50% efficiency of utilization of added NO_3-N by various field crops at field capacity in lysimeters.

The better utilization by rice tops of NH_4-N than NO_3-N only at water-logging may be due to the greater loss of NO_3-N by denitrification than of NH_4-N by ammonia volatization. It may also be due to the fact that under this moisture level, rice prefers ammonia to nitrate in accordance with the suggestion made by Shibuya et. al. (1935) that rice was an "ammophile" plant. This did not however apply in this study

to the "upland" moisture level where reduced nitrogen losses from nitrate may account for more NO_3-N uptake than at water-logging.

Changes in soil pH after cropping.

Result.

The original soil pH was 6.50. The changes in the soil pH after cropping rye-grass and rice at different moisture levels and nitrogen treatments are shown in Table 34 and Fig. 49.

For rye-grass, where no nitrogen treatment was applied there were significant decreases in soil pH only at the low and medium moisture levels compared with the original soil pH. Where NH_4-N was applied there were highly significant decreases which were most pronounced at the medium moisture level. Where NO_3-N was applied a significant decrease in pH was observed at the low moisture level but highly significant and similar increases in pH at the medium and high moisture levels.

For rice, the pH was always higher at water-logging than at the "upland" moisture level. There were significant decreases in the soil pH where NH_4-N or no nitrogen was applied compared with the original soil pH. The decreases were much more pronounced with NH_4-N than without nitrogen treatment. Where NO_3-N was applied, there were no significant changes in soil pH compared with the original soil pH.

Discussion.

For both rye-grass and rice, addition of NH_4-N always lowered the soil pH. This agrees with the results obtained by several workers including Prince et. al. (1941), Morgan and Jacobson (1942) and Bizzell (1943). Addition of NO_3-N however increased the pH especially at the higher moisture levels. Yuen and Pollard (1957) have classified NH_4-N and NO_3-N as "physiologically" acid and basic treatments respectively. NH_4-N from $(NH_4)_2SO_4$ is nitrified in the soil or absorbed by the plant leaving the SO_4^{--} radical which forms H_2SO_4 and thus produces acidity while the uptake of NO_3-N leaves the basic ion and thus reduces acidity.

The acidifying effect of NH_4-N being most pronounced at the medium moisture level may be due to the greater uptake of nitrogen at that moisture level than at the high or low moisture level. It may also be due to the medium moisture level being more suited for nitrification than the high or low moisture levels.

The higher pH values obtained when the soil was at the higher than at the lower soil moisture level irrespective of nitrogen treatments may be due to the effect of anaerobic conditions in increasing soil pH. The fact that this difference in pH still existed after the soil had been dried shows that the process causing increase in pH under high moisture levels was not completely reversible. Dennett (1932), however, reported a return to the original soil pH when water-logged soils were drained.

General Discussion.

Irrespective of which crop was grown in the soil under study, there was a significant response to nitrogen treatments in dry-matter yields and in nitrogen, phosphorus and potassium uptake, especially at the higher soil moisture levels. This was probably due to the paucity of available nitrogen in the soil receiving no nitrogen treatment where the different moisture treatments had no differential effects on dry-matter yields and nutrient uptake.

When NH_4-N was added, total dry-matter yields and uptake of nutrients tended to follow similar trends. They increased with moisture level from low to medium and then remained more or less constant with a further increase in moisture level when rye-grass was grown. When rice was grown they were more or less similar at the "upland" moisture level and water-logging.

When NO_3-N was added, total dry-matter yields and uptake of phosphorus and potassium followed similar trends, increasing with moisture level under rye-grass. Whilst nitrogen uptake was always higher at the medium moisture level than at other moisture levels under both crops, dry-matter yields and phosphorus uptake were higher at water-logging than at "upland" moisture level and potassium uptake was similar at both moisture levels under rice.

Thus soil moisture limited growth and nutrient uptake by rye-grass only at low soil moisture contents compared with soil moisture contents up to 80% of the maximum water-holding capacity. This effect of low soil moisture content may be expected to apply to rice since Palis (1935) reported a total failure of the crop at 20% of the maximum water-holding capacity.

The differences in the performance of the crops between NH_4-N and NO_3-N treatments arise, (a) from the differences in their effects on the soil pH as far as phosphorus uptake is concerned (Yuen and Pollard (1957)), (b) from the toxic effects of H_2S produced from $(NH_4)_2SO_4$ in NH_4-N treatment under anaerobic conditions as far as dry-matter yields are concerned (Greene (1960)) (c) from the differences in the nitrogen loss to the atmosphere (see Chapter V) as far as nitrogen uptake is concerned and (d) from the presence of extra potassium with NO_3-N as far as potassium uptake is concerned.

The effects on the soil pH produced by NH_4-N and NO_3-N result in increased soil acidity by NH_4-N and reduced soil acidity by NO_3-N. These effects interacted with soil moisture treatments to produce higher pH at the high than at the medium moisture levels.

As a measure of the quality of rye-grass as an animal feeding stuff and of both rye-grass and rice straws as materials for compost as far as the nitrogen and inorganic nutrient contents are concerned, the nitrogen content was

increased by nitrogen treatments compared with no nitrogen treatment, but possibly due to dilution by increased growth, the phosphorus content was decreased by nitrogen treatment except at the high moisture levels where phosphorus was probably mobilized (Shapiro (1958)). The nitrogen content however decreased with increasing moisture level due to nitrogen losses. The potassium content of rye-grass generally decreased with increasing moisture level but that of rice followed a similar trend only when NO_3-N was added.

Thus the ratio of nitrogen to phosphorus content was narrowest when no nitrogen treatment was given. When nitrogen was applied, the ratio was narrowest at the higher moisture levels under both NH_4-N and NO_3-N treatments.

Conclusions.

The effects of (A) three soil moisture levels, low, medium and high (about 20%, 42% to 53%, and 80% respectively of the maximum water-holding capacity) on the dry-matter yields and the uptake of nitrogen phosphorus and potassium by rye-grass tops and (B) two soil moisture levels, medium ("upland") moisture level and water-logging (about 50% and 130% of the maximum water-holding capacity respectively) on the dry-matter yields and the uptake of nitrogen, phosphorus and potassium by rice tops, when given different inorganic nitrogen (NH_4-N or NO_3-N) were determined.

The nitrogen, phosphorus and potassium contents of the plant tops, the efficiency of utilization of the added nitrogen and the effect of the different nitrogen forms on the pH of the residual soil were also determined.

(A) (1) There were no significant differences in the dry-matter yields and in the uptake of the nutrients between the various treatments when rye-grass was grown without nitrogen treatment. This was probably due to inadequate nitrogen exerting limiting effects on rye-grass performance more than did differences in soil moisture.

(2) The limiting effects of low available nitrogen was shown by the great response to nitrogen treatments in the performance of the rye-grass.

(3) When either form of nitrogen (NH_4-N or NO_3-N) was applied, the dry matter yields, and nitrogen, phosphorus and potassium uptake increased with moisture level from low to medium and while remaining constnat with NH_4-N, they increased further with NO_3-N (except for nitrogen uptake which decreased under both nitrogen treatments) with a further increase in moisture level to high. This was probably due to increased growth with increasing moisture level and to nitrogen losses to the atmosphere at the high soil moisture level.

(4) Dry-matter yields, nitrogen uptake and the efficiency of added nitrogen utilization were higher with NO_3-N than with NH_4-N. This might be due to a preference for NO_3-N to NH_4-N

by rye-grass or to the presence of extra potassium added in the NO_3-N treatment which thus increased the nutrient level of the soil.

(5) Phosphorus uptake was higher at the medium moisture level with NH_4-N than with NO_3-N. This might be due to the acidifying effect of $(NH_4)_2SO_4$ which made iron phosphate more available.

(B) (1) As with rye-grass, there were no significant differences in the dry-matter yields and nitrogen, phosphorus and potassium uptake at the two moisture levels by rice tops when no nitrogen treatment was applied. The application of both nitrogen forms (NH_4-N and NO_3-N) caused large responses in the performance of the rice tops.

(2) When NH_4-N was applied dry-matter yields and nitrogen and phosphorus uptake followed similar trends each remaining more or less constant at both moisture levels. Potassium uptake was higher at water-logging than at "upland" moisture level. The latter result may be due to the greater release of non available potassium by organic acids produced from anaerobic processes.

(3) When NO_3-N was applied dry-matter yields and phosphorus uptake were higher at water-logging than at the "upland" moisture level but the reverse was the case for nitrogen uptake. The latter result might be due to denitrification.

(4) At water-logging, the dry-matter yields were higher with NO_3-N than with NH_4-N. This might be due to the toxic effects on the roots of H_2S produced from the SO_4 added with the NH_4-N. This reason might also explain the inability of the rice tops to produce greater dry-matter yields or take up more phosphorus at water-logging than at "upland" moisture level when NH_4-N was applied (see (B)(2) above).

(5) At water-logging the nitrogen uptake and the efficiency of nitrogen utilization were higher with NH_4-N than with NO_3-N. This might be due to greater loss of nitrogen by denitrification than that by volatilization of ammonia.

In general, addition of nitrogen increased the nitrogen % of rye-grass or rice tops, the increase decreasing with increasing moisture level. Phosphorus % was however decreased by the addition of nitrogen to values which remained constant or increased with increasing moisture levels. For rye-grass, the potassium % decreased with increasing moisture level, but for rice where no nitrogen or NH_4-N was applied, the potassium % was higher at water-logging than at "upland" moisture level. Most of the decreases in nutrient content were presumably due to dilution by increased growth of the plant while the increases with increasing moisture levels might arise from increased release of the nutrient.

Application of NH_4-N reduced the soil pH, more so at the aerobic moisture levels than at the anaerobic. This was probably due to the acidifying action of ammonium sulphate and the interaction of this with anaerobic moisture levels to produce a soil pH below the original pH but above the aerobic moisture level pH. Application of NO_3-N, on the other hand generally increased the soil pH especially at anaerobic moisture levels.

Thus rye-grass performed better with NO_3-N than NH_4-N at all moisture levels while rice although it yielded worse with NH_4-N than NO_3-N, utilized NH_4-N better than it did NO_3-N under water-logging.

CHAPTER VII

THE EFFECT OF (A) THE HEIGHT OF WATER OF SUBMERGENCE DURING GROWTH ON THE PERFORMANCE OF RICE PLANTS (B) THE LENGTH OF PERIOD OF STORAGE OF SOIL UNDER "UPLAND" MOISTURE AND WATER-LOGGED CONDITIONS PRIOR TO CROPPING ON THE PERFORMANCE OF TRANSPLANTED RICE SEEDLINGS.

Introduction.

The general practice of flooding the soil during rice growth has been reported by several workers as improving the performance of the crop either by physiological stimulation and increasing nutrient availability or by weed control. Usually, the soil is water-logged just before transplanting the seedlings and kept so until just before the ripening of the grain.

In Chapter VI of this study it was shown that water-logging was effective in improving rice performance only when nitrogen fertilizers were applied. The low nitrogen level of the soil without nitrogen treatment was presumably thought to account for the lack of significance in the differences between the performance of rice under "upland" moisture conditions and water-logging.

Since in Chapter VI the rice plants were grown under 1 cm. of water of submergence at water-logging, it may be possible that the lack of significance in the differences in th top performance under the two moisture levels was due to the low height of submergence at water-logging. It may also be connected with root development and the translocation of nutrients from the roots to the shoots under the two moisture levels.

Furthermore, there may be a temptation for rice farmers to transplant seedlings into fields which had been swampy and muddy for a considerable length of time. The

effect of such conditions existing prior to transplanting has not been studied in any detail up to date but the degree of chemical reduction existing in the soil prior to cropping is likely to affect rice performance. Similarly, the length of time during which the soil is kept fallow at "upland" soil moisture levels may also affect nutrient metabolism.

Thus in the present chapter of this work, the dry-matter yields, and nitrogen, phosphorus and potassium uptake by rice plants (tops and roots) are studied (A) under different heights of water of submergence and (B) for different lengths of wet storage at "upland" moisture level and at water-logging prior to cropping.

(A) The effect of height of water of submergence during growth in pots on the performance of rice plants.

Materials.

Soil 1 (Harlington soil) and Soil 2 (Garden soil) whose properties are shown in Table 4 and in Fig. 1 and Fig. 2 were used in this study. The air-dry 2 mm.-sieved soils taken from top 6" were mixed with acid-washed silver sand in the ratio soil : sand of 1 : 3.

The chemical characteristics (oven-dry basis) were:

Soil	%C	%N	Available P_2O_5 p.p.m.	Available K_2O p.p.m.
1	1.32	0.14	47	168
2	3.50	0.44	118	324

Experimental methods.

300 g. of the soil/sand mixture hereafter referred to as soil was weighed into plastic pots whose drainage holes were covered with glass cloth. Seven rice seeds were sown in each pot and the pot placed in a tub of distilled water until the soil was well soaked. The pots were left in the greenhouse (temperature 25° to 30°C) and adequately watered until the seeds germinated and the seedlings were 18 days old.

The inside wall of the pot was calibrated at 0, 1, 3 and 5 cm. above the soil surface and the drainage hole was plugged with a rubber bung. For another eight weeks, the soil was submerged under water maintained at 0, 1, 3 and 5 cm. above the soil surface.

At the end, the tops of the plants were cut, and the soil washed off the roots. The tops and roots were dried in a steam oven for 24 hours, separately weighed and ground in a mill. The total nitrogen, phosphorus and potassium uptake and hence the percentage contents of these nutrients were determined (analysis by the salicylic acid modified wet digestion method).

Dry-matter yields and nutrient uptake.

(i) Results.

N.B. All increases and decreases in the dry-matter yields or nutrient uptake mentioned in the results and discussion are significant at 5% level.

Dry-matter yields.

The dry-matter yields of rice plants grown in soil 1 and soil 2 submerged under different heights of water are shown in Table 35 and Fig. 50.

In soil 1, the top, root and total dry-matter yields increased with increasing height of water from 0 cm. to 1 cm., remained constant with increase in height of water to 3 cm. and then greatly increased with a further increase in height of water to 5 cm. Top yields were always significantly higher than root yields.

In soil 2, top dry-matter yields were constant as height of water increased from 0 cm. to 3 cm. but was higher at 5 cm. than at 0 cm. or 1 cm. of water. The root and total dry-matter yields increased with increasing height of water. Whilst root dry-matter yields were significantly lower than top dry-matter yields at 0 cm., they were significanlty higher at 3 cm. and 5 cm. of water.

Nitrogen uptake.

The nitrogen uptake by rice plants grown in soil 1 and soil 2 submerged under different heights of water is shown in Table 36 and Fig. 51.

In soil 1, the nitrogen uptake by tops, roots and whole plant increased with increasing height of water from 0 cm. to 1 cm., remained constant to 3 cm. and then increased with a further increase in height of water to 5 cm. Nitrogen

uptake by the tops was significantly higher than the nitrogen uptake-by the roots.

In soil 2, the nitrogen uptake by the tops was similar at heights of water 1 cm. to 5 cm. and decreased at 0 cm., whilst the nitrogen uptake by the roots and by the whole plants increased with increasing height of water. The nitrogen uptake by the roots was significantly lower at 0 cm. and 1 cm. and higher at 3 cm. and 5 cm. of water than the nitrogen uptake by the tops.

Phosphorus uptake.

The phosphorus uptake is shown in Table 37 and Fig. 52.

In soil 1, the phosphorus uptake by the tops was similar up to 3 cm. of water and then increased under 5 cm. The uptake by the roots and whole plant however, increase with increasing moisture level, the uptake by the roots being always lower than the uptake by the tops.

In soil 2, phosphorus uptake by the tops was also similar up to 3 cm. of water and increased under 5 cm., whilst the uptake by the roots and the whole plants increased with increasing height of water up to 3 cm. and remained constant to 5 cm. The phosphorus uptake by the roots was lower at 0 cm. and higher at 1 cm. to 5 cm. of water than the uptake by the tops.

Potassium uptake.

The potassium uptake is shown in Table 38 and Fig. 53.

TABLE 35.

Dry-matter yields (mg./pot) of rice plants grown in soils 1 and 2 submerged under different heights of water.

SOIL 1						
cm. of water above soil surface	0	1	3	5	L.S.D.	
					at 5%	at 1%
Tops	571	631	622	1014	48	70
Roots	246	366	399	855		
TOTAL	817	997	1021	1869	100	165
SOIL 2						
Tops	760	739	836	939	127	185
Roots	369	795	1075	1714		
TOTAL	1129	1534	1911	2653	245	406

TABLE 36.

Nitrogen uptake (mg./pot) by rice plants grown in soils 1 and 2 submerged under different heights of water.

SOIL 1						
cm. of water above soil surface	0	1	3	5	L.S.D.	
					at 5%	at 1%
Tops	7.2	8.3	8.3	13.0	0.5	0.8
Roots	2.8	3.7	3.9	5.6		
TOTAL	10.0	12.0	12.2	18.6	1.7	2.9
SOIL 2						
Tops	9.1	9.9	10.2	10.5	0.7	1.0
Roots	4.9	6.8	11.8	15.0		
TOTAL	14.0	16.7	22.0	25.5	1.2	2.0

Fig. 50: DRY-MATTER YIELDS OF RICE PLANTS GROWN IN TWO SOILS SUBMERGED UNDER DIFFERENT HEIGHTS OF WATER IN POTS.

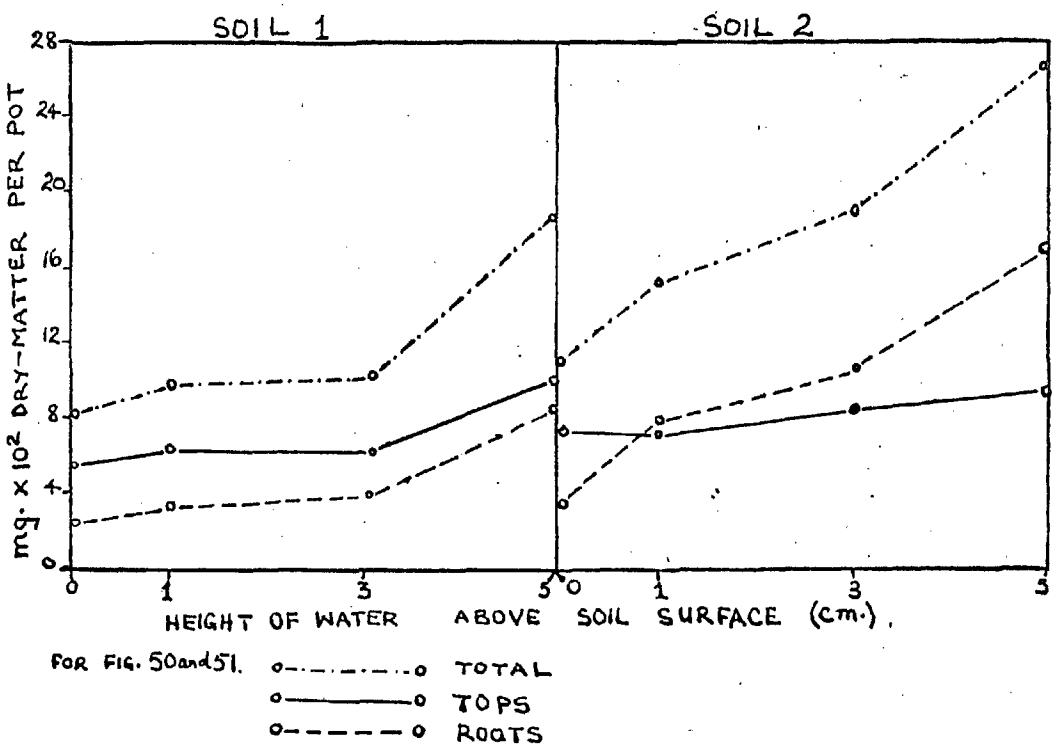
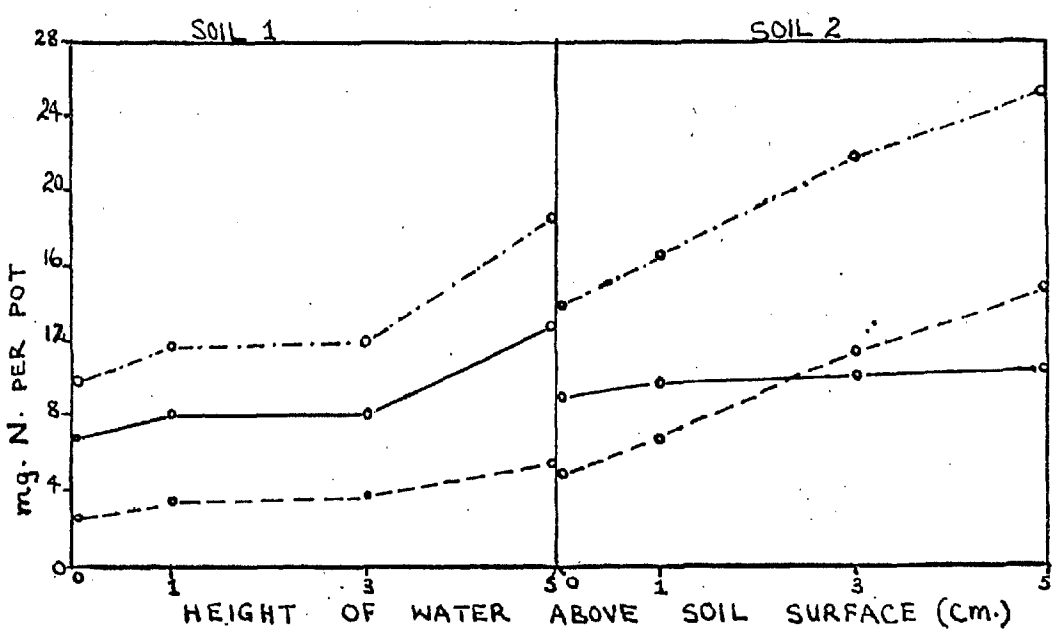


Fig. 51: NITROGEN UPTAKE BY RICE PLANT GROWN IN TWO SOILS SUBMERGED UNDER DIFFERENT HEIGHTS OF WATER IN POTS.



In soil 1, the potassium uptake by the tops, roots and whole plants increased with increasing height of water from 0 cm. to 1 cm., remained constant to 3 cm. and then increased with a further increase in height of water to 5 cm. The uptake by the roots was much lower than the uptake by tops.

In soil 2, the potassium uptake by the tops was similar at 0 cm. and 1 cm. of water, increased to similar levels under 3 cm. and 5 cm., whilst the uptake by the roots and the whole plants increased with increasing height of water. The uptake by the roots was much lower than the uptake by the tops.

Generally, dry-matter yields, nitrogen, phosphorus and potassium uptake followed similar trends in their relationship with the height of water of submergence, being lowest at 0 cm. and highest at 5 cm. of water. Dry-matter yields and nitrogen and phosphorus uptake by the tops were higher than those by the roots under all heights of water in soil 1 but were higher at the lower heights of water and lower at the greater heights of water than those by the roots in soil 2. Potassium uptake by the tops was, however, higher than that by the roots at all heights of water in both soils.

(ii) Discussion.

The general increase in dry-matter yields and nutrient uptake with increase in the height of water of submergence in both soils indicates that the height of water of submergence of rice soils definitely improves rice performance. Jones (1933)

TABLE 37.

Phosphorus uptake (mg. P_2O_5/pot) by rice plants grown in soil 1 and soil 2 submerged under different heights of water.

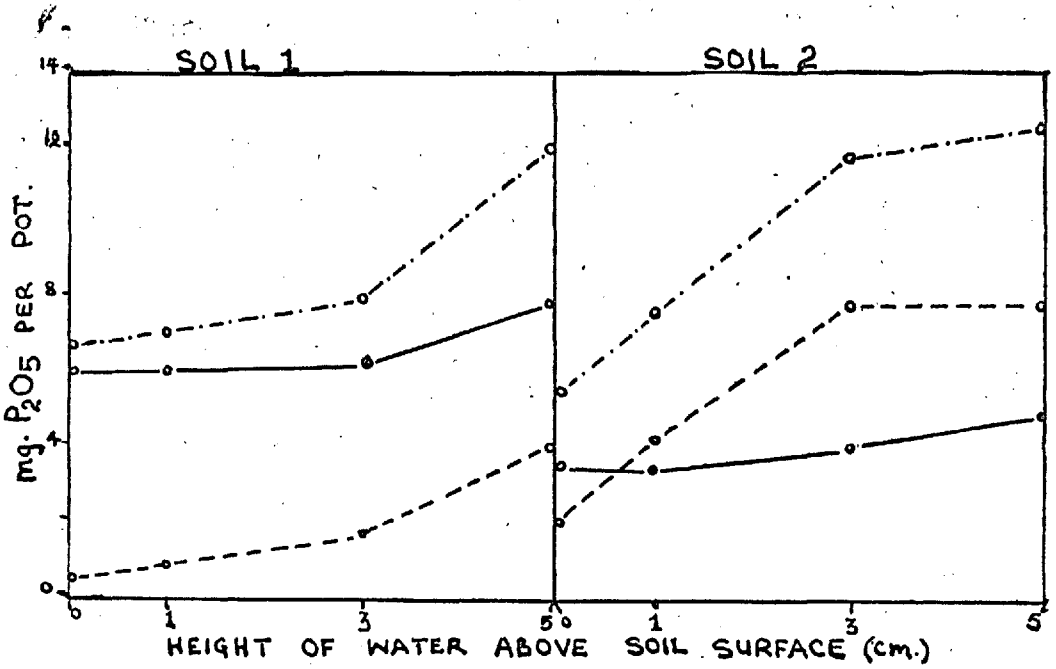
SOIL 1						
cm. of water above soil surface	0	1	3	5	L.S.D. at 5%	L.S.D. at 1%
Tops	6.2	6.1	6.3	7.9	0.3	0.5
Roots	0.6	1.0	1.8	4.1		
TOTAL	6.8	7.1	8.1	12.0	0.6	1.1
SOIL 2						
Tops	3.6	3.5	4.0	4.8	0.5	0.8
Roots	2.0	4.2	7.8	7.7		
TOTAL	5.6	7.7	11.8	12.5	1.0	1.6

TABLE 38.

Potassium uptake (mg. K_2O/pot) by rice plants grown in soil 1 and soil 2 submerged under different heights of water.

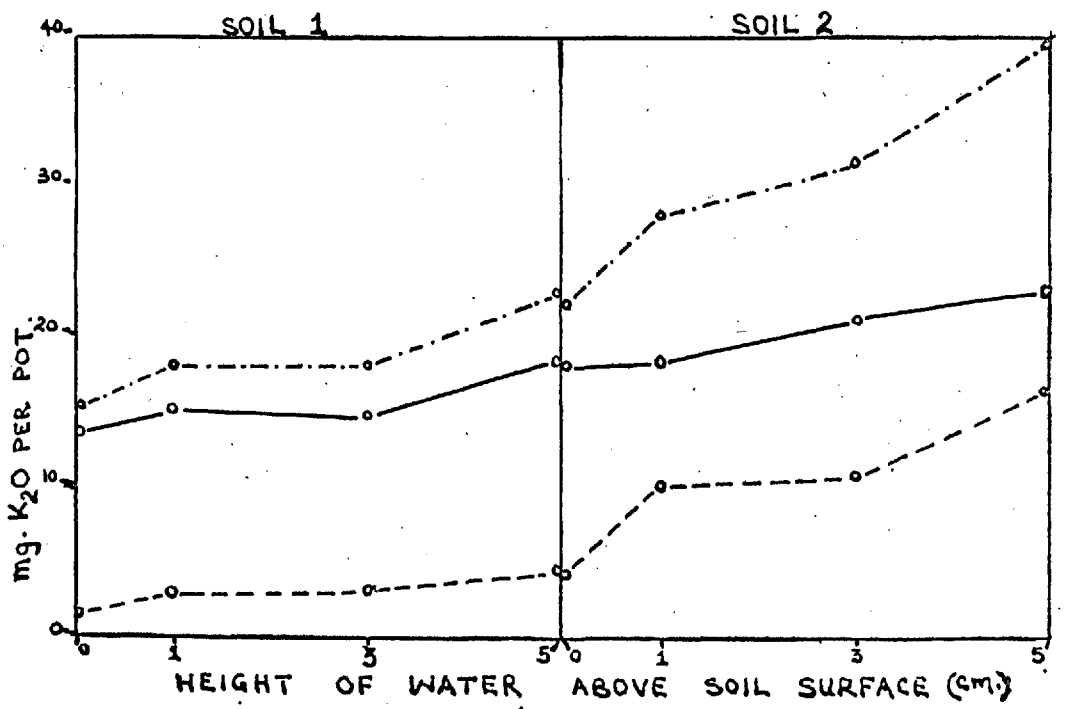
SOIL 1						
cm. of water above soil surface	0	1	3	5	L.S.D. at 5%	L.S.D. at 1%
Tops	13.8	15.3	14.9	18.5	0.7	1.1
Roots	1.6	3.1	3.3	4.5		
TOTAL	15.4	18.4	18.2	23.0	1.4	2.4
SOIL 2						
Tops	18.0	18.3	20.9	23.2	1.9	2.8
Roots	4.0	9.9	10.5	16.3		
TOTAL	22.0	28.2	31.4	39.5	2.5	4.2

Fig. 52: PHOSPHORUS UPTAKE BY RICE PLANTS GROWN IN TWO SOILS SUBMERGED UNDER DIFFERENT HEIGHTS OF WATER IN POTS.



FOR FIG. 52 and 53 o-·-·-·-o TOTAL
o——— o TOPS
o- - - - - o ROOTS

Fig. 53: POTASSIUM UPTAKE BY RICE PLANTS GROWN IN TWO SOILS SUBMERGED UNDER DIFFERENT HEIGHTS OF WATER IN POTS.



used flooding to control weeds (barn-yard grass) in rice fields and obtained the poorest yields when the soil was in a "mucky" condition, and best yields under 10 inches of submergence.

Since weeds were absent in this study, the improved yields under high compared with low water of submergence must be due mainly to the effect which the water has on the physiological conditions in which the rice was grown. Alberda (1953) after reviewing work on this subject concluded that rice was able to grow in a soil containing hardly any oxygen and that the oxygen necessary for the roots was transported thrcugh the plant itself by means of large air-spaces mainly in the leaf sheaths and roots (root aerenchyma). Alberda (1953) also found that rice plants developed a superficial mat of fine abundantly branched roots at the surface of the soil which obtained oxygen from the surface of the soil and transported it to the roots below.

Apparently, these peculiarities in the root respiration of rice plants are adaptations to combat the limited oxygen supply in the water-logged soil. Logically, they should be adopted by rice plants irrespective of the height of water of submergence once the soil is submerged. These respiratory adaptations may therefore not explain the differences in the performance of rice at water-logging under different heights of water. In fact, the mere fact that they are adaptations to combat limited oxygen supply should at least prevent yields increasing under

water-logging compared with "upland" moisture levels where oxygen is in less limited supply.

The cause of better performance of rice with increasing height of water of submergence must be sought in factors other than the respiratory adaptations. Greene (1960) showed that the supernatant water standing above the water-logged rice soil surface had a higher redox potential than the soil below. Alberda (1953) showed that the redox potential of the soil remained constant during the growth of the matted roots mentioned above for a given height of water of submergence. Although Alberda (1953) did not show that it was different for different heights of water of submergence, . . a presumption that this may be the case may help to throw light on the phenomenon of better rice performance with increasing height of water of submergence.

Thus with this assumption, it may be argued that increasing the height of submergence increases the degree of reduction in the soil. Greater phosphorus mobilization, (Shapiro (1958)), increased ammonia accumulation (Kapp (1933)) and increased anaerobic processes will result. Since rice is "ammophile" (i.e. prefers ammonia-N to nitrate-N) (Shibuya et. al. (1935) and is capable of utilizing ethyl alcohol (Alberda (1953)), greater degree of reduction in the soil should stimulate greater performance of the crop. In addition to these factors, it is possible that increased anaerobiosis might result in increasing production of growth promoting substances.

Thus the factors which cause increased rice yields and nutrient uptake with increasing height of water of submergence and indeed under water-logging compared with "upland" moisture conditions are probably not derived directly from the respiratory adaptions of rice plants under water-logging but presumably arise from the degree of reduction of the soil under flooding and associated processes which are not fully understood.

The chemically extractable phosphorus and potassium of soil 1 was lower than that of soil 2 and the differences in the total dry-matter yields and nutrient uptake between the two soils were more pronounced under the greater heights of water of submergence than under the smaller heights. This emphasizes the importance of the height of water of submergence in the stimulation of crop performance as determined by the availability of nutrients. The differences between the two soils under 5 cm. of water seem to be at a minimum in phosphorus uptake, since phosphorus might have been equally mobilized in the two soils.

While root yields and the uptake of the nutrients were invariably lower than those of the tops in soil 1, the reverse was the case at the greater heights of water of submergence in soil 2, except for potassium uptake which was the same as in soil 1. It seems that when the nutrient level is high, in the original soil or as a result of increasing the height of water of submergence, dry-matter yields and especially phosphorus uptake by the roots tend to increase relative to those of the tops.

Thus as the height of water increased, yields and phosphorus uptake by the roots became higher than those by the tops from the water height of 1 cm. to 5 cm. in soil 2 which had originally higher nutrient status than soil 1. Also when the height of water was 5 cm., there was a tendency for root dry-matter yields and phosphorus uptake to approach values similar to those of the tops in soil 1.

The difference in the root and top uptake of potassium compared with the uptake of other nutrients in soil 2 may be due to the ease with which potassium is translocated to the tops from the roots compared with that with which nitrogen and especially phosphorus is translocated. Foster and Russell (1958) suggested an indirect interaction of iron with phosphate in the rice root resulting in the retention of phosphorus in the roots. Ohira (1955) reported that this retention of phosphorus in the root increased with increasing concentration of soluble iron in the culture medium. Thus phosphorus is less easily translocated than potassium from roots to tops under water-logging, where the anaerobic conditions stimulate the production of soluble ferrous iron and phosphorus, which are both taken up by the roots and immobilized there by interacting.

Nutrient % in the plant.

(i) Results.

The nitrogen % of tops, roots and whole plants of rice grown under different heights of water of submergence is

shown in Table 39 and Fig. 54.

In soil 1, the nitrogen % of the tops was more or less similar under all heights of water while that of the roots decreased with increasing height of water.

In soil 2, the nitrogen % of tops also remained constant under all heights of water except under 1 cm. where it was increased. The nitrogen % of the roots decreased with increasing height of water from 0 cm. to 1 cm. increased to 3 cm. and decreased again as the height of water increased to 5 cm.

Generally in soils 1 and 2, the nitrogen % of the whole plants decreased with increasing height of water from 0 cm. to 1 cm., remained constant to 3 cm. and decreased with a further increase in height of water to 5 cm. The nitrogen % of roots was lower than that of tops except in soil 2 under 0 cm. of water.

The phosphorus % is shown in Table 40 and Fig. 55. In soil 1, the phosphorus % of the tops decreased with increasing height of water from 0 cm. to 1 cm., remained constant to 3 cm. and then decreased under 5 cm. of water. The phosphorus % of the roots, however, increased with increasing height of water, and was lower than that of the tops. The phosphorus % of the whole plants decreased with increasing height of water from 0 cm. to 1 cm., increased under 3 cm. and finally decreased under 5 cm. of water.

In soil 2, the phosphorus % of the tops and of the whole plants was similar under all heights of water except under 3 cm. where the phosphorus % of the whole plants was increased. That of the roots was constant under 0 cm. and 1 cm., increased under 3 cm. and decreased under 5 cm. of water but was generally higher than the phosphorus % of the tops.

The potassium % is shown in Table 41 and Fig. 56. In soil 1, the potassium % of the tops, roots and whole plants decreased only under 5 cm. of water.

In soil 2, the potassium % of the tops was similar under all heights of water whilst that of the roots increased under 1 cm. compared with under all other heights of water. The potassium % of the whole plants generally decreased with increasing height of water.

For both soils the potassium % of the roots was lower than that of the tops.

(ii) Discussion.

The general decrease in nutrient content of the whole plants may be due to dilution by increased dry-matter yields.

The differences in nitrogen and in potassium content between tops and roots may be due to the ease with which these nutrients are translocated from the roots to the tops. This is particularly so since these differences were not related to dry-matter yields.

TABLE 39.

Percentage nitrogen in rice plants grown in soils 1 and 2 submerged under different heights of water.

SOIL 1						
cm. of water above soil surface	0	1	3	5	L.S.D. at 5%	L.S.D. at 1%
Tops	1.26	1.31	1.34	1.28	0.07	0.10
Roots	1.14	1.02	0.98	0.66		
Whole plants	1.23	1.20	1.20	1.00	0.06	0.09
SOIL 2						
Tops	1.19	1.34	1.22	1.13	0.10	0.14
Roots	1.33	0.86	1.10	0.88		
Whole plants	1.24	1.09	1.15	0.96	0.11	0.18

TABLE 40.

Percentage P_2O_5 in rice plants grown in soils 1 and 2 submerged under different heights of water.

SOIL 1						
cm. of water above soil surface	0	1	3	5	L.S.D. at 5%	L.S.D. at 1%
Tops	1.10	0.98	1.01	0.78	0.06	0.09
Roots	0.23	0.26	0.45	0.48		
Whole plants	0.83	0.72	0.78	0.65	0.06	0.09
SOIL 2						
Tops	0.47	0.47	0.48	0.51	0.07	0.09
Roots	0.55	0.53	0.73	0.45		
Whole plants	0.50	0.50	0.62	0.47	0.07	0.11

TABLE 41.

Percentage K_2O in rice plants grown in soils 1 and 2 submerged under different heights of water.

SOIL 1						
cm. of water above soil surface	0	1	3	5	L.S.D.	
					at 5%	at 1%
Tops	2.43	2.43	2.40	1.83	0.16	0.23
Roots	0.65	0.85	0.83	0.53		
Whole plants	1.89	1.85	1.79	1.23	0.15	0.27
SOIL 2						
Tops	2.38	2.48	2.50	2.48	0.12	0.17
Roots	1.08	1.25	0.98	0.95		
Whole plants	1.95	1.84	1.65	1.59	0.12	0.20

FOR FIG. 54, 55, 56 o——o TOPS, o- - - -o ROOTS, o·····o WHOLE PLANTS

Fig. 54: PERCENTAGE NITROGEN IN RICE PLANTS GROWN IN TWO SOILS SUBMERGED UNDER DIFFERENT HEIGHTS OF WATER IN POTS.

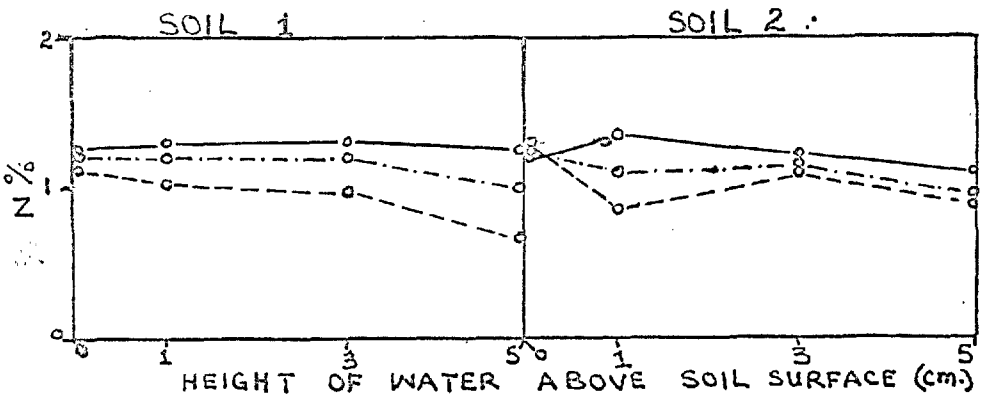


Fig. 55: PERCENTAGE PHOSPHORUS IN RICE PLANTS GROWN IN TWO SOILS SUBMERGED UNDER DIFFERENT HEIGHTS OF WATER IN POTS.

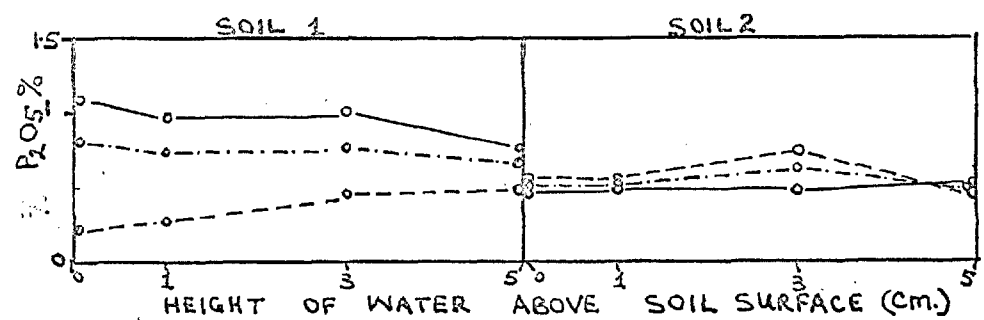
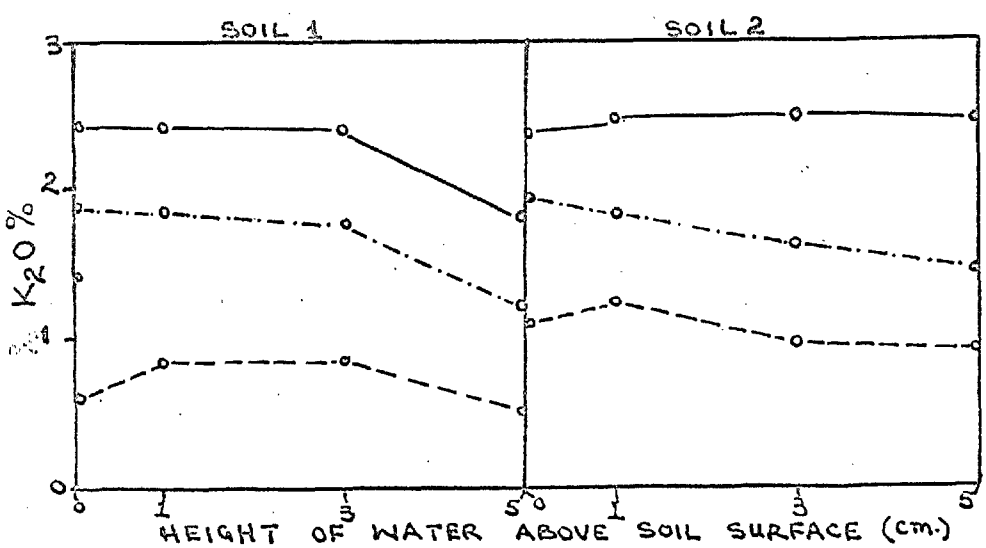


Fig. 56: PERCENTAGE POTASSIUM IN RICE PLANTS GROWN IN TWO SOILS SUBMERGED UNDER DIFFERENT HEIGHTS OF WATER IN POTS.



The higher phosphorus % of the roots than that of the tops in soil 2 must be related to the fact which has already been discussed, that due to the possible precipitation of iron and phosphorus in the root under anaerobic conditions (Ohira (1955)) the phosphorus % of the roots is higher than that of the tops. This was not observed for soil 1 where, nevertheless, the phosphorus % of the roots increased with increasing height of water. Thus in both soils more phosphorus was retained per gram of root material as the height of water increased, causing greater iron and phosphorus mobilization in the soil.

Generally, the nutrient content of the tops was more or less similar under all heights of water and it would seem that the differences in the nutrient content of the whole plants were produced by differences in the nutrient content of the roots. Thus roots play an important role in metabolism of nutrients by rice as studied under different heights of water of submergence.

(B) The effect of length of period of storage under "upland" moisture and water-logged conditions prior to cropping on the performance of transplanted rice seedlings.

Materials.

Soil 1 (Harlington soil) whose properties are shown in Tables 3 and 4 and in Fig. 1 as well as under (A) of the present chapter was used for this study. The air-dry 2 mm.-sieved soil which had been taken from the top 6" was mixed with

acid-washed silver sand in the ratio soil : sand of 1 : 3.

Experimental method.

Nine weeks before the rice seedlings were to be transplanted, 300 g. lots of the soil/sand mixture (hereafter referred to as the soil) were weighed into 16 plastic pots. The drainage holes of 8 pots had been covered with glass cloth and those of the other 8 pots were closed with rubber bungs.

At the beginning, and then every three weeks, duplicate pots were brought to 50% of the maximum water holding capacity (from those pots whose drainage holes were covered with glass cloth) and to water-logging (under 5 cm. of water of submergence from those pots whose drainage holes were closed with rubber bungs). All pots were placed on the table in the laboratory and the moisture levels maintained by adding appropriate amounts of water every day after weighing.

Three weeks before the date of transplanting rice seeds were sown in a tray of soil and watered adequately until they germinated and the seedlings were about 16 days old.

Thus prior to transplanting the rice, the soils in the pots had been maintained at "upland" moisture level (50% maximum water holding capacity) and water-logging (submerged below 5 cm. of water) for 9, 6, 3 and 0 weeks.

Seedlings of uniform size were transplanted at the rate of five per pot spaced evenly in the soil. The moisture

levels were maintained and the seedlings allowed to grow for four weeks. Duplicate bunches of five equally uniform seedlings were selected from the nursery during transplanting and their tops separated from the roots. The tops and roots were dried in a steam oven for 24 hours , weighed and stored for future analysis.

At the end of 4 weeks growth of the transplanted seedlings, the tops were cut and the soil washed off the roots. Roots and tops were dried in a steam oven for 24 hours and weighed.

All tops and roots including those of the seedlings dried at transplanting were ground in a mill and analysed for nitrogen, phosphorus and potassium by the salicylic acid modified wet digestion method. Values of dry-matter yields, nitrogen, phosphorus and potassium obtained for the seedlings dried at transplanting were subtracted from the values for the seedlings which were transplanted into the treated soil samples.

(i) Results.

N.B. All increases and decreases in dry-matter yields and nutrient uptake mentioned in the results and discussion are significant at 5% level.

Dry-matter yields.

The dry-matter yields of rice seedlings grown in pots in the soil maintained at "upland" moisture level and water-logging for different lengths of time prior to and during cropping are shown as part of Table 42 and in Fig. 57.

TABLE 42.

Dry-matter yields and uptake of nitrogen, phosphorus and potassium by rice seedlings grown in soil 1 which had been maintained at "upland" moisture and water-logged conditions for different lengths of time before cropping.

DRY-MATTER YIELDS (mg./pot)						
Length of time (wks.)	Moisture levels					
	"upland" (50% m.w.h.c.)			Water-logged (under 5cm. water)		
	Tops	Roots	Total	Tops	Roots	Total
0	332	254	586	443	606	1049
3	298	264	562	446	679	1125
6	193	249	442	348	784	1132
9	206	199	405	248	124	372
N UPTAKE (mg./pot)						
0	6.9	2.8	9.7	8.4	5.1	13.5
3	1.9	1.9	3.8	5.3	4.3	9.5
6	1.1	1.1	2.2	3.1	5.8	8.9
9	1.0	1.7	2.7	2.0	1.0	3.0
P_2O_5 UPTAKE (mg./pot)						
0	8.5	1.0	9.5	4.8	10.2	15.0
3	6.0	0.9	6.8	3.0	8.4	11.4
6	5.0	0.9	6.0	1.1	8.0	9.4
9	3.7	0.7	4.4	1.2	1.9	3.1
K_2O UPTAKE (mg./pot)						
0	13.3	2.6	15.9	22.1	2.9	25.0
3	9.7	3.9	13.6	16.1	8.9	25.1
6	6.0	1.8	7.9	3.8	7.0	10.8
9	6.8	3.9	10.7	8.9	0.9	9.8

L.S.D. for	Yields		Nitrogen		Phosphorus		Potassium	
	at 5%	at 1%	at 5%	at 1%	at 5%	at 1%	at 5%	at 1%
Tops and Roots	214	295	1.7	2.3	2.0	2.7	2.2	3.0
Total (Tops+Roots)	219	307	2.9	4.2	2.9	4.2	4.9	7.1

DRY-MATTER YIELDS AND NITROGEN UPTAKE BY RICE SEEDLINGS GROWN IN SOIL MAINTAINED AT TWO MOISTURE REGIMES FOR DIFFERENT LENGTHS OF TIME PRIOR TO CROPPING.

Fig. 57: DRY-MATTER YIELDS.

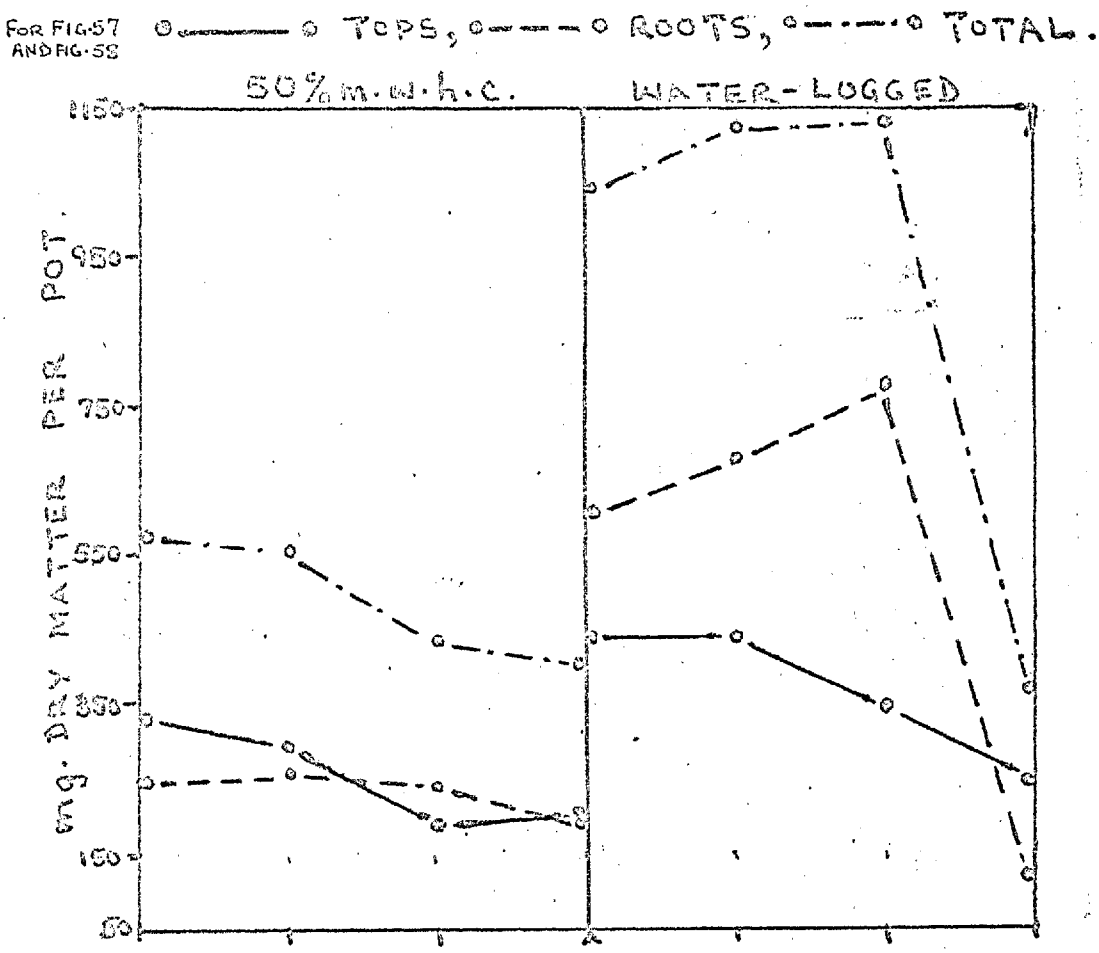
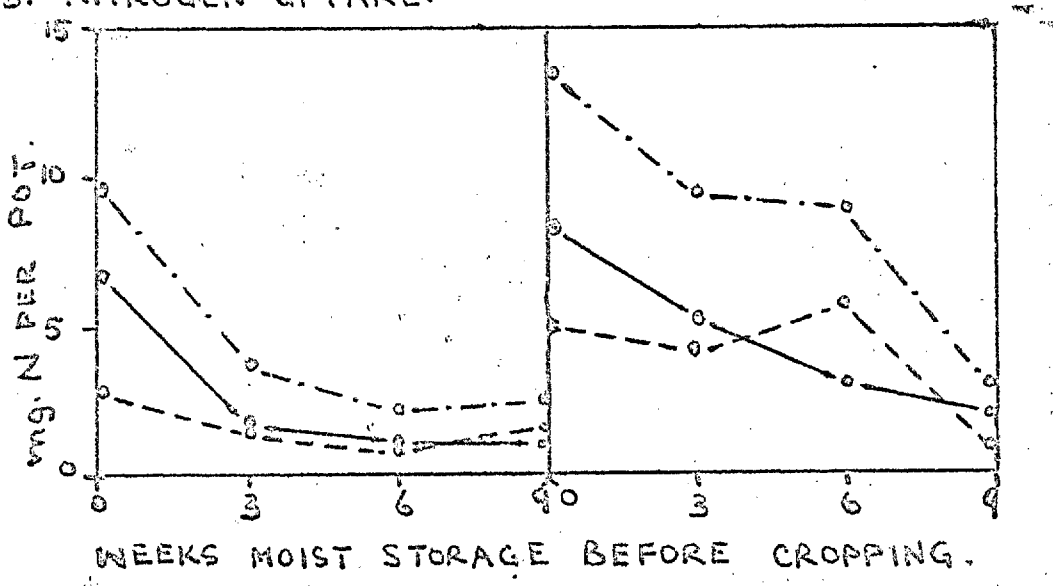


Fig. 58: NITROGEN UPTAKE.



PHOSPHORUS AND POTASSIUM UPTAKE BY RICE SEEDLINGS GROWN IN SOIL MAINTAINED AT TWO MOISTURE REGIMES FOR DIFFERENT LENGTHS OF TIME PRIOR TO CROPPING.

Fig. 59: PHOSPHORUS UPTAKE.

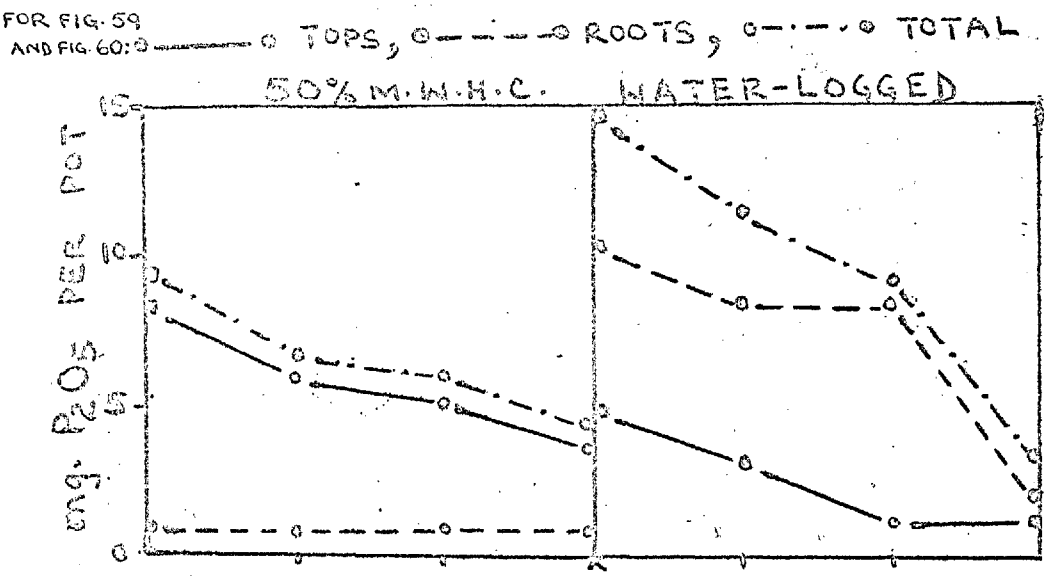
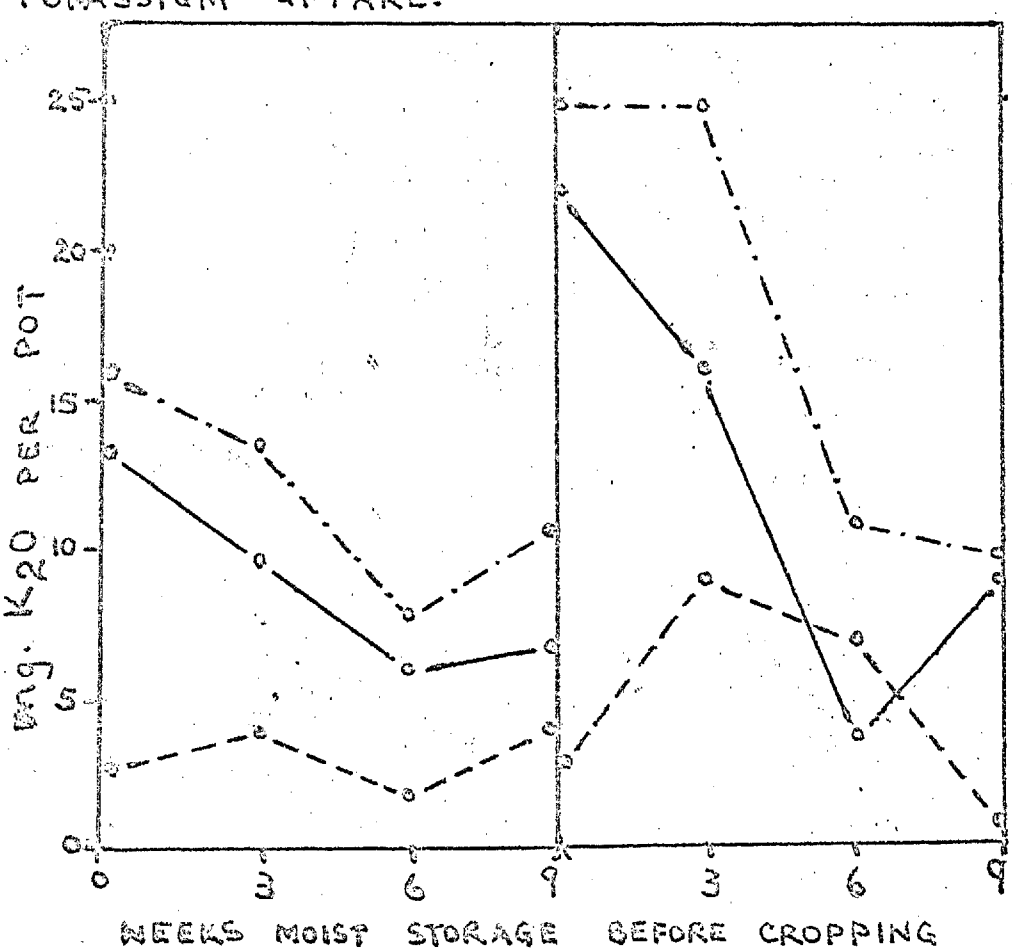


Fig. 60: POTASSIUM UPTAKE.



There were no significant differences in the dry-matter yields between rice tops and roots and between the different times of moist storage when the soil was maintained at "upland" moisture level. When, however, the soil was water-logged prior to and during cropping, dry-matter yields were decreased only when the soil was stored for 9 weeks prior to cropping compared with other times of storage.

Dry-matter yields of rice roots and of whole seedlings were significantly higher when the soil was water-logged than when maintained at "upland" moisture level. Under water-logging, dry-matter yields of roots were significantly higher than those of tops, except when the soil was stored for 9 weeks prior to cropping where root and top dry-matter yields were similar.

Nitrogen uptake.

The nitrogen uptake is shown as part of Table 42 and in Fig. 58.

When the soil was maintained at "upland" moisture level prior to, and during cropping, nitrogen uptake by tops and whole seedlings increased for 0 week storage compared with all other times of storage for which nitrogen uptake was similar. Nitrogen uptake by the roots was however, higher for 0 weeks than for only 6 weeks. The differences in nitrogen uptake between the tops and roots were significant only for 0 week storage, uptake by the tops being higher than uptake by the roots.

When the soil was water-logged prior to and during cropping, the nitrogen uptake by the tops decreased with increasing time of storage and that by the roots and the whole plants decreased with increasing time of storage from 0 week to 3 weeks, remained constant to 6 weeks and then decreased with a further increase in time of storage to 9 weeks. Differences in the nitrogen uptake between the tops and roots were significant only at 0 week and 6 weeks, uptake by the tops being higher than those by the roots.

Nitrogen uptake by the tops, roots and whole seedlings were higher when the soil was water-logged than when maintained at "upland" moisture level, except when it was stored for 9 weeks prior to cropping, when nitrogen uptake was similar at both moisture regimes.

Phosphorus uptake.

The phosphorus uptake is shown as part of Table 42 and in Fig. 59.

When the soil was maintained at "upland" moisture level prior to and during cropping the phosphorus uptake by the tops and whole seedlings increased when storage was for 0 week compared with other times of storage, was constant for 3 and 6 weeks storage and was lower for 9 weeks than for 6 weeks storage. There were no significant differences in phosphorus uptake by the roots between the different times of storage, and for each

time, the phosphorus uptake by the roots was lower than that by the tops.

When the soil was water-logged prior to and during cropping, phosphorus uptake by the tops was similar for 0 week and 3 weeks storage but was lower for 6 weeks and 9 weeks storage than for 0 week storage. The phosphorus uptake by the roots was higher for 0 weeks than for 6 weeks storage, and was lower for 9 weeks than for all other times. There were no significant differences in phosphorus uptake by the roots between 0 week and 3 weeks and between 3 weeks and 6 weeks. For 9 weeks storage phosphorus uptake by the tops and the roots was similar, but for all other times of storage, phosphorus uptake by the roots was higher than that by the tops. The phosphorus uptake by the whole seedlings however, increased with decreasing time of storage.

While the phosphorus uptake by the tops was higher under "upland" moisture level than under water-logging, the phosphorus uptake by the roots was higher under water-logging than under "upland" moisture level. The uptake of phosphorus by the whole seedlings was however higher under water-logging than under "upland" moisture level, except for 9 weeks storage where it was similar at the two moisture regimes.

Potassium uptake.

The potassium uptake is shown as part of Table 42 and in Fig. 60.

The potassium uptake by the tops when "upland" moisture level was maintained decreased with increasing time of storage from 0 week to 6 weeks and remained constant to 9 weeks whilst the potassium uptake by the roots was similar for all times of storage and was always lower than the uptake by the tops.

When the soil was water-logged, the potassium uptake by the tops decreased with increasing time of storage from 0 week to 6 weeks and increased to 9 weeks. Under the same conditions the potassium uptake by the roots increased with increasing time of storage from 0 week to 3 weeks, remained constant to 6 weeks and decreased to 9 weeks.

The uptake of potassium by the whole seedlings was similar for 0 week and 3 weeks storage and decreased to similar levels for 6 weeks and 9 weeks storage, whether "upland" moisture level or water-logging was maintained.

Whole seedlings took up more potassium under water-logging than under "upland" moisture level. Potassium uptake by the tops was higher for 0 week and 3 weeks storage and lower for 6 weeks storage under water-logging than under "upland" moisture level and was similar under both moisture levels for 9 weeks storage. The uptake by the roots, on the other hand, was higher for 3 weeks and 6 weeks storage and lower for 9 weeks under water-logging than under "upland" moisture level and was similar under both moisture levels for 0 week storage.

Thus, generally, the dry-matter yields and nutrient uptake by the whole seedlings increased with decreasing time of storage prior to cropping and were higher under water-logging than under "upland" moisture level except for 9 weeks storage where they were similar under both moisture regimes.

(ii) Discussion.

The better performance (higher dry-matter yields and nutrient uptake) of rice seedlings under water-logging than under "upland" moisture level agrees with the result obtained earlier in Section (A) of the present chapter and by several workers including Shapiro (1958) and Vlamis and Davis (1944).

The generally improving performance of the whole rice seedlings with decreasing time of storage prior to cropping under "upland" moisture conditions may be due to the leaching of nutrients from the top few inches of the soil in the pot to the lower layers. This may be important since water was being added in small amounts on the surface of the soil during storage to maintain the moisture regime and the longer this water addition lasted prior to cropping the more the nutrient was leached. The whole leaching process was probably accentuated by the fact that the soil was diluted with sand which increased its porosity.

This leaching process was not likely to be important under water-logged conditions since water was standing 5 cm. above the soil surface and Greene (1960) indicated that nutrients were

distributed between the soil and supernatant water in rice fields. The improvement in the performance of rice seedlings with decreasing time of water-logged storage must be connected with the degree of reduction in the soil.

While it has been suggested in Section (A) of the present chapter that the degree of reduction or anaerobiosis under a growing rice crop produced by increasing heights of water of submergence may stimulate increased performance of the crop, the degree of reduction or anaerobiosis prior to cropping as indicated by the development of algae (Brizi (1906)) may have different effects on the crop. Alberda (1953) showed that rice plants were oxidative from the seedling stage to the end of the period of tillering after which they became reducing. He also found that the introduction of seedlings into reduced media ameliorated the reduced condition. In the present study, the chances of seven seedlings adequately ameliorating the reduced conditions in the 300 g. soil were probably slim. Thus with increasing degree of reduction due to increasing time of water-logged storage the extent of amelioration by the seedlings probably decreased and so did the performance of the seedlings.

It was also possible that the establishment of the seedlings was hampered by the toxic effects of reduction products such as H_2S and manganous ions and this effect increased with increasing degree of reduction.

These limiting effects of the degree of reduction on the performance of the seedlings seemed extremely important when the soil was water-logged for 9 weeks prior to cropping, with the result that they suppressed the advantageous effect of water-logging compared with "upland" moisture conditions.

The dry-matter yields of the roots under water-logging was higher than those of the tops and higher than those of the roots under "upland" moisture level when the soil was stored no longer than 6 weeks before cropping. Similar differences in dry-matter yields were obtained in Section (A) for soil 2 but not for soil 1 which has been used here. It was supposed that the increased general nutrient level of the original soil or water-logging (Kapp (1934)) might have stimulated increased relative growth of roots. It would, however, seem that while this may be true, the increased relative root growth was a response to reduced conditions by which the adaptation mechanisms for combating limited oxygen supplies were increased (the more root development there was, the more aerenchymatous tissue would be present). The eventual better performance of rice plants under water-logging than under "upland" conditions may lie in this initial excessive root development.

Nutrient % in the seedlings.

(i) Results.

The nitrogen % of rice seedlings (tops, roots and whole seedlings) when grown in the soil maintained at "upland" moisture level or at water-logging prior to and during cropping is shown as part of Table 43 and in Fig. 61.

Generally, the nitrogen % of all parts of the plants decreased with increasing length of storage under both moisture levels from 0 week to 3 weeks and remained more or less constant with a further increase in the time of storage. The nitrogen % of the roots was not different from that of tops except for 0 week storage under "upland" moisture level and for 0 week and 3 weeks storage under water-logging where the nitrogen % of the tops was higher than that of the roots. The nitrogen % of the roots was similar under both moisture levels whilst that of the tops was higher, only for 3 weeks, under water-logging than under "upland" moisture level. For the nitrogen % of the whole seedlings, the reverse was the case but only for 0 week storage.

The phosphorus %, is shown as part of Table 43 and in Fig. 62.

The phosphorus % of the tops under"upland" moisture level decreased with increasing time of storage from 0 week to 3 weeks, increased to 6 weeks and then decreased to 9 weeks, whilst that of the roots and of the whole seedlings was similar for all periods of storage. The phosphorus % of the root was lower than that of the tops.

TABLE 43.

Percentage content of nitrogen, phosphorus and potassium in rice seedlings grown in soil 1 which had been kept at two moisture levels for different lengths of time before cropping.

Length of time (wks.)	Moisture Levels: 50% m.w.h.c. Tops	50% m.w.h.c. Roots	50% m.w.h.c. Whole seedlings	Water-logged Tops	Water-logged Roots	Water-logged Whole seedlings
NITROGEN %						
0	2.09	1.09	1.66	1.91	0.87	1.31
3	0.63	0.71	0.67	1.18	0.63	0.85
6	0.59	0.45	0.50	0.86	0.74	0.78
9	0.49	0.83	0.65	0.76	0.85	0.80
P_2O_5%						
0	2.56	0.39	1.64	1.06	1.75	1.43
3	1.99	0.34	1.22	0.68	1.24	1.02
6	2.61	0.36	1.35	0.30	1.03	0.80
9	1.78	0.36	1.08	0.45	1.56	0.82
K_2O%						
0	4.02	1.06	2.75	5.01	0.48	2.42
3	3.24	1.47	2.41	3.61	1.32	2.23
6	3.16	0.74	1.79	1.06	0.96	0.99
9	3.05	1.98	2.52	3.50	0.66	2.55

L.S.D. for	N% at 5%	N% at 1%	P_2O_5% at 5%	P_2O_5% at 1%	K_2O% at 5%	K_2O% at 1%
Tops and Roots	0.46	0.58	0.57	0.79	0.54	0.74
Whole seedlings	0.31	0.46	0.34	0.49	0.62	0.91

PERCENTAGE NUTRIENTS IN RICE SEEDLINGS GROWN IN SOIL WHICH WAS MAINTAINED AT TWO MOISTURE REGIMES FOR DIFFERENT LENGTHS OF TIME PRIOR TO CROPPING.

Fig. 61: PERCENTAGE NITROGEN.

FOR FIG. 61, FIG. 62 AND FIG. 63: o——o TOPS, o- - - -o ROOTS, o-·-·-·-o WHOLE SEEDLINGS

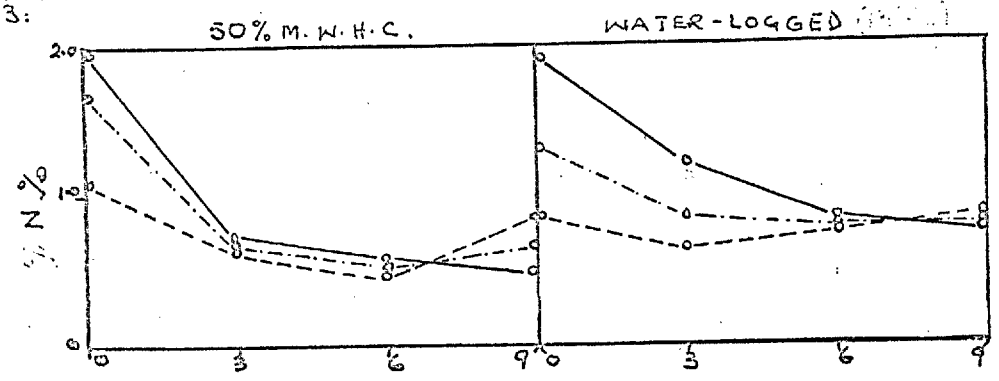


Fig. 62: PERCENTAGE PHOSPHORUS.

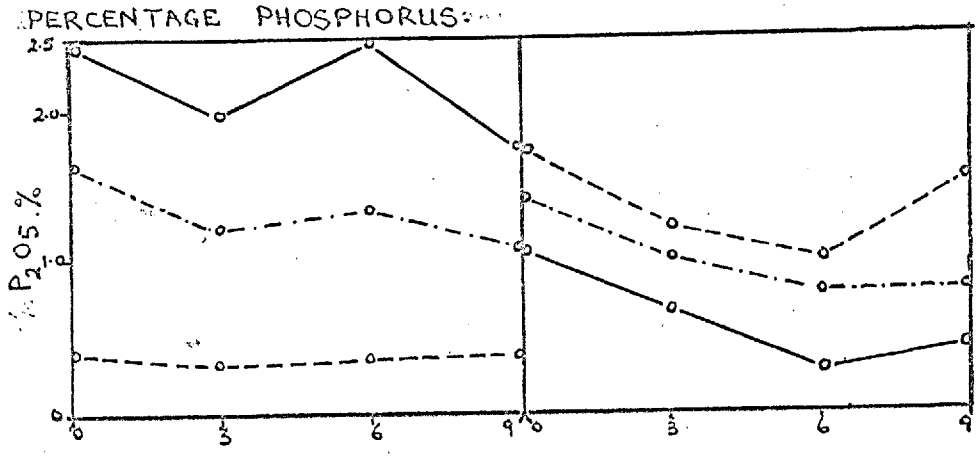
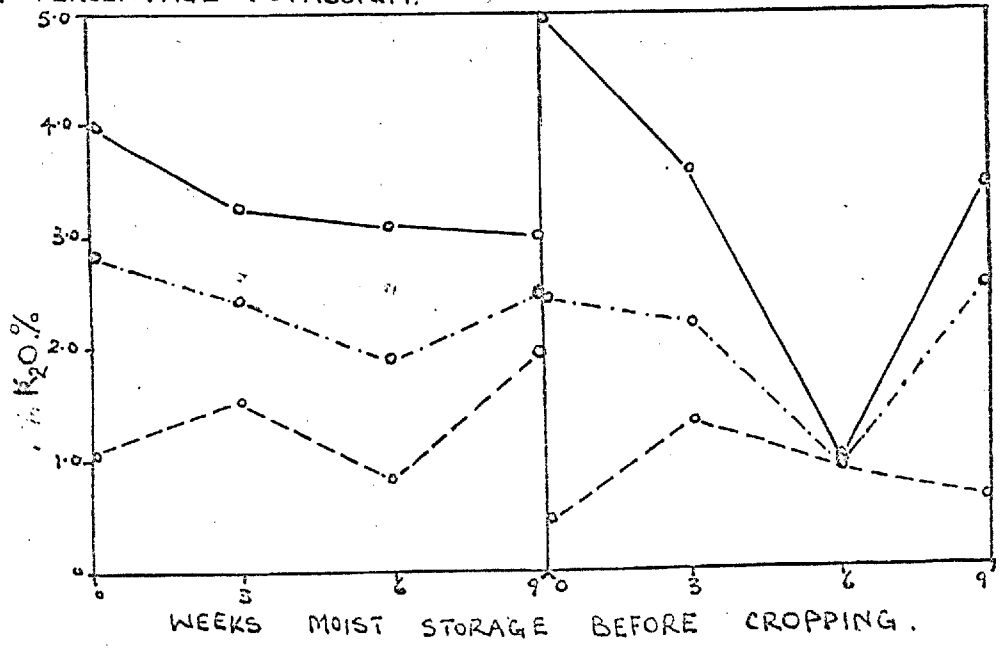


Fig. 63: PERCENTAGE POTASSIUM.



Under water-logging, the phosphorus % of the tops and of the whole seedlings decreased generally with increasing time of storage to similar levels for 6 weeks and 9 weeks storage. That of the roots was lowest for 6 weeks storage and was higher than that of the tops.

The phosphorus % of the tops was lower whilst that of the roots was higher under water-logging than under "upland" moisture level, but that of the whole seedlings was similar under both moisture levels.

The potassium %, is shown as part of Table 43 and in Fig. 63.

Under "upland" moisture level, the potassium % of the tops decreased with increasing time of storage from 0 week to 3 weeks and remained constant with a further increase in time of storage to 9 weeks. The only significant decrease in the potassium % of the roots and of the whole seedlings was for 6 weeks storage when the potassium % of the roots was lower than that of the tops.

Under water-logging, the potassium % of the tops was higher for 0 week storage than for all other times of storage for which a decrease in potassium % occurred only at 6 weeks. A similar decrease at 6 weeks storage also occurred in the potassium % of the whole seedlings whilst the potassium % of the roots first increased with increasing time of storage from 0 week to 3 weeks and then generally decreased to 9

weeks storage. The potassium % of the roots was lower than that of the tops, and that of the whole seedlings under water-logging was similar to that under "upland" moisture level except for 6 weeks storage when the former was lower than the latter.

(ii) Discussion.

The general decrease in the nutrient content of the whole seedlings with increasing time of storage prior to cropping could not be due to dilution since in fact dry-matter yields tended to increase in the opposite direction. It must therefore be connected with the availability of nutrients, and the ability of the seedlings to take up the nutrients.

The first idea may apply to the "upland" moisture condition where due to the leaching of nutrients from the top layers of the soil in the pot to the lower layers, nutrient availability was diminished in the vicinity of the young roots for the short time they grew (4 weeks).

The second idea may apply to the water-logged condition where due to increased degree of reduction in the soil, the metabolic activity of the seedlings were probably reduced and thus reduced the nutrient content.

It may also be argued that since the soil was kept air-dry for different lengths of time before the moist storage treatments were given, these different periods of soil drying might have some effects on nutrient availability. Birch (1958),

(1959) and (1960) has shown that the length of air-dry storage prior to wetting increased nitrogen mineralization.

The general similarity in nitrogen and in potassium contents of the tops under "upland" moisture and water-logged conditions might be due to the ease with which these nutrients were translocated from the roots to the tops. This was confirmed by the lower content of these nutrients in the roots than in the tops.

In the case of phosphorus %, however, phosphorus was translocated easily to the tops from the roots under the "upland" moisture condition, whilst it was largely retained in the roots under the water-logged condition. This was probably due to the fact which has been discussed before that under water-logging, iron and phosphorus were mobilized and both elements reacted in the roots (Ohira (1955) and Foster and Russell (1958)) or on the outer wall of the roots (Greene (1960)) as ferrous iron was oxidized to ferric by the oxygen supplied through root aerenchyma.

General Conclusions.

In the present chapter (A) under different heights (0-5cm.) of water of submergence in soil 1 and soil 2 and (B) under "upland" (50% m.w.h.c.) moisture and water-logged (5 cm. of water) conditions in soil 1 maintained for 0, 3, 6 and 9 weeks prior to cropping and the same moisture regimes maintained during cropping, the dry-matter yields and the uptake of nitrogen, phosphorus and potassium by rice plants grown in pots were studied. The percentage content of the nutrients in the plant tissues was also determined.

1. The dry-matter yields and the uptake of the nutrients by rice plants increased with increasing height of water of submergence. This was presumably due to increased degree of reduction in the soil which transformed the nutrients to forms best utilized by rice.

2. The dry-matter yields and the uptake of the nutrients by rice seedlings increased with decreasing time of wet maintenance prior to cropping. Leaching under "upland" moisture condition and detrimental effects of the degree of reduction prior to cropping on the plant metabolism under water-logging were suggested.

3. Water-logging improved total dry-matter yields and the nutrient uptake compared with "upland" moisture condition but most of the improvement was through yields and nutrient

uptake by the roots. The relative increase in the root contribution to total performance was presumably thought to be a growth response to anaerobic conditions to combat oxygen deficiency.

4. Generally, with increasing height of water of submergence and at water-logging compared with "upland" moisture regime, the phosphorus uptake by and content of, the roots increased This was thought to be due to the precipitation of iron and phosphorus inside and outside the root as mobilized ferrous iron was oxidized to ferric with oxygen supplied by the roots.

5. Thus it might be concluded that water-logging soils under rice would improve the crop performance even when there were no weeds to control. This effect of water-logging was much more pronounced when the height of water of submergence was 5 cm. than when it was less.

6. The results observed indicate that it might not be advisable to water-log the soil for too long a time before transplanting the rice seedlings.

CHAPTER VIII

THE EFFECT OF LENGTH OF PERIOD OF AIR-DRY STORAGE OF SOILS PRIOR TO (A) WETTING AND INCUBATION ON CARBON AND NITROGEN MINERALIZATION AND (B) CROPPING ON THE PERFORMANCE OF RYE-GRASS

Introduction.

Before 1920, much work was done on the effects of heating and drying of soils on their nutrient status. The drying or heating temperatures were usually higher than those which might be expected under natural field conditions. The results obtained under such abnormal conditions could not confidently be related to actual field observations.

More recently, studies of the effect of air-drying soils prior to wetting (a condition which obtains seasonally or periodically under natural field conditions) on the subsequent organic matter decomposition and nutrient status have become important. All these studies were done by wetting the soils to about field capacity moisture regime and most of them in incubation experiments. Results generally showed that air-drying prior to wetting increased organic matter decomposition compared with no drying , and that this effect was accentuated by increasing the time of air-dry storage of the soils. The effects of air-dry storage prior to water-logging on soil nutrient metabolism have not been studied up to date; neither have the effects of air-dry storage of soils prior to cropping on the performance of crops been widely studied.

In the present chapter of this work, (A) carbon and nitrogen mineralization is studied in five soils of different organic carbon and nitrogen contents which were incubated at "upland" moisture level or water-logging after air-dry storage for different lengths of time and (B) the effects of air-dry

storage of three soils for different lengths of time prior to cropping on the performance of rye-grass plants are studied.

(A) The effect of length of period of air-dry storage of soils prior to wetting and incubation on carbon and nitrogen mineralization.

Materials.

Soils 3, 4, 5, 6 and 1 (decreasing order of organic carbon content) whose characteristics are shown in Table 4 and in Fig. 1, 3, and 4 (Chapter II) were used. They were sampled from the top 6", air-dried and ground to pass a 2 mm. sieve.

Experimental method.

10 g. samples of the soils were weighed into test-tubes (6" x 1" internal diameter) and were brought to 50% of the meximum water-holding capacity. A suspension of barium peroxide contained in a glass vial was placed in each tube and all the tubes were incubated for 2 weeks at 28°C. This preliminary incubation was done to eliminate the effect of the different air-dry storage periods of the different soils since sampling.

After the preliminary incubation four samples of each soil were taken, one duplicate was left at 50% of the maximum water-holding capacity and the other duplicate was water-logged (133% m.w.h.c.). These represented no drying or 0 week air-dry storage. The other samples of each soil were air-dried in a greenhouse ($30-35^{\circ}$C).

After every three weeks up to twelve weeks, four samples of each soil were taken, one duplicated brought to 50% m.w.h.c. and the other duplicate water-logged. Thus after 0,3,6, 9, and 12 weeks air-dry storage the soil samples were brought to 50% m.w.h.c. or to water-logging, a suspension of barium peroxide in a glass vial was placed in each test-tube for carbon dioxide determination, and all samples were incubated at 28°C for 3 weeks. Mineralized carbon and nitrogen were then determined.

(N.B. All increases and decreases in carbon and nitrogen mineralization mentioned in the following results and discussion are significant at 5% level).

(i) Results.

Carbon mineralization.

The carbon dioxide (mg. CO_2/10 g. soil basis) evolved when the different soils were wetted and incubated after different periods of air-dry storage is shown in Table 44 and in Fig. 64.

For all soils and periods of air-dry storage prior to wetting, carbon dioxide evolution was significantly higher when incubation was done at 50% m.w.h.c. than at water-logging.

For soil 1 with organic carbon content of 1.32%, during incubation at both moisture levels, carbon dioxide evolution was very similar for all periods of air-dry storage except for a slight increase at water-logging for 3 weeks air-dry storage compared with the other periods.

TABLE 44.

Mineralization of carbon (mg.CO_2/10g. soil) in soils wetted and incubated for 3 weeks after different periods of air-dry storage. (Soils arranged in decreasing order of organic carbon content).

Soil	Total N %	Moisture level during incubation	Period of air-dry storage (weeks)				
			0	3	6	9	12
3	13.90	50% m.w.h.c.	48.7	50.6	56.1	77.0	100.1
		Water-logging	8.7	14.7	19.7	30.1	45.1
4	7.00	50% m.w.h.c.	15.4	17.3	20.0	26.0	40.7
		Water-logging	5.1	7.0	8.8	8.8	9.9
5	3.90	50% m.w.h.c.	12.8	14.0	14.3	16.5	20.9
		Water-logging	4.0	8.8	6.6	10.6	13.0
6	2.93	50% m.w.h.c.	11.0	12.7	12.9	15.2	16.5
		Water-logging	4.0	5.5	6.7	7.9	8.8
1	1.32	50% m.w.h.c.	9.2	9.2	9.5	9.2	9.2
		Water-logging	3.7	5.7	4.8	4.4	4.4

L.S.D. = 1.3 at 5% and 1.7 at 1% levels.

Fig. 64: MINERALIZATION OF CARBON IN SOILS WETTED AND INCUBATED FOR 3 WEEKS AFTER DIFFERENT PERIODS OF AIR-DRY STORAGE.

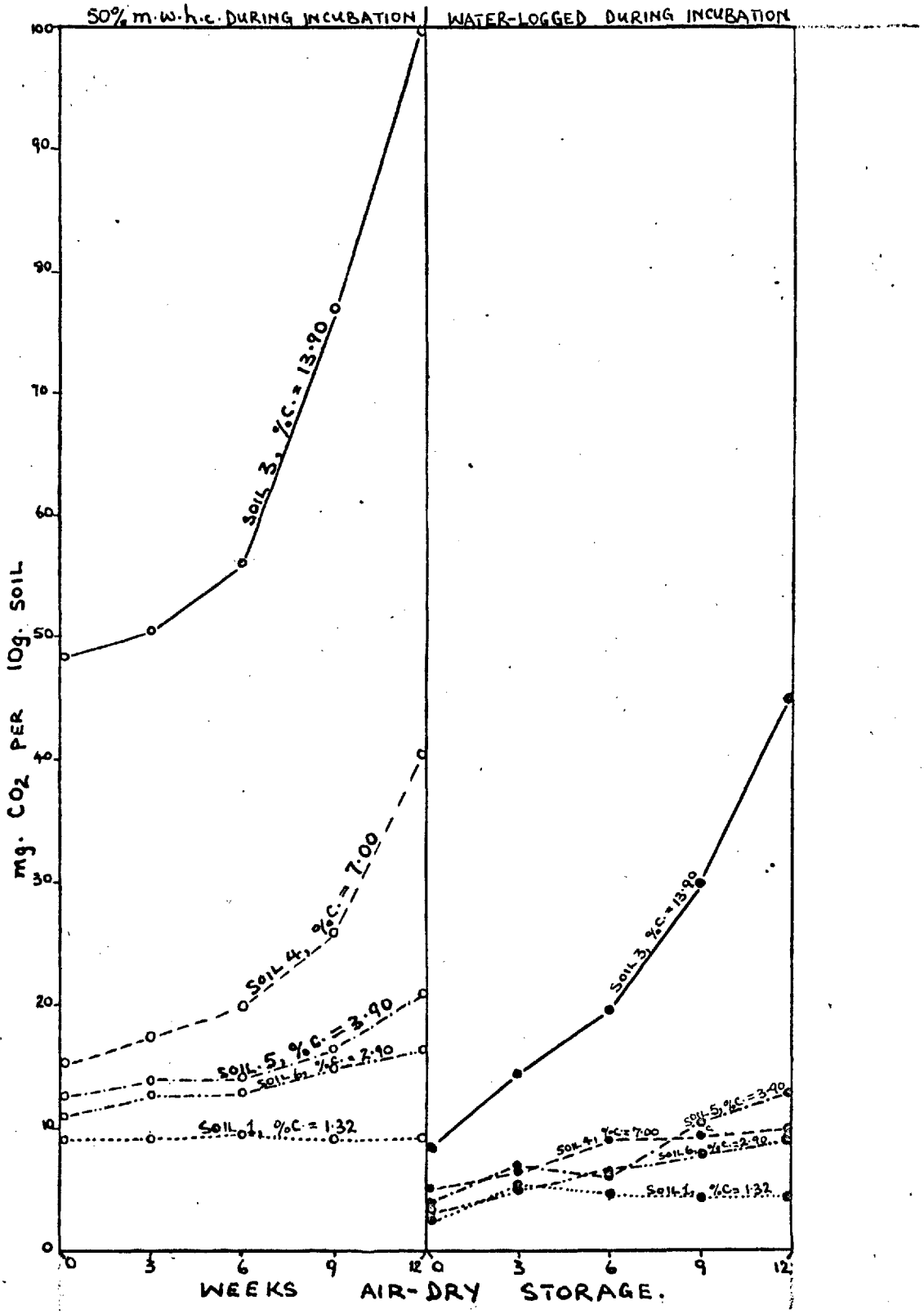


Fig. 65: REGRESSION LINE OF THE LOGARITHM OF THE INCREASE IN CO_2 EVOLUTION DUE TO AIR-DRY STORAGE OF SOILS COMPARED WITH NO DRYING, ON THE PERIOD OF AIR-DRY STORAGE PRIOR TO INCUBATION AT 50% m.w.h.c.

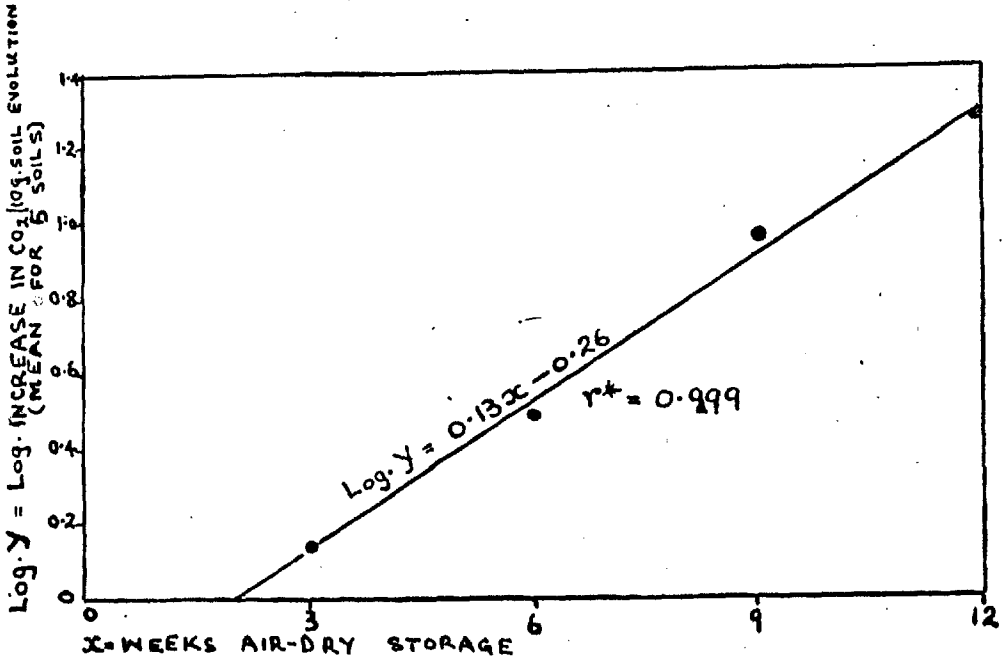
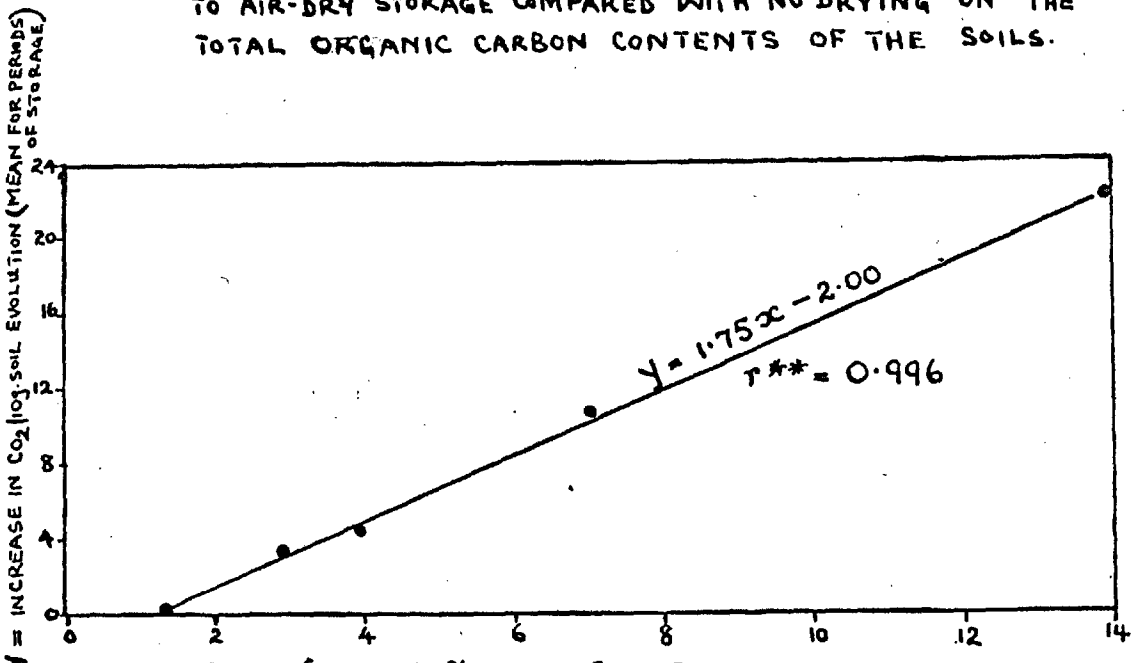


Fig. 66: REGRESSION LINE OF THE INCREASE IN CO_2 EVOLUTION DUE TO AIR-DRY STORAGE COMPARED WITH NO DRYING ON THE TOTAL ORGANIC CARBON CONTENTS OF THE SOILS.



** SIGNIFICANT AT 1% LEVEL.

For all the other soils the significance of the differences in carbon dioxide evolution for the different periods of air-dry storage may be summarized as follows: where weeks air-dry storage represent the respective values of carbon dioxide evolution in descending order of magnitudes and all figures above the same horizontal line are not significantly different from each other but are significantly different from all others.

For soil 3 at 50% m.w.h.c.: 12, 9, 6, 3, 0

For soil 4 at " " 12, 9, 6, 3, 0

For soil 5 at " " 12, 9, 6, 3, 0

For soil 6 at " " 12, 9, 6, 3, 0

For soil 3 at water-logging: 12, 9, 6, 3, 0

For soil 4 at " " " 12, 9, 6, 3, 0

For soil 5 at " " " 12, 9, 3, 6, 0

For soil 6 at " " " 12, 9, 6, 3, 0

For soils with 2.93% or more of organic carbon, carbon dioxide evolution increased with increasing time of air-dry storage prior to wetting whether the soil was incubated at "upland" moisture level or at water-logging.

Carbon dioxide evolution for all periods of air-dry storage also increased generally with increasing organic carbon content, especially when the subsequent incubation was done at "upland" moisture level.

Nitrogen mineralization.

The total nitrogen mineralized (NH_4-N + NO_3-N) in the soils stored air-dry for different periods prior to wetting and incubation is shown in Table 45 and in Fig. 67.

For soils 3, 4, 6 and 1, more nitrogen was mineralized at 50% m.w.h.c. than at water-logging subsequent to air-dry storage. For soil 5, however, the reverse was the case except for 3 and 12 weeks storage, where the differences in nitrogen mineralization at the two moisture levels were non-significant.

At 50% m.w.h.c. the nitrogen mineralization increased with increasing time of air-dry storage for all soils except soil 5 where increases were non-significant until 12 weeks air-dry storage.

At water-logging, the significance of the differences in nitrogen mineralization may be summarised as follows: where the periods of air-dry storage represent the respective values of nitrogen mineralization in descending order of magnitudes.

Soil 3: 12, 9, 6, 3, 0

Soil 4: 12, 9, 3, 6, 0

Soil 5: 12, 9, 6, 0, 3

Soil 6: 12, 9, 6, 0, 3

Soil 1: 12, 9, 0, 6, 3

TABLE 45.

Mineralization of nitrogen (p.p.m. soil basis) in soils wetted and incubated for 3 weeks after different periods of air-dry storage.

Soil	Total N %	Moisture level during incubation	Period of air-dry storage (weeks)				
			0	3	6	9	12
3	2.27	50% m.w.h.c.	994.0	1288.0	1652.0	2156.0	2380.0
		Water-logging	960.0	1218.0	1596.0	1722.0	1852.0
4	1.01	50% m.w.h.c.	243.5	317.8	450.0	521.0	588.0
		Water-logging	73.5	159.5	156.8	165.0	189.0
5	0.50	50% m.w.h.c.	125.3	126.0	129.5	134.0	175.0
		Water-logging	156.3	116.2	151.9	173.0	184.0
6	0.33	50% m.w.h.c.	125.0	149.0	161.0	168.0	175.0
		Water-logging	28.0	0.0	40.0	45.5	48.0
1	0.14	50% m.w.h.c.	71.4	74.4	93.0	103.6	127.0
		Water-logging	30.8	0.0	23.8	38.5	60.0

L.S.D. = 11.3 at 5% and 15.1 at 1% levels.

Fig. 67: MINERALIZATION OF NITROGEN IN SOILS WETTED AND INCUBATED FOR 3 WEEKS AFTER DIFFERENT PERIODS OF AIR-DRY STORAGE

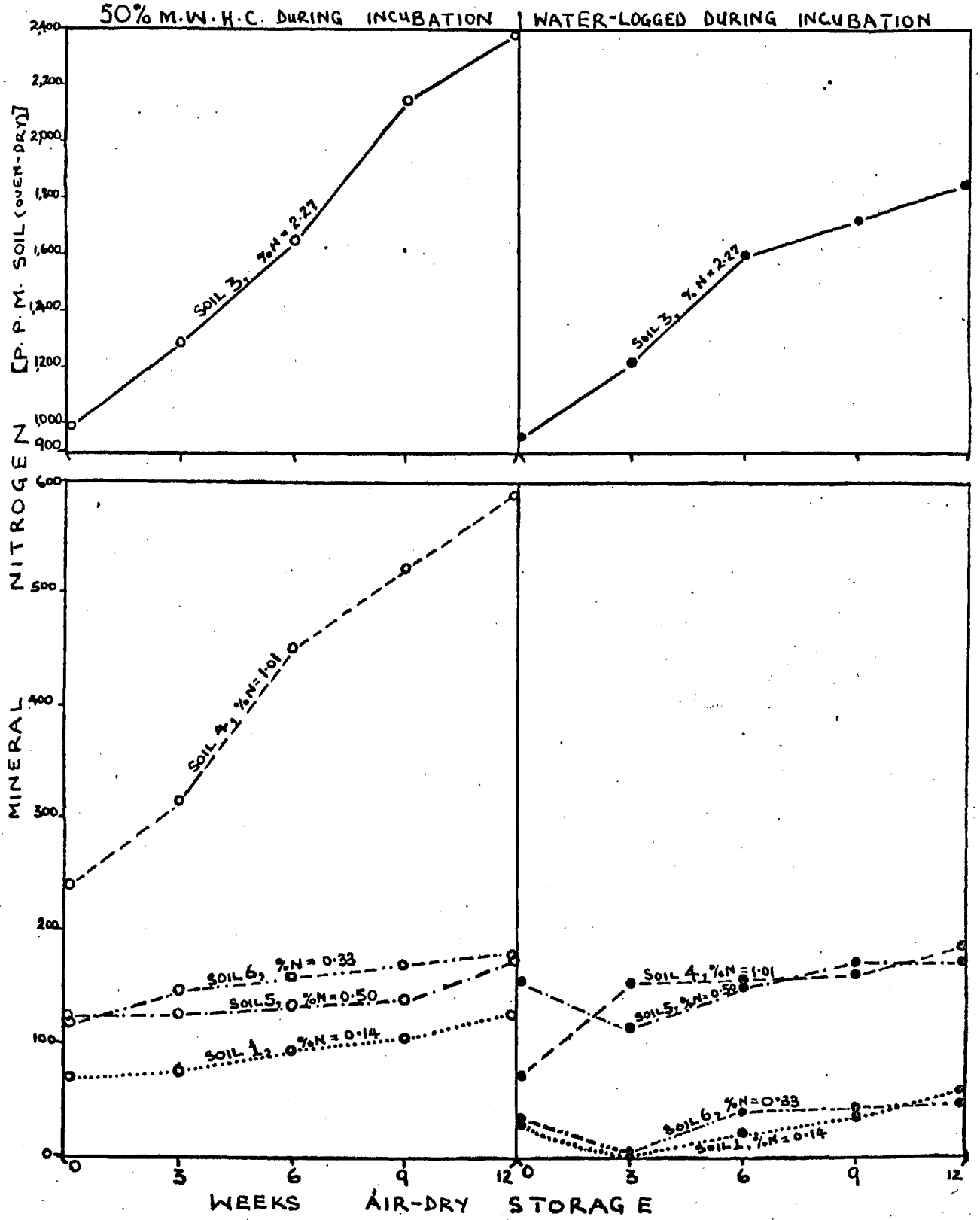
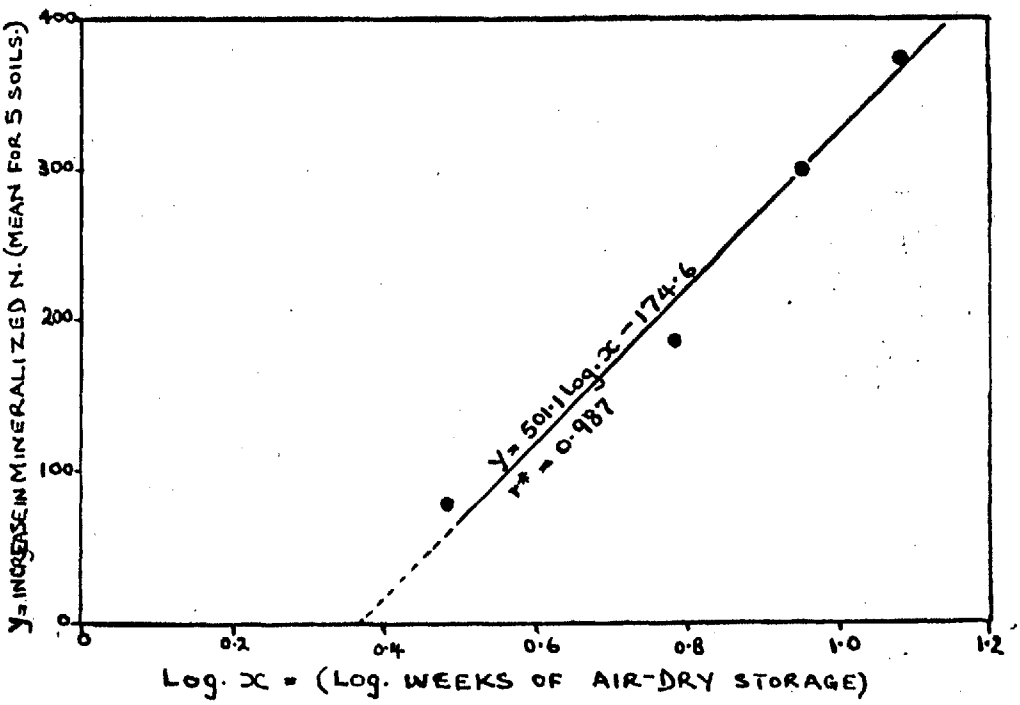
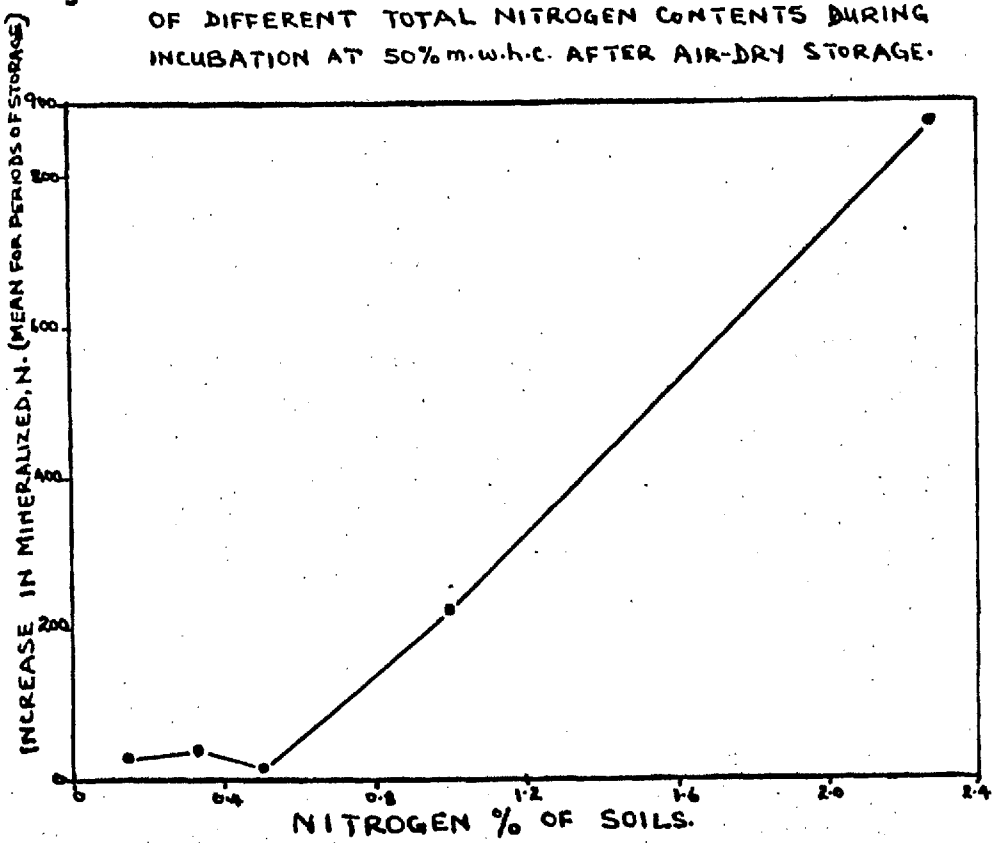


Fig. 68: REGRESSION LINE OF THE INCREASE IN MINERALIZED NITROGEN AS A RESULT OF AIR-DRY STORAGE OF SOILS ON THE LOGARITHM OF THE PERIOD (WEEKS) OF AIR-DRY STORAGE PRIOR TO INCUBATION AT 50% m.w.h.c.



* SIGNIFICANT AT 2% LEVEL.

Fig. 69: INCREASE IN MINERALIZED NITROGEN IN SOILS OF DIFFERENT TOTAL NITROGEN CONTENTS DURING INCUBATION AT 50% m.w.h.c. AFTER AIR-DRY STORAGE.



At 50% m.w.h.c. nitrogen mineralization for 3, 6, and 9 weeks air-dry storage increased with increasing total nitrogen content from 0.14% (soil 1) to 0.33% (soil 6), decreased to 0.50% (soil 5) and then increased with a further increase in nitrogen content to 2.27% (soil 3). For 0 and 12 weeks, a similar trend in nitrogen mineralization was observed except that it was similar for 0.33% (soil 6) and 0.50% (soil 5).

At water-logging, the significance of the differences in nitrogen mineralization between the different total nitrogen contents (soils) may be summarized as follows where the percentage represents the total nitrogen content and the figure in parenthesis represents the soil.

0 week air-dry storage: 2.27%(3), 0.50%(5), 1.01%(4), 0.14(1), 0.33%(6

3 weeks " " :2.27(3), 1.01%(4), 0.50%(5), 0.33%(6), 0.14%(1)

6 weeks " " :2.27%(3), 1.01(4), 0.50%(5), 0.33%(6), 0.14%1)

9 weeks " " :2.27%(3), 0.50%(5), 1.01%(4), 0.33%(6), 0.14%(1)

12 weeks " " :2.27%(3), 1.01%(4), 0.50%5), 0.14%1), 0.33%(6)

Thus there was a general tendency for nitrogen mineralization during wetting and incubation of soils to increase with increasing time of air-dry storage prior to wetting and with increasing total nitrogen content of the soils except for soil 5 (total N = 0.50%) for which this general tendency was broken.

(ii) Discussion.

The general tendency for carbon and nitrogen mineralization to be higher when the soil was incubated at 50% m.w.h.c. than at water-logging agrees with the results obtained in the previous chapters of this work. At the aerobic moisture level of 50% m.w.h.c., conditions were at about optimum for organic matter decomposition whilst at water-logging anaerobic conditions slowed down organic matter decomposition and might have stimulated nitrogen loss through ammonia volatization or denitrification (Bremner and Shaw (1958)).

Generally, the carbon and nitrogen mineralization increased with increasing period of air-dry storage prior to wetting and incubation. The importance of the effect of the period of air-dry storage on carbon mineralization during subsequent incubation at 50% m.w.h.c. was shown by the regression line in Fig. 65 of the logarithm of the increase (mean for the five soils) in CO_2 evolution due to air-dry storage compared with no drying on the period of air-dry storage. The regression equation was $\text{Log } Y = 0.13x - 0.26$ ($r = 0.999$ significant at 0.1% level). This indicated that with a given increase in the period of air-dry storage prior to incubation there was a more than proportionate increase in carbon mineralization during incubation.

Birch (1960), however, obtained a less than proportionate increase in carbon mineralization with a proportionate increase in the period of air-dry storage.

Since, however, the increase in organic matter decomposition on subsequent incubation due to air-dry storage compared with no drying was supposed by Birch (1960), Cooke and Cunningham (1958) and several others, to be due to the effect of partial sterilization of the soil and to an increase in the surface area of the organic gel composed of a labile fraction of the soil organic matter, during air-dry storage, it must be imagined that these effects increased with increasing period of air-dry storage.

As microbial populations increased more than proportionat ly compared with time when optimum conditions were provided after a spell of adverse conditions and as the ratio of the surface area to mass increased rapidly as particles became smaller, the more than proportionate increase in carbon mineralization with the proportionate increase in the period of air-dry storage observed in this study might be justified.

From the regression line (Fig. 65) and equation, by extrapolation (if this is justified) and calculation, it would be found that for carbon mineralization to increase by 1 mg. CO_2/10 g. soil compared with no drying, the soils must be stored air-dry for at least 2 weeks prior to incubation.

The regression line of the increase during incubation in mineral nitrogen (mean of the five soils) due to air-drying compared with no drying of soils on the logarithm of the period of air-dry storage prior to incubation is shown in Fig. 68 and the regression equation was $Y = 501.1 \log.x - 174.6$ ($r = 0.987$, significant at 2% level).

Unlike the increase in carbon mineralization, there was a less than proportionate increase in nitrogen mineralization compared with the increase in the period of air-dry storage prior to incubation. The difference between carbon and nitrogen mineralization relationships with the period of air-dry storage prior to incubation must be due to the fact that whilst CO_2 derived from carbon mineralization was evolved from the soil system, mineral nitrogen derived from nitrogen mineralization was retained in the system or immobilized by micro-organisms. Thus whilst the carbon metabolic process moved continuously to the right of the equation

$$\text{Organic C} + O_2 \xrightarrow{\text{Micro-organisms}} CO_2,$$

nitrogen metabolic process tended towards an equilibrium thus:

$$\text{Organic N} \xrightleftharpoons{\text{Micro-organisms}} NH_4^- + NO_3\text{-N}.$$

By extrapolation and calculation it was found that the number of weeks for which the soils must be stored air-dry prior to incubation before any increase in mineral nitrogen compared with no drying, can be obtained was 2.3 weeks, 0.3 week longer than the minimum period for increase in carbon mineralization. This indicated that for this difference in the periods of air-dry storage carbon mineralization proceeded without nitrogen mineralization. A similar result has been obtained by Birch (1960) and may be due to the fact that nitrogen immobilization was greater than mineralization.

The regression line of the increase in CO_2 evolution (mean of periods of storage) during incubation at 50% m.w.h.c. due to air-drying compared with no drying of the soils on the percentage carbon of the soils is shown in Fig. 66. The regression equation was $Y = 1.75x - 2.00$ ($r = 0.996$, significant at 1% level). It was therefore evident that the soil carbon content was a very important factor in determining the amount of extra carbon dioxide evolved as a result of air-dryihg prior to incubation. A similar result was obtained by Birch (1958).

The lowest carbon content below which no increase in carbon mineralization would occur during incubation after air-dry storage was about 1.35%. It seemed that when the organic carbon content of the soil was 1.35% or below, the organic gel fraction of the organic matter which Birch (1960) supposed was affected by air-dry storage might be so small that air-dry storage even for a long period produced no extra surface area compared with no drying. Thus it was observed that in soil 1 having an organic carbon content of 1.32%, there was no increase in carbon mineralization as a result of drying.

The relation between the increase in nitrogen mineralization (mean of periods of storage) caused by air-drying compared to no drying and the total nitrogen content of the soils was not as regular as that between increase in carbon mineralization and the total organic carbon content of the soils. The former relationship is shown in Fig. 69,

and while there were increases in nitrogen mineralization as a result of air-dry storage of all soils, these increases remained more or less constant for soils 1, 6 and 5 and then increased with increasing total nitrogen content. This trend has been influenced by the general lack of increase in nitrogen mineralization with increasing period of air-dry storage in soil 5 until 12 weeks storage.

When however other characteristics of the soils (3, 4, 5, 6 and 1) such as pH were considered, it was seen that soil 5 had a pH of 4.58. It seemed that this low pH excerted an influence on nitrogen mineralization which overshadowed the influence of air-dry storage. It might also explain why it was in this particular soil 5 that nitrogen mineralization was generally higher under water-logging than at 50% m.w.h.c. during incubation after the different periods of air-dry storage. A similar result was obtained in chapter IV of this work in which mineralization of nitrogen was higher at water-logging than at 50% m.w.h.c. only when the soil pH was as low as 4.72.

Birch (1958) obtained a regular increase in the extra organic matter decomposition produced as a result of air-dry storage with increasing soil organic matter content despite differences in soil pH or type. The results for carbon mineralization versus total organic carbon of the soil obtained in this study agreed with this but the results for nitrogen mineralization versus total nitrogen of the soil did not.

This was understandable since micro-organisms decomposing organic carbon are of many types, e.g. fungi, actinomycetes and bacteria and are active at various soil pH levels, whilst nitrifying bacteria are especially sensitive to soil pH (Waksman (1952)).

Furthermore, a definite minimum organic carbon content of the soils for increasing carbon mineralization at 50% m.w.h.c. due to previous air-drying was obtained at 1.35%, thus justifying the similarity in carbon mineralization in soil 1 (%C = 1.32) for all periods of air-dry storage. No such threshhold value of total N was obtained for nitrogen mineralization. This might be due to the fact that the organic gel fraction of the soil organic matter, which was the part affected by air-drying, was very nitrogenous (Birch (1960)). Thus, even when this fraction was too small and so prevented increases in carbon mineralization, there was enough organic nitrogen to ensure increased nitrogen mineralization on wetting after the soil was air-dried.

The regression lines and equations discussed above related mainly to the soils incubated at 50% m.w.h.c. after air-dry storage. Since there was a general tendency for carbon and nitrogen mineralization during incubation to increase with increasing period of air-dry storage prior to water-logging, partial sterilization and increased surface area of the organic gel fraction of the soil organic matter due to the air-dry storage must also be operating under water-logging although in a less marked manner than at 50% m.w.h.c.

It must, however, be noted that for soils 1, 6, and 5, under water-logging, there was a decrease in nitrogen mineralization for 3 weeks storage compared with 0 week and 6 weeks storage. This decrease might correspond to a lag in mineral nitrogen accumulation since under water-logging many factors such as denitrification and ammonia volatilization (Wahhab et. al. (1957)) as well as microbial immobilization, were operating to keep down the value of mineral nitrogen accumulated from organic matter decomposition. Air-dry storage of the soil for only three weeks prior to water-logging might well increase denitrification and nitrogen immobilization after water-logging by increasing microbial numbers through its partial sterilization effect to an extent greater than the increase in nitrogen mineralization resulting from its effect on the surface area of the nitrogenous organic gel fraction of the soil organic matter. It seemed that air-dry storage of the soils for more than three weeks prior to water-logging shifted the balance in favour of nitrogen accumulation. This hypothesis is strengthened by the fact that it did not apply to soils 3 and 4 where total nitrogen content was comparatively high and mineral nitrogen accumulation thus increased continuously with increasing period of air-dry storage prior to water-logging.

The difference in nitrogen accumulation between 50% m.w.h.c. and water-logging was greatest for soil 4 which was very calcareous and had a pH of 7.62. This might be due

to the fact that under water-logging a lot of mineralized nitrogen must have been lost through ammonia volatilization (Wahhab et. al. (1957)). It was also possible that water-logging further increased the soil pH (Kapp (1933)) to a level detrimental to microbial activity especially as carbon mineralization was as low as for soil 5, which had a much lower carbon content than soil 4. Conversely, the exceptionally low carbon dioxide evolution from water-logged soil 4 might be due to the fact that carbon dioxide produced was retained in the soil by reacting with calcium carbonate to form bicarbonate thus:

$$CaCO_3 + CO_2 + H_2O = Ca(HCO_3)_2.$$

(B) The effect of length of period of air-dry storage of soils prior to cropping on the performance of rye-grass.

Materials.

Soils 7, 8, and 9, whose characteristics are shown in Table 4 and Fig. 5 (Chapter II) were used. They were sampled from top 6", air-dried and ground to pass a 2 mm. sieve.

Experimental method.

The experiment was designed in such a way as to grow the rye-grass at the same time in all pots which had received differential drying period treatments.

The air-dry soils were mixed with acid-washed silver sand in the ratio of 1 : 3 soil : sand and 300 g. lots of the soil/sand mixture (hereafter referred to as 'the soil') were

weighed into 0.3 litre plastic pots whose drainage holes were covered with glass cloth. 14 weeks before the cropping, duplicate pots for each soil were brought to 50% m.w.h.c. and maintained by weighing and appropriate watering for two weeks. They were then air-dried and stored in the greenhouse to give 12 weeks air-dry storage before cropping. In the same way, 10 weeks, 6 weeks and 2 weeks before cropping, duplicate pots of each soil were wetted for two weeks and air-dried to give 8, 4 and 0 weeks air-dry storage before cropping.

Just before cropping, the soil in each pot was poured out and thoroughly mixed to ensure uniformity in the content of nutrients which might have been washed to the bottom layers in the pot during the watering before drying.

The two weeks watering period before drying was intended to eliminate the effect of the drying since the soils were taken from the field. To reduce the differences in nutrient metabolism due to the difference in the period of drying since the soil was taken from the field till the two weeks watering, the soils were left air-dry for about 50 weeks after removal from the field. It was supposed that since the effect of period of air-dry storage tended to level out when the storage was for a long time, the differences in nitrogen mineralization between air-dry storage for 50 weeks and for 62 weeks before the two weeks wetting would be small, (i.e. the difference in nitrogen mineralization during the two weeks wetting before 12 weeks drying and before 0 week drying would be small).

Thus after mixing the soil was put back in each pot and 0.25 g. of rye-grass seed was sown in each pot and the pots containing dry soils were placed in a tub of water until the soils were well soaked. All pots were left on the bench in the greenhouse and the moisture levels maintained at 50% m.w.h.c. by weighing and appropriate additions of water until the seedlings were eighteen days old.

The tops were cut and the soil washed off the roots, roots and tops were dried in a steam oven for 24 hours and weighed. They were ground in a mill and the total nitrogen, phosphorus and potassium uptake determined by the salicylic acid modification of the wet digestion method.

Results.

The dry-matter yields and nutrient uptake by rye-grass grown in soils stored air-dry for different periods prior to cropping are shown in Table 46 and in Fig. 70 (Dry-matter yields), Fig. 71 (Nitrogen uptake), Fig. 72 (Phosphorus uptake) and Fig. 73 (Potassium uptake).

For soil 7, there were no significant differences at 5% level in dry-matter yields or in nitrogen, phosphorus and potassium uptake between the different periods of air-dry storage (0-12 weeks) prior to cropping.

For soil 8, dry-matter yields and the uptake of the three nutrients, significantly (5% level) decreased with increasing period of air-dry storage prior to cropping from

TABLE 46.

Dry-matter yields (mg./pot) and nutrient uptake (p.p.m. soil) by rye-grass (tops + roots) grown for 3 weeks in soils stored air-dry for different periods prior to cropping.

Soil	Period of air-dry storage (weeks)				L.S.D.	
	0	4	8	12	at 5%	at 1%
DRY-MATTER YIELDS						
7	521	579	563	531	124	174
8	560	387	446	566		
9	426	465	451	521		
NITROGEN UPTAKE						
7	170	160	172	176	23	32
8	120	89	112	132		
9	100	86	98	124		
PHOSPHORUS UPTAKE						
7	85	90	95	93	15	21
8	93	69	75	95		
9	56	73	76	82		
POTASSIUM UPTAKE						
7	157	169	178	170	59	83
8	439	240	289	331		
9	150	166	211	235		

DRY-MATTER YIELDS AND NUTRIENT UPTAKE BY RYE-GRASS (TOPS+ROOTS) GROWN FOR 3 WEEKS IN SOILS STORED AIR-DRY FOR DIFFERENT PERIODS PRIOR TO CROPPING.

Fig.70: DRY-MATTER YIELDS.

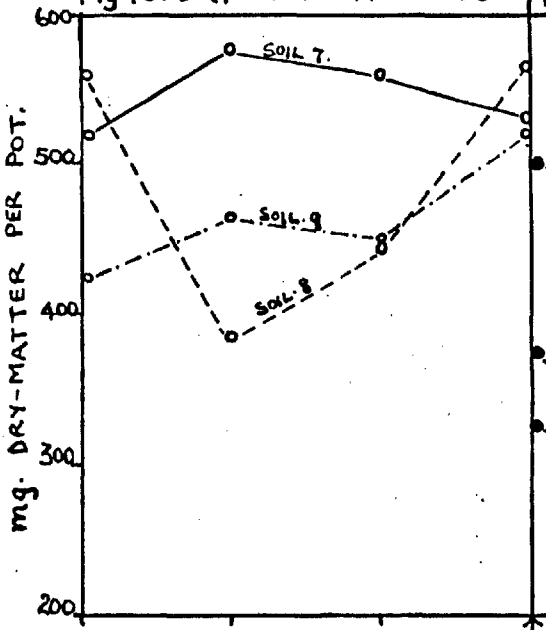


Fig.71: NITROGEN UPTAKE.

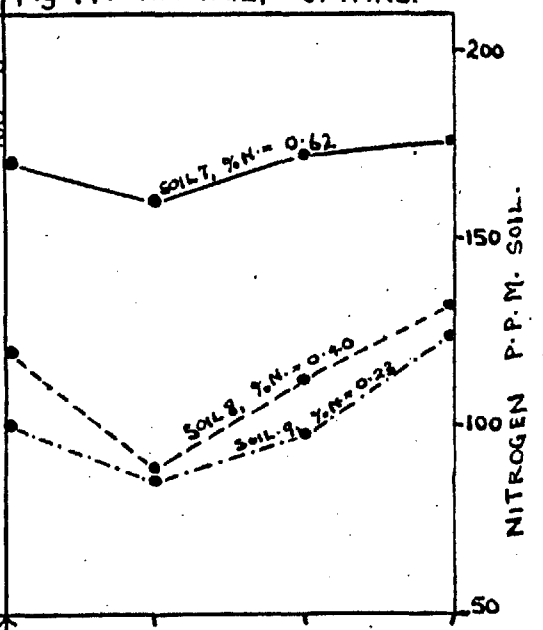


Fig.72: PHOSPHORUS UPTAKE.

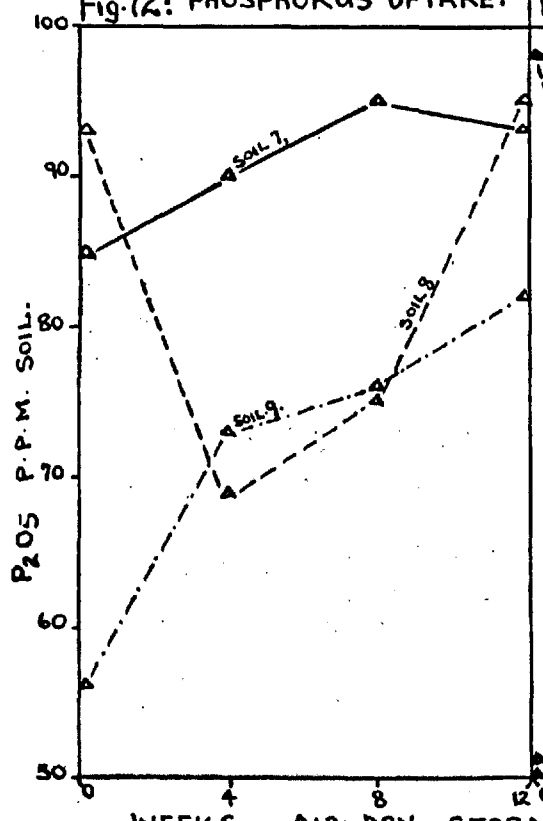
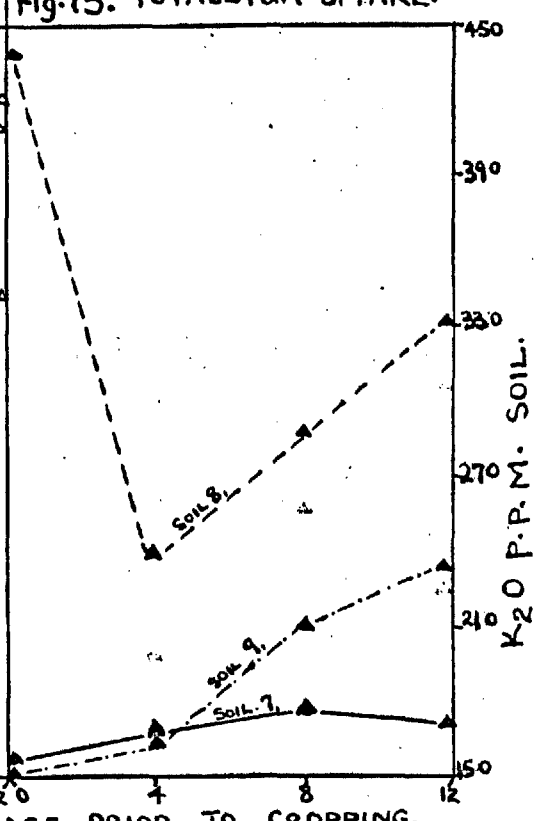
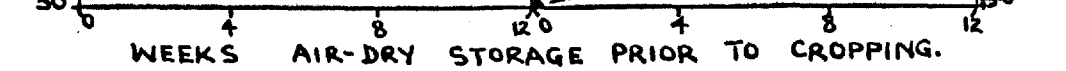


Fig.73: POTASSIUM UPTAKE.





0 to 4 weeks and then increased with a further increase in the period of air-dry storage to 12 weeks. Each of dry-matter yield, nitrogen and phosphorus uptake was similar for 12 weeks and 0 week air-dry storage whilst the potassium uptake was significantly lower for 12 weeks than for 0 week.

For soil 9, there were no significant differences in dry-matter yields between the different periods of air-dry storage. There were significant increases in nitrogen uptake for 12 weeks storage compared with the other periods, but phosphorus uptake was lower for 0 week than for all other periods. Potassium uptake was significantly higher for 8 weeks than for 0 week whilst the potassium uptake for 12 weeks was higher than that for 0 and 4 weeks air-dry storage.

Thus for all soils, the nitrogen uptake generally decreased for 4 weeks air-dry storage compared with that for all other periods and increased with increasing soil total nitrogen (soil 9, 0.23%N; soil 8, 0.40%N; soil 7, 0.63%N). Furthermore, the phosphorus and potassium uptake from soil 9 (whose original Morgan's extractable P_2O_5 was 32 p.p.m. and K_2O was 128 p.p.m.) was higher than the original Morgan's extractable values. In this soil, the phosphorus and potassium uptake tended to increase with increasing period of air-dry storage. More phosphorus and potassium than the Morgan's extractable were released by the drying of this soil, the release tending to increase with period of air-dry storage.

For soil 8 however, less phosphorus and potassium were taken up by rye-grass than was extracted by Morgan's reagent from the original soil (P_2O_5 192 p.p.m., and K_2O 350 p.p.m. soil). In this soil, the phosphorus and potassium uptake decreased for 4 weeks storage compared with the other periods and in view of the similarity in dry-matter yields for 12 and 0 weeks and the greater uptake of potassium for 0 week than for 12 weeks storage, it was obvious that the air-dry storage must have caused potassium fixation.

Discussion.

The tendency for the uptake of nitrogen to decrease for 4 weeks air-dry storage of the soils prior to cropping compared with for other periods agrees with the result obtained by Harpstead and Brage (1958) who found that the nitrate accumulated after 3 weeks air-dry storage was lower than after 0 weeks but increased more or less regularly with the increase in length of period of air-dry storage thereafter. They suggested that this was due to a lag in biological activity. It was thought here, however, that there was no evidence to support this suggestion since several workers including Birch (1958), (1959) and (1960), Gasser (1961) and Eagle (1961), indicated that air-drying soils increased microbial activity during subsequent wetting through its partial sterilization effect.

It seemed therefore, that the lag in the uptake of nitrogen observed here for 4 weeks air-dry storage was not due to a lag in the microbial activity or nitrogen mineralization but probably arose from the dynamic nature of mineral nitrogen accumulation. It has been earlier observed that under water-logged incubation of soils previously stored air-dry for a number of periods and having total nitrogen contents up to 0.5% a lag in mineral nitrogen accumulation was observed for 3 weeks air-dry storage. This was supposed to be due to the relatively greater loss of mineral nitrogen through denitrification, ammonia volatilization or microbial immobilization than gain of mineral nitrogen through increased mineralization of organic nitrogen as a result of the air-drying effect.

Under the rye-grass grown in soils at 50% m.w.h.c., losses of nitrogen through denitrification or ammonia volatilization were probably insignificant. Thus the observed lag in nitrogen uptake for 4 weeks air-dry storage might be due mainly to the relatively greater immobilization than mineralization of nitrogen compared with the other periods of air-dry storage.

Gasser (1961) found that the trend of increasing mineralization of nitrogen with increasing period of air-dry storage became regular only after the first 12-16 weeks storage. Harpstead and Brage (1958) showed that the correlation between the accumulated mineral nitrogen during incubation after

air-dry storage of soils and the response of oats grown in pots to equivalent amounts of fertilizer nitrogen was poor until the soil was stored for 18 weeks. These observations might explain why the differences in dry-matter yields and in nitrogen uptake by rye-grass obtained in this study, and by Wagner and Smith (1960), between the different periods of air-dry storage (up to only 12 weeks) were non-significant (except for the lag for 4 weeks only in soil 8).

The observation of Harpstead and Brage (1958) might also explain the fact that whereas in soils incubated at 50% m.w.h.c. in section (A) of this chapter nitrogen mineralization generally increased with increasing period of air-dry storage, in soils cropped with rye-grass at the same moisture level, the nitrogen uptake not only consistently decreased (though non-significantly) for 4 weeks air-dry storage compared with other periods, but also generally was not significantly different between all the periods.

This difference in the trends of nitrogen metabolism versus period of air-dry storage prior to wetting between incubation and cropping might be due to the fact that growing crops might increase nitrogen immobilization by micro-organisms by increasing the numbers of heterogenous micro-organisms through the rhizospheres.

The increase in phosphorus and potassium uptake from the soil 9 with increasing period of air-dry storage prior to cropping might be due to the greater release of these nutrients as a result of air-drying as compared with no drying. This agrees with results obtained by Shioiri and Aomine (1940), Aderikhim (1960) and Thermlitz (1953) for phosphorus, and by Rouse and Bertramson (1950), Ayres (1949) and Scott and Smith (1957) for potassium.

The decrease in phosphorus uptake from soil 8 for 4 weeks compared with other periods of air-dry storage seemed to be due to the similarly decreased dry-matter yields, whilst the lower potassium uptake for 4, 8 and 12 weeks than for 0 week air-dry storage might be due to the fixation of potassium as a result of air-drying. The latter result agrees with those of Volk (1934), Grissinger (1957) and Piper et. al. (1960).

The lack of significance in the differences in phosphorus and in potassium uptake from soil 7 between the different periods of air-dry storage might be due to the similarity in dry-matter yields for all the periods and showed that air-drying compared with no drying had no effect on the availability of these nutrients to rye-grass.

It would seem therefore, that in soil 9 in which the Morgan's extractable potassium was low air-drying compared with no drying, increased the availability of potassium to rye-grass.

In soil 8, in which Morgan's extractable potassium was high, air-drying compared with no drying, decreased the availability of potassium to rye-grass. This general trend in the behaviour of potassium availability to the plant might follow the principle of equilibrium of all forms of potassium suggested by Bray and DeTurk (1939), Cook and Hutcheson (1960) and Matthews and Sherrell (1960), that potassium fixation and release depended on whether the initial exchangeable potassium of the soilwas high or low; if it was high fixation occurred but if it was low release was obtained.

The phosphorus uptake from the three soils closely followed the dry-matter yields and may be said to be affected by periods of air-dry storage through the amount of growth.

In soil 7, it seemed that the available form of soil potassium has already attained the equilibrium status since air-drying had no effect on potassium uptake. The pH of this soil (pH 5.05) might contribute to the attainment of the equilibrium status. Alternatively, it might be thought that the nitrogen content of this soil (0.62%N) was so high that dilution with sand was unable to bring out the differential effects of air-dry storage periods on the general performance of the rye-grass.

The nitrogen uptake by the rye-grass increased with increasing nitrogen content of the soils. This agrees with results obtained by Birch (1958) and Gasser (1961) in incubation studies, emphasizing the importance of the total

soil nitrogen in determining the availability of nitrogen to crops.

Conclusions.

(A) Carbon and nitrogen mineralization was determined in soils 3, 4, 5, 6 and 1 after three weeks incubation at 50% m.w.h.c. or at water-logging subsequent to air-dry storage for 0, 3, 6, 9 and 12 weeks. (B) The dry-matter yields and nitrogen, phosphorus and potassium uptake by rye-grass (tops + roots) grown in pots for 18 days at 50% m.w.h.c. in soils 7, 8 and 9 which had been stored air-dry for 0, 4, 8 and 12 weeks were determined.

(A) 1. At 50% m.w.h.c. incubation, carbon and nitrogen mineralization generally increased with increasing period of air-dry storage. This as supposed to be partly due to the partial sterilization effect produced in the soil as a result of air-dry storage, and also partly due to the exposure of a greater surface due to drying of the organic gel fraction of the soil organic matter which was easily decomposable.

2. At 50% m.w.h.c. incubation, the minimum air-dry storage period required for increased carbon mineralization was 2.0 weeks; for increasing nitrogen mineralization the minimum period was 2.3 weeks.

The difference in the minimum periods between carbon and nitrogen mineralization might be due to greater immobilization than mineralization of nitrogen for the air-dry period upto 2.3 weeks.

3. Under 50% m.w.h.c. incubation, carbon and nitrogen mineralization generally increased with increasing organic carbon and total nitrogen contents except for soil 5 which had a low pH (4.58) and did not conform to the pattern as far as nitrogen was concerned.

4. The minimum organic carbon content of the soil at which there was an increase in carbon mineralization due to drying compared with no drying was 1.35%. There was no such minimum level for total nitrogen effect on nitrogen mineralization for the soils used in this study. The difference in the results for carbon and nitrogen mineralization might be due to the very nitrogenous nature of the easily decomposable organic gel fraction of the soil organic matter.

5. Although carbon and nitrogen mineralization was generally higher at 50% m.w.h.c. than water-logged incubation due to differences in oxygen availability, trends of carbon and nitrogen mineralization increasing with increasing period of air-dry storage and increasing organic carbon and total nitrogen content obtained at 50% m.w.h.c. applied to a less marked degree to water-logged incubation.

B. 1. Air-dry storage compared with no drying did not affect the performance of rye-grass grown in soil 7 nor the dry-matter yields and nitrogen uptake in soil 9.

2. Phosphorus and potassium uptake by rye-grass in soil 9, however, increased with increasing period of air-dry storage. This might be due to the release of these nutrients as a result of air-drying.

3. In soil 8 the crop performed worst for 4 weeks air-dry storage compared with all other periods and there was a definite indication of potassium fixation as a result of air-dry storage compared with no drying.

Air-dry storage compared with no drying caused a release of potassium to the grass from the soil originally low in exchangeable potassium (soil 9) and caused a fixation of potassium against crop uptake in the soil originally high in available potassium (soil 8).

4. Nitrogen uptake by the rye-grass increased with increasing soil total nitrogen content.

Whilst nitrogen mineralization significantly increased with increasing period of air-dry storage of soils during incubation at 50% m.w.h.c., there were usually no significant differences in the nitrogen uptake by rye-grass from soils between the different periods of air-dry storage. The results indicate that in the field periods of soil dryness lasting for up to 12 weeks would have no effect on subsequent nitrogen uptake by crops although nitrate losses in fallow soil may be increased with increasing period of dryness.

CHAPTER IX

(A) THE EFFECT OF ALTERNATE WETTING AND AIR-DRYING SOILS ON THE MINERALISATION OF NITROGEN AND AVAILABILITY OF PHOSPHORUS AND POTASSIUM
(B) THE EFFECT OF ALTERNATE RAISING AND LOWERING COMPARED WITH MAINTAINING CONSTANT MOISTURE LEVELS ON THE PERFORMANCE OF RYE-GRASS

Introduction.

In all soils, the moisture regime is in a dynamic state; the soil may be dry in one period or season and wet at another. When the soil is wet the moisture regime varies according to the balance in soil moisture content between moisture loss through surface flow, drainage, transpiration and evaporation, and moisture gain through rain, irrigation or ground water.

It may therefore be thought that the most natural moisture condition which obtains in the field is in a state of alternate wetting and drying or of alternate rising and falling of the moisture level. This dynamic state exists under fallow prior to cropping as well as under growing crops. Thus the effect of soil moisture on nutrient metabolism is best studied under conditions of alternate wetting and drying of soils.

In the present chapter of this work, (A) the effect of alternate wetting to three moisture levels and air-drying of two soils, one of low nutrient status (soil 9) and one of high nutrient status (soil 2), on the accumulation of mineral nitrogen and the availability (Morgan's extract) of phosphorus and potassium, is described. (B) The effect of alternate raising and lowering the soil moisture levels between or continuously maintaining the moisture levels at 20%, 50%, and 80% m.w.h.c. while the crop is growing in soil 2 on the performance of rye-grass is described.

(A) The effect of alternate wetting and air-drying of soils on the mineralization of nitrogen and the availability (Morgan's extract) of phosphorus and potassium.

Materials.

Soils 9 and 2 whose characteristics are shown in Table 4 and in Fig. 5 (for soil 9) and Fig. 2 (for soil 2) in Chapter II were used. They were sampled from the top 6", air-dried and ground to pass a 2 mm. sieve.

Experimental method.

10 g. samples of the soils were weighed into flat-bottomed test-tubes (4" x 1" internal diameter) and for each soil, one third of the tubes were brought to 20% m.w.h.c. another third to 50% m.w.h.c. and the other to 133% m.w.h.c. or water-logging. Vials containing a suspension of barium peroxide were placed in the tubes after mixing the soil and added water with a thin glass rod. From then, they were incubated at these moisture levels for three weeks, air-dried for another three weeks and wetted to the original moisture levels and incubated for the next three weeks. This alternation of wetting and air-drying was done for a total of 18 weeks giving three cycles.

At each change of the moisture regime from wet to air-dry or air-dry to wet, duplicate samples of each moisture treatment of each soil were extracted with Morgan's reagent and NH_4-N, NO_3-N, P_2O_5 and K_2O determined on the extract.

N.B. All decreases and increases in the nutrient status mentioned in the following results and discussions are significant at 5% level and percentage maximum water holding capacity (m.w.h.c.) is expressed as a percentage e.g. 50% = 50% m.w.h.c.

1. NH_4-N and NO_3-N.

(i) Results.

The NH_4-N and NO_3-N accumulation in the soils alternately wetted to three moisture levels and air-dried is shown in Table 47 and Fig. 74. The original values of NH_4-N and NO_3-N have been substracted.

NH_4-N.

During the alternation of 20% and air-drying, the NH_4-N in both soils decreased on wetting the soil and increased on air-drying. During the alternation of 50% and air-drying, NH_4-N in soil 9 increased up to the end of the first drying and then decreased continuously whether the soil was wetted or dried. In soil 2, however, during the alternation of 50% with drying, the NH_4-N increased on drying and decreased on wetting until the last cycle when it was at the same level on both wetting and drying. During the alternation of 133% with drying, the NH_4-N in soil 9 remained constant in the first cycle, increased to constant levels in the second cycle and in the third cycle,

TABLE 47.

NH_4-N and NO_3-N (p.p.m. soil basis) accumulation in soils alternately wetted to 3 moisture levels and air-dried at 3 weekly intervals.

SOIL 9												
Moisture level (% m.w.h.c.)	Wet		Dry		Wet		Dry		Wet		Dry	
	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N
20	15	21	37	30	18	37	26	21	15	47	28	5
50	11	24	25	20	21	66	6	41	-24	120	-24	109
133	21	3	21	-4	51	7	47	12	42	18	56	13
SOIL 2												
20	-21	63	6	61	-21	171	7	111	-21	125	13	102
50	-21	101	39	54	-21	238	42	104	-21	100	-21	91
133	69	4	70	11	57	-26	64	-34	39	-8	29	-10

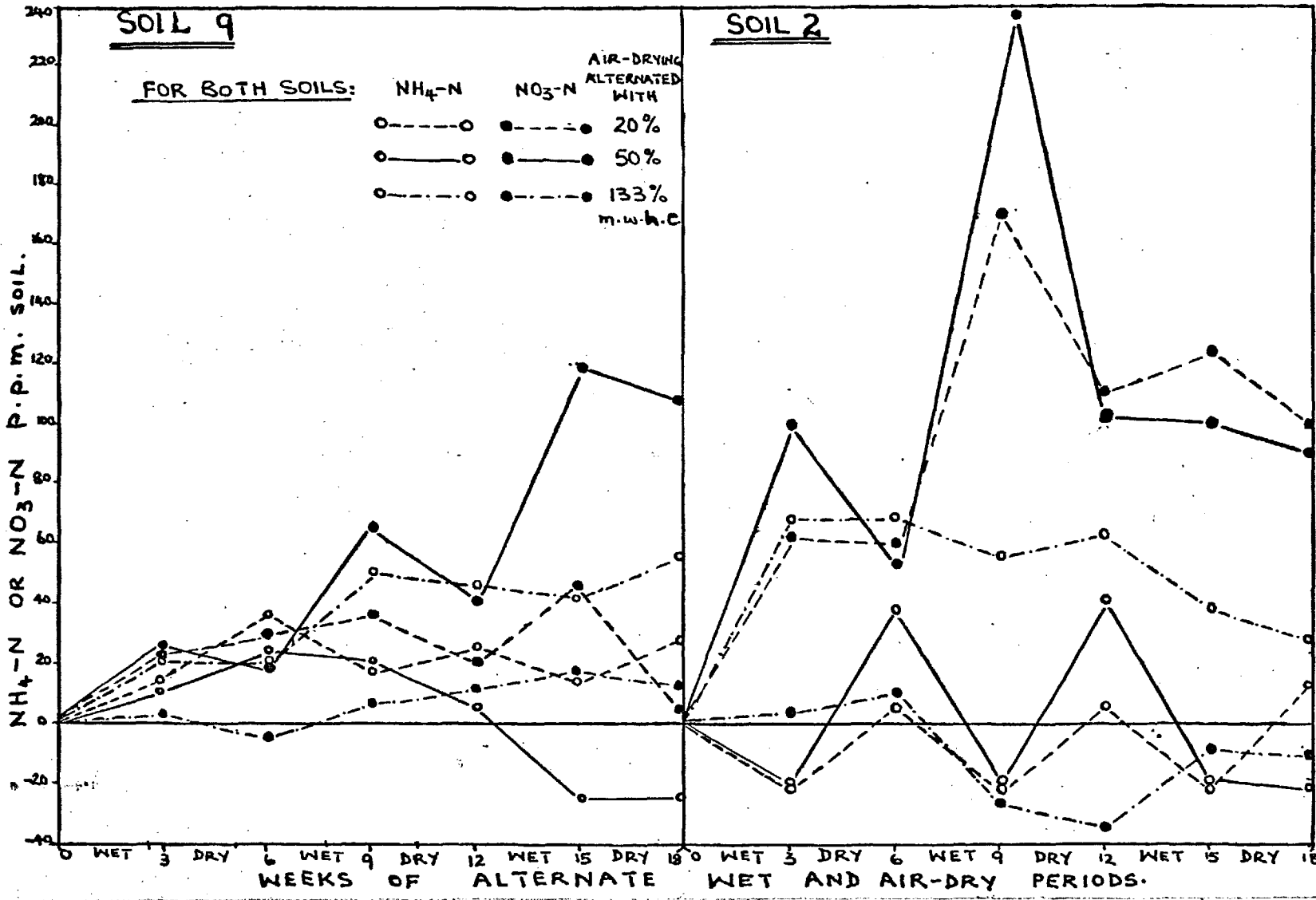
NH_4-N:

SOIL 9: L.S.D. = 5 at 5% and 6 at 1% levels.
SOIL 2: L.S.D. = 8 at 5% and 9 at 1% levels.

NO_3-N:

SOIL 9: L.S.D. = 6 at 5% and 8 at 1% levels.
SOIL 2: L.S.D. = 13 at 5% and 17 at 1% levels.

Fig. 74: NH_4-N AND NO_3-N ACCUMULATION IN SOILS ALTERNATELY WETTED TO 3 MOISTURE LEVELS AND AIR-DRIED AT 3 WEEKLY INTERVALS.



decreased on wetting and increased on drying. In soil 2, the NH_4-N during the alternation of 133% with drying was constant in the first cycle, decreased on wetting and increased on drying in the second cycle, and then decreased continuously in the third cycle.

Generally, in soil 9, NH_4-N was similar for alternations of 20% and 50% with air-drying in the wet phases of the first and second cycles, and increased for the alternation of 133% with air-drying. In the dry phases of all cycles and in the wet phase of the third cycle, the NH_4-N decreased in the order 133% > 20% > 50% alternated with air-drying.

Generally, in soil 2, NH_4-N was similar for alternations of 20% and 50% with air-drying in the wet phases of all cycles but was higher for 50% than for 20% alternated with air-drying during the dry phases of the first and second cycles. During both phases of all cycles, NH_4-N was highest for the alternation of 133% with air-drying.

NO_3-N.

During the alternations of 20% and 50% with air-drying in both soils, the NO_3-N generally increased during the wet phase and decreased during the dry phase being always higher for 50% alternated with air-drying than for 20% in soil 9. In soil 2, however, the NO_3-N was higher for 50% alternated with air-drying than for 20% only in the wet phase of the first and

second cycles whilst in all dry phases and in the wet phase of the third cycle the reverse was the case. The maximum value of NO_3-N was attained for alternations of 20% and 50% with air-drying during the wet phase of the third cycle in soil 9 but during the wet phase of the second cycle in soil 2.

During the alternation of 133% with air-drying, NO_3-N was generally low in both soils compared with the alternations of 20% and 50% with air-drying. Despite this, the NO_3-N tended to increase continuously from the dry phase of the first cycle to the wet phase of the third in soil 9, and then decreased in the last dry phase. In soil 2, however, NO_3-N was similar during the first cycle, decreased in the second cycle and increased to similar levels for both phases of the third cycle.

In general, as NH_4-N increased during the dry phase for alternations of 20% and 50% with air-drying, NO_3-N decreased and as NH_4-N decreased during the wet phase NO_3-N increased. Increases and decreases in NH_4-N were generally less pronounced than increases and decreases in NO_3-N. For alternations of 133% with air-drying, changes in NH_4-N and NO_3-N as the soils were wetted and air-dried were generally independent of each other, NH_4-N being continuously relatively high and NO_3-N low, and were less pronounced than for alternations of 20% and 50% with air-drying.

(ii) Discussion.

The general increase in NH_4-N during the dry phases for alternations of 20% and 50% with air-drying agrees with

results obtained by Robinson (1957) and (1960) that during periods of very low soil moisture regimes up to the permanent wilting percentage, ammonia built up in the soil. The simultaneous decrease in NO_3-N during the dry phases might be due to microbial immobilization during the drying process.

The results obtained in this study may therefore, be justified in view of the fact that Calder (1954) found that streptomyces were predominant over fungi and bacteria during air-drying phases of the soil moisture regime. This plus the fact that Davis and Owen (1954) found that ammonification of organic nitrogen added to steamed soils occurred without nitrification indicates that micro-organisms which bring about ammonification without nitrification are active under the partially sterilized conditions caused by air-drying or steaming. Thus as the degree of partial sterilization increased during the drying process, ammonia accumulation increased because of reduced nitrification and the ammonifying organisms are probably immobilizing nitrate.

The general decrease in NH_4-N and increase in NO_3-N in the wet phases during alternations of 20% and 50% with air-drying may be due to the nitrification of the ammonia accumulated during the dry phase by bacterial nitrifiers which are active at soil moisture levels between wilting point and field capacity (Robinson 1957).

The fact that there was a more pronounced change in NO_3-N than in NH_4-N as the soil moisture regimes were

alternated between 20% or 50% and air-drying indicated that during drying, the NO_3-N did not directly revert to NH_4-N and strengthens the case for supposing that the NO_3-N was immobilized by micro-organisms, especially since denitrification was most unlikely. It might also be supposed from this fact that in addition to NO_3-N derived from the NH_4-N which disappeared during the wet phase, NO_3-N was also derived from mineralization of soil organic nitrogen.

Before the maximum values of NO_3-N were attained, for alternations of 20% and 50% with air-drying, after the wet phase of the third cycle in soil 9 and after the wet phase of the second cycle in soil 2, each wetting gave an increment in NO_3-N higher than the previous one. This might be due to the partial sterilization effect of the air-drying phase and the mineralization of nitrogen contained in the cells of dead micro-organisms of the generations of the previous wet phase. Birch (1958) found constant increments for each wet phase after air-drying.

In soil 9, (low total nitrogen content) for alternations of 20% and 50% with air-drying the attainment of the maximum value of NO_3-N was slower and the maximum value of NO_3-N was lower than in soil 2 (high total nitrogen content). This was probably due to the influence of total nitrogen content on the mineralization of nitrogen. Thus in soil 2, after the maximum NO_3-N value had been attained in the wet phase of the second cycle, the NO_3-N decreased to a more or less

constant level despite the alternations in the third cycle. This might be due to the fact that the NO_3-N had reached such high levels that during the last phase immobilization became more important than nitrification. Simpson (1960) stated that when the nitrate was high, micro-organisms tended to immobilize it and reduced it to lower levels. It would seem that whilst this obtained in soil 2 in the second phase, the NO_3-N was not yet high enough in soil 9 to warrant a predominance of nitrogen immobilization over mineralization within the period of the experiment. It is possible that NO_3-N would have increased further with a fourth cycle for soil 9.

For the alternation of 133% with air-dry, the generally high level of NH_4-N, which did not vary in any regular fashion with changes in the phases of soil moisture regime in both soils, may be due to the fact that during the wet phase, the water-logged condition stimulated ammonia accumulation (Kapp (1933)) and Gerretsen (1921)) and during the dry phase, the air-dry condition similarly stimulated ammonia accumulation (Shioiri and Aomine (1940) and Robinson (1957)). It was no wonder therefore that NO_3-N was continuously low despite the changes in the two soil moisture regimes.

It would seem generally that micro-organisms responsible for ammonification are active at all moisture levels from near air-dry to water-logging but those responsible

for nitrification are apparently inactive at near air-dry and water-logging soil moisture regimes; thus ammonia accumulates and nitrate disappears.

2. Phosphorus.

(i) Results.

The available (Morgan's extract) phosphorus in soils alternately wetted and air-dried is shown in Table 48 and Fig. 75.

The available phosphorus in soil 9 when 20% was alternated with air-drying was similar in both wet and dry phases of the first cycle, in the second decreased to similar levels for the two phases, and in the third cycle decreased during the wet and increased during the dry phases. When 50% was alternated with air-drying, the available phosphorus was similar in both phases of the second cycle but decreased during the wet and increased during the dry phases in the first and third cycles.

The available phosphorus in soil 2 when 20% was alternated with air-drying, was similar in both wet and dry phases of the first cycle, increased to similar levels in both phases of the second cycle and then decreased continuously in the third cycle. When 50% was alternated with air-drying the available phosphorus also decreased continuously in the third cycle but increased in the wet and decreased in the dry phases of the first and second cycles.

Thus, while in soil 9 with a low original available phosphorus (32 p.p.m.) alternate wetting to 20% or 50% and air-drying caused a release of phosphorus after three cycles, in soil 2 with a high original available phosphorus (118 p.p.m.) it caused a fixation of phosphorus.

In both soils, when 133% was alternated with air-drying, phosphorus was greatly mobilized during the wet phases and was fixed below the original soil levels during the dry phases. In both soils mobilized phosphorus values were highest during the wet phase of the second cycle. Whilst the values of phosphorus after fixation were similar during all the dry phases of soil 9, they tended to increase as the number of cycles increased in soil 2.

The available phosphorus was generally similar when 20% and when 50% were alternated with air-drying in soil 9 but in soil 2, during the first and second phases available phosphorus was generally lower when 50% than when 20% was alternated with air-drying except in the wet phase of the first cycle when the reverse was the case. During the wet phases of all cycles, the available phosphorus in both soils was highest and during the dry phases was lowest for the alternation of 133% with air-drying compared with the alternation of 20% and 50% with air-drying.

(ii) Discussion.

The general decrease in the available phosphorus during the wet phases and increase during the dry phases in soil 9 alternately wetted to 20% or 50% and air-dried agrees with results obtained by Tendille and Eynard (1959) and Khanna (1960). This might be due to the reduction of the activities of hydrated iron and aluminium oxides as a result of the drying thus reducing their reactions with and fixation of phosphates (Ryzhov and Machigin (1939)). In the wet phase the reverse process occurred and some of the phosphorus was fixed.

In soil 2, alternating 20% with air-drying did not have much effect on the availability of phosphorus in the first two cycles whilst alternating 50% with air-drying caused phosphorus fixation during the dry phase and release during the wet phase. The latter result might be due to increase in the mobility of phosphate ions when the soil was wetted hence an increase in the extractable phosphorus (Müller (1954) and Reitemeier (1946)). During the dry phase the reverse process occurred and phosphorus was fixed. This would be strengthened by the fact that during drying the soil colloidal surfaces were degraded and phosphate ions enabled to penetrate the soil particles (Rydky (1938)).

Since the two soils were sandy loams and their pH values were not very different (between 6.0 and 7.0), the

TABLE 48.

Available (Morgan's extractable) phosphorus (P_2O_5 p.p.m. soil basis) in soils alternately wetted to 3 moisture levels and air-dried at 3 weekly intervals.

SOIL 9						
Moisture level (% m.w.h.c.)	Wet	Dry	Wet	Dry	Wet	Dry
20	33	35	29	32	26	39
50	28	37	33	33	24	40
133	130	26	142	24	120	24
SOIL 2						
20	113	110	117	117	109	100
50	120	101	114	107	102	94
133	154	34	240	43	232	47

Soil 9: L.S.D. = 5 at 5% and 6 at 1% levels.
Soil 2: L.S.D. = 5 at 5% and 7 at 1% levels.

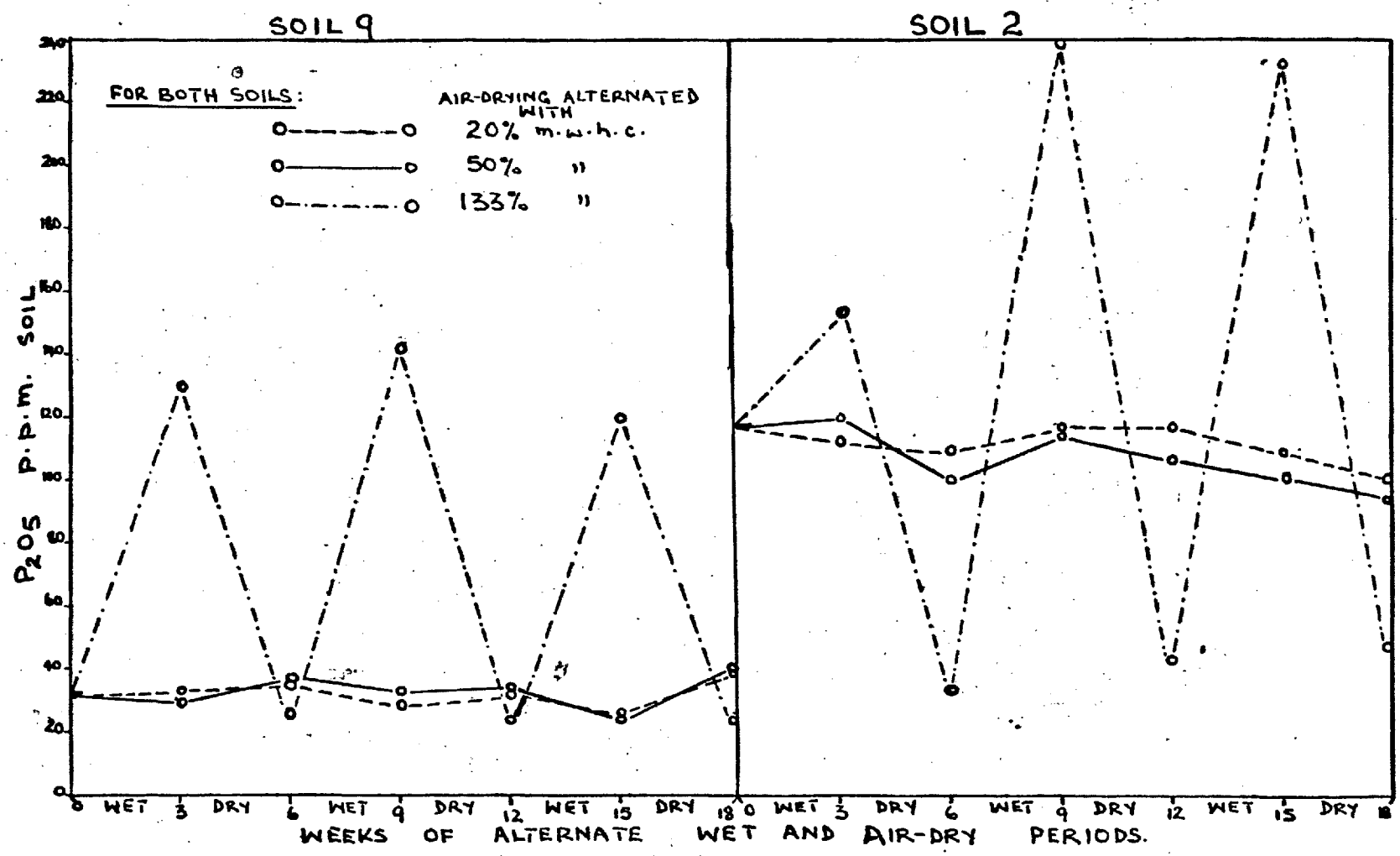
TABLE 49.

Available (Morgan's extractable) potassium (K_2O p.p.m. soil basis) in soils alternately wetted to 3 moisture levels and air-dried at 3 weekly intervals.

SOIL 9						
Moisture level (% m.w.h.c.)	Wet	Dry	Wet	Dry	Wet	Dry
20	128	128	126	102	96	97
50	121	135	126	108	87	91
133	114	142	126	102	87	89
SOIL 2						
20	341	364	343	282	264	240
50	341	391	332	294	288	248
133	334	398	322	306	270	248

Soil 9: L.S.D. = 4 at 5% and 5 at 1% levels.
Soil 2: L.S.D. = 12 at 5% and 16 at 1% levels.

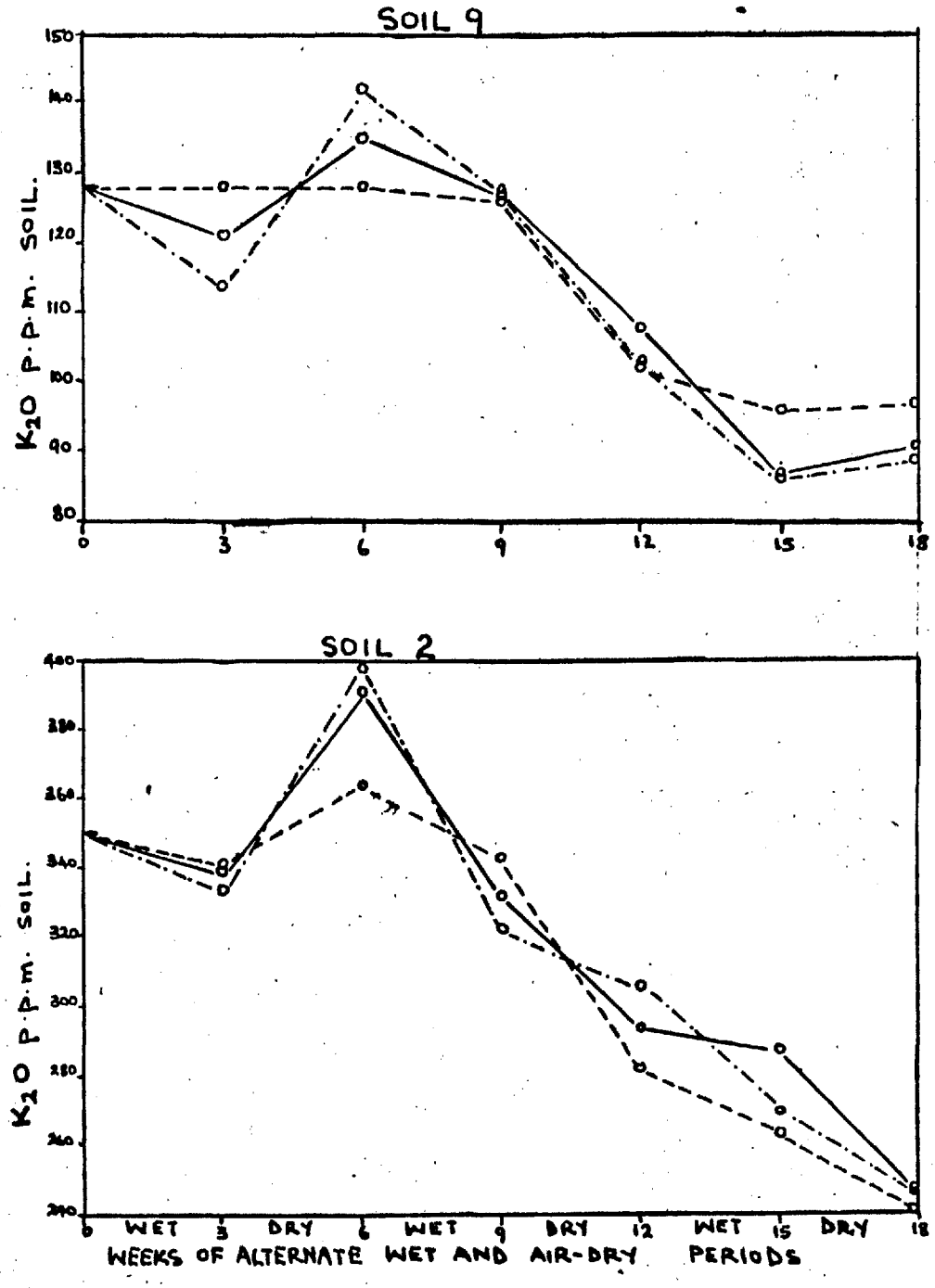
Fig. 75: AVAILABILITY (MORGAN'S EXTRACTABLE) PHOSPHORUS IN SOILS ALTERNATELY WETTED TO 3 MOISTURE LEVELS AND AIR-DRIED AT 3 WEEKLY INTERVALS.



release of phosphorus by alternate wetting to 20% or 50% and air-drying in soil 9 for 3 cycles and the fixation of phosphorus under the same conditions in soil 2 may lie in the difference between their original available phosphorus status. It would seem that alternate wetting and air-drying released phosphorus in soil 9 of low original available phosphorus while fixing phosphorus in soil 2 of high original available phosphorus. Barbier and Tyszkiewicz (1951) found some soils fixing phosphorus and others releasing it when they were subjected to alternate wetting and drying.

The mobilization of phosphorus during the wet phases when both soils were alternately water-logged and air-dried might be due to the reduction of iron and hydrolysis of aluminium phosphates under anaerobic conditions (Shapiro and Armiger (1958) and Gasser and Bloomfield (1955)). The fixation of phosphorus during the dry phases to levels lower than the original soil available phosphorus might be due to the precipitation of the iron and aluminium as phosphate compounds as the iron was oxidized and the soil dehydrated. Since compounds of iron other than iron phosphate were mobilized during the water-logging, the precipitation of the mobilized phosphorus plus some of the original soil available phosphorus during the oxidation of the reduced iron would be expected.

Fig. 76: AVAILABILITY (MORGAN'S EXTRACTABLE) POTASSIUM IN SOILS ALTERNATELY WETTED TO 3 MOISTURE LEVELS AND AIR-DRIED AT 3 WEEKLY INTERVALS.



3. Potassium.

(i) Results.

The available (Morgan's extract) potassium in the soils alternately wetted and air-dried is shown in Table 49 and Fig. 76.

The available potassium in soil 9, when 20% was alternated with air-drying, remained constant until the end of the wet phase of the second cycle after which it decreased continuously to constant levels during both phases of the third cycle. When 50% or 133% was alternated with air-drying, in soil 9, and when all moisture levels were alternated with air-drying in soil 2, the available potassium, decreased in the wet phase of the first cycle compared with the original soil available potassium of 128 p.p.m. for soil 9 and 350 p.p.m. for soil 2. In the dry phase of the first cycle, the available potassium increased to exceed the original soil available potassium. In both phases of the second and third cycles, the available potassium decreased continuously in soil 2 but to a constant level for the third cycle in soil 9.

Thus generally, the dry phase of the first cycle caused potassium release and after that, potassium fixation was caused by both wet and dry phases until the end of the experiment. For both soils, alternate wetting and drying for three cycles caused a fixation of native original available potassium.

Within the first cycle in both soils fixation of potassium during the wet phase and potassium release during the dry phase increased with increasing moisture level of the wet phase. At the end of the third cycle, potassium was fixed by alternate wetting to 50% and 133% and air-drying soil 9 than by alternate wetting to 20% and air-drying. In soil 2, the amount of potassium fixed at the end of the third cycle was similar for alternations of all moisture levels with air-drying.

(ii) Discussion.

The release or non-fixation of potassium at the end of the first cycle of alternating all moisture levels with air-drying and the fixation of potassium in both soils in the second and third cycles agrees with results obtained by Mick and Lynd (1957). It has already been established by several workers that potassium fixation and release took place mostly in the clay fraction of the soil. Karim and Malek (1957) suggested that potassium fixing capacity was a specific property of minerals of expanding lattice type. It would seem therefore that the fixation of potassium during the wet phase of the first cycle observed here might be due to the swelling of such minerals which may be present in these soils thus allowing potassium ions to enter the lattice voids and become fixed.

In the dry phase of the first cycle, the release of potassium might be due to a reversion of the process since

Tendille et. al. (1956) showed that potassium fixation in some cases was a reversible process and Carter (1961) observed a release of potassium when soils containing montmorillonite, a clay mineral with an expanding lattice, were dried.

It might be thought that since montmorillonite might be converted to illite (a clay mineral whose lattice expanded but little on hydration) by the trapping of potassium ions between the lattices, a process similar to this was taking place after the first cycle of alternate wetting and drying in this study. Thus in the first cycle, the reversible process of fixation and release took place due to the expansion and contraction of the expanding lattice mineral. From the end of the first cycle onwards, lack of expansion and contraction tended to reduce the reversibility of the fixation process and fixation was continuous till the end of the experiment.

The increase in the amount of potassium fixation and release during the wet and dry phases respectively of the first cycle with increasing moisture level of the wet phase might be said to emphasize the importance of the roll of minerals with expanding lattices in the fixation and release of potassium in the first cycle. This would be especially so since the amount of expansion and contraction of the lattice would increase with the increase in the amount of water present in the soil. Karim and Malek (1957) also observed similar results.

The lack of significance in the differences in the amount of potassium fixation at the end of three cycles between the different moisture levels of the wet phases might emphasize the suggestion that at that time the roll of minerals whose lattices expanded but little was predominant in determining the irreversibility of potassium fixation since the amount of water in the soil in the wet phases no longer had any differential effect on the fixation of potassium.

(B) The effect of alternate raising and lowering soil moisture compared with continuously maintaining moisture levels under growing crop, on the performance of rye-grass.

Materials.

Soil 2 whose characteristics are shown in Table 4 and Fig. 2 (Chapter II) was used. The soil was sampled from the top 6", air-dried and ground to pass a 2 mm. sieve.

Experimental method.

75 g. lots of the soil were mixed with 225 g. of acid-washed silver sand. The soil/sand mixture (hereafter referred to as 'soil') was placed in 0.3 litre plastic pots whose drainage holes were covered with glass cloth. 0.15 g. of rye-grass seeds were sown in each pot and the pots were placed in a tub of distilled water until the soil was well soaked. The pots were kept in the greenhouse and watered twice daily until the seeds germinated and the seedlings were two weeks old.

The tops of the seedlings were then cut and discarded. Thereafter, the following soil moisture treatments were given to the samples in the pots and maintained by weighing and appropriate watering; the soil moisture continuously maintained at 80% (high), 50% (medium) and 20% (low) of the maximum water holding capacity; 80% (high) was alternated with 50% (medium) or with 20% (low) and 50% (medium) was alternated with 20% (low).

The tops of the rye-grass were cut after 2, 4, 7, 10 and 13 weeks since the differential soil moisture treatments began. In those treatments where moisture levels were alternated, the change in moisture level was made after each cutting, starting at the beginning of the differential moisture treatments with the high r moisture level in each case.

Each cutting of the tops was seperately steam oven-dried, weighed and analysed for total nitrogen, phosphorus and potassium using the salicylic acid modification of the wet digestion method.

(i) Results.

Cumulative dry-matter yields and nutrient uptake by rye-grass tops grown with the different treatments are shown in Table 50 and in Fig. 77 (Dry-matter yields), Fig. 78 (Nitrogen uptake), Fig. 79 (Phosphorus uptake) and Fig. 80 (Potassium uptake).

Dry-matter yields (Fig. 77).

There were no significant differences in the total dry-matter yields between the different soil moisture treatments until the cutting done after 10 weeks, when the dry-matter yield in the soil continuously maintained at the low moisture level only was significantly lower than those in the soil continuously maintained at the high moisture level. In the last cutting done after 13 weeks, the significance of the differences in total dry-matter yields between the different soil moisture treatments may be summarised as follows where H represents high, M medium and L low soil moisture levels and these letters or combinations of them also represent the relevant dry-matter yields in a descending order of magnitudes. All letters above the same horizontal line are not significantly (5% level) different from each other but are significantly different from all others.

H, H/M, M, H/L, M/L, L

1. Among the treatments where the moisture levels were alternated only the alternation of high and low moisture levels caused pronounced change in dry-matter yields with change in moisture level, the dry-matter yields in the low moisture phases being higher than the dry-matter yields in the high moisture phases.

2. Nitrogen uptake (Fig. 78).

There were no significant differences in total nitrogen uptake between the different moisture treatments until

TABLE 50.

Dry-matter yields and nutrient uptake by rye-grass tops grown in soil 2 maintained continuously at or alternately irrigated and dried between three moisture levels.

Soil moisture level	Weeks after which cuttings were taken and moisture levels changed.				
	2	4	7	10	13
DRY-MATTER YIELDS (mg./pot)					
Continuous High	94	160	280	442	619
" " Medium	88	153	265	356	456
" " Low	65	93	165	236	292
Alternated High/Medium	102	180	263	377	463
" " High/Low	99	145	206	321	394
" " Medium/Low	93	128	204	286	386
NITROGEN UPTAKE (p.p.m. soil basis)					
Continuous High	24	46	77	116	158
" " Medium	23	46	74	100	128
" " Low	25	42	64	83	100
Alternated High/Medium	27	53	83	117	147
" " High/Low	26	48	69	106	130
" " Medium/Low	29	47	79	99	131
PHOSPHORUS UPTAKE (P_2O_5 p.p.m. soil basis)					
Continuous High	21	36	54	84	108
" " Medium	22	38	55	72	86
" " Low	18	26	37	50	53
Alternated High/Medium	21	38	52	73	84
" " High/Low	20	31	40	58	68
" " Medium/Low	19	27	48	62	81
POTASSIUM UPTAKE (K_2O p,p.m. soil basis)					
Continuous High	66	104	168	258	339
" " Medium	67	102	155	202	242
" " Low	51	65	113	144	159
Alternated High/Medium	64	112	193	274	321
" " High/Low	61	92	121	201	226
" " Medium/Low	67	88	158	200	249

L.S.D.		Dry-matter yields	N	P_2O_5	K_2O
	at 5%	177	11	21	21
	at 1%	239	15	28	29

DRY-MATTER YIELDS AND NITROGEN UPTAKE BY RYE-GRASS TOPS GROWN IN SOIL MAINTAINED CONTINUOUSLY AT OR ALTERNATELY IRRIGATED AND DRIED BETWEEN 3 MOISTURE LEVELS

Fig. 77: DRY-MATTER YIELDS.

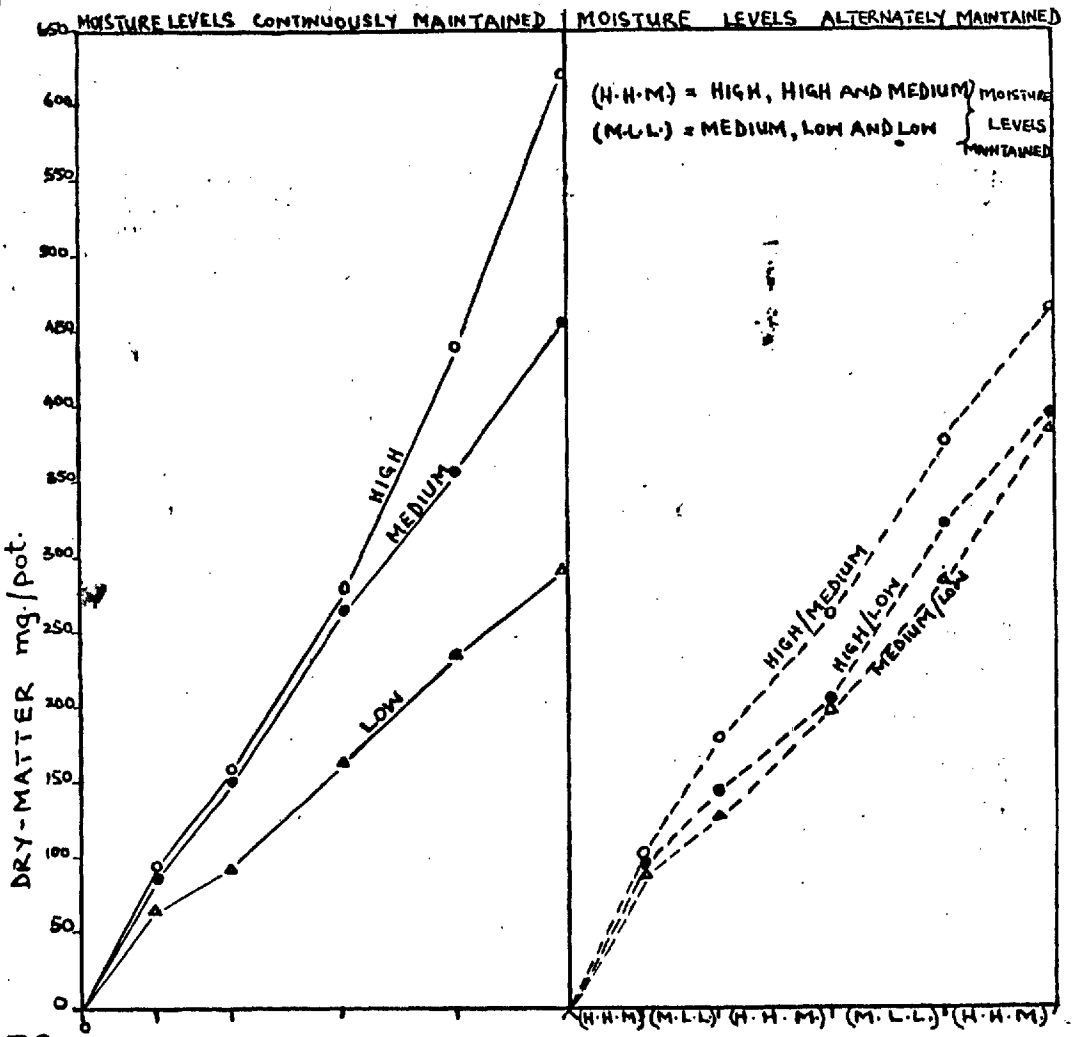
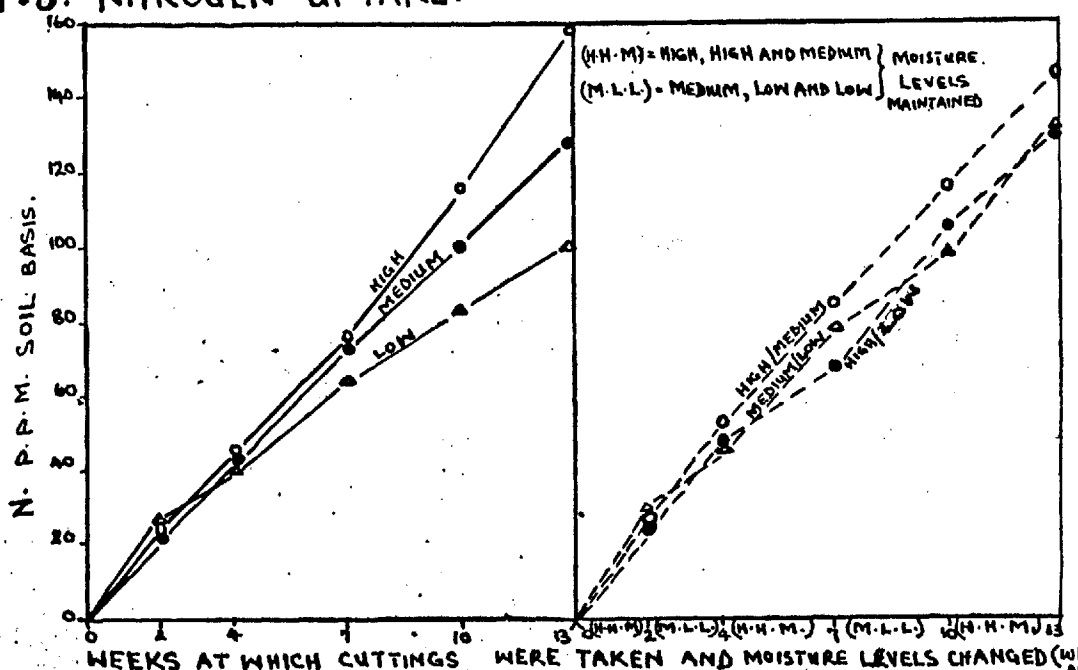


Fig. 78: NITROGEN UPTAKE.



the cutting done after 4 weeks at which the nitrogen uptake in the soil maintained continuously at the low moisture level was lower than that in soil alternately maintained at the high and at the medium moisture levels.

Thereafter, the significance of the differences in nitrogen uptake between the different moisture treatments may be summarised as follows using the notations as used for dry-matter yields above.

At the third cutting done after 7 weeks:

H/M, M/L, H, M, H/L, L

At the fourth cutting done after 10 weeks:

H/M, H, H/L, M, M/L, L

At the fifth cutting done after 13 weeks:

H, H/M, M/L, H/L, M, L

Among the treatments where the moisture levels were alternated only the alternations of medium and low and of high and low moisture levels showed pronounced changes in nitrogen uptake as the moisture levels were changed. Alternation of medium and low moisture levels showed a greater uptake of nitrogen during the medium moisture phases than during the low moisture phases while the alternation of high and low

moisture levels showed a greater uptake of nitrogen during the low moisture phases than during the high moisture phases.

3. Phosphorus uptake (Fig. 79).

There were no significant differences in the phosphorus uptake between the different soil moisture treatments until the fourth cutting done after 10 weeks from which time the significance in the differences in phosphorus uptake between the different soil moisture treatments may be summarised as follows using the usual notations:

At the fourth cutting done after 10 weeks:

H, H/M, M, M/L, H/L, L

At the fifth cutting done after 13 weeks:

H, M, H/M, M/L, H/L, L

All treatments in which the moisture levels were alternated showed pronounced changes in phosphorus uptake as the moisture levels were changed. Alternation of the high moisture with the medium showed greater uptake of phosphorus during themedium moisture phase than during the high moisture phase. The alternation of the medium moisture with the low showed greater uptake of phosphorus during the medium moisture phases than during the low moisture phases. But when high moisture level was alternated with low, there was a greater uptake of phosphorus

PHOSPHORUS AND POTASSIUM UPTAKE BY RYE-GRASS TOPS GROWN IN SOIL CONTINUOUSLY MAINTAINED AT OR ALTERNATELY IRRIGATED AND DRIED BETWEEN 3 MOISTURE LEVELS.

Fig. 79: PHOSPHORUS UPTAKE.

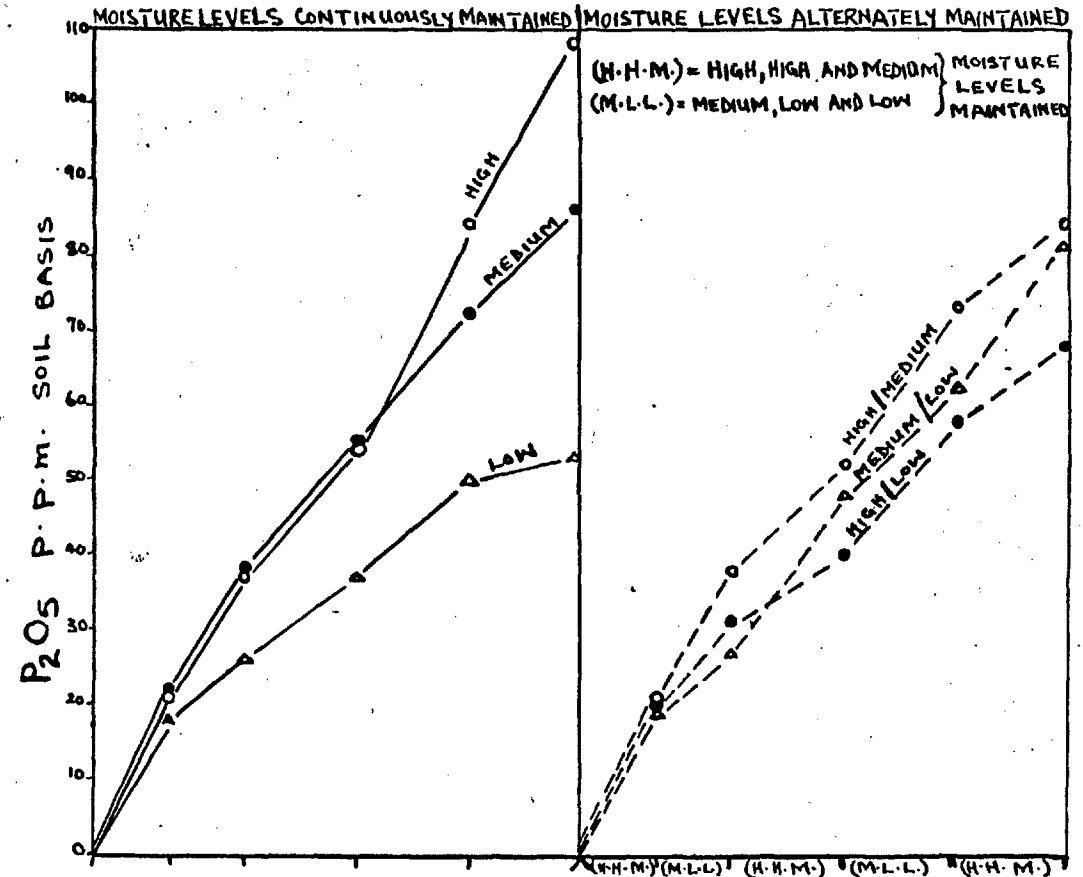
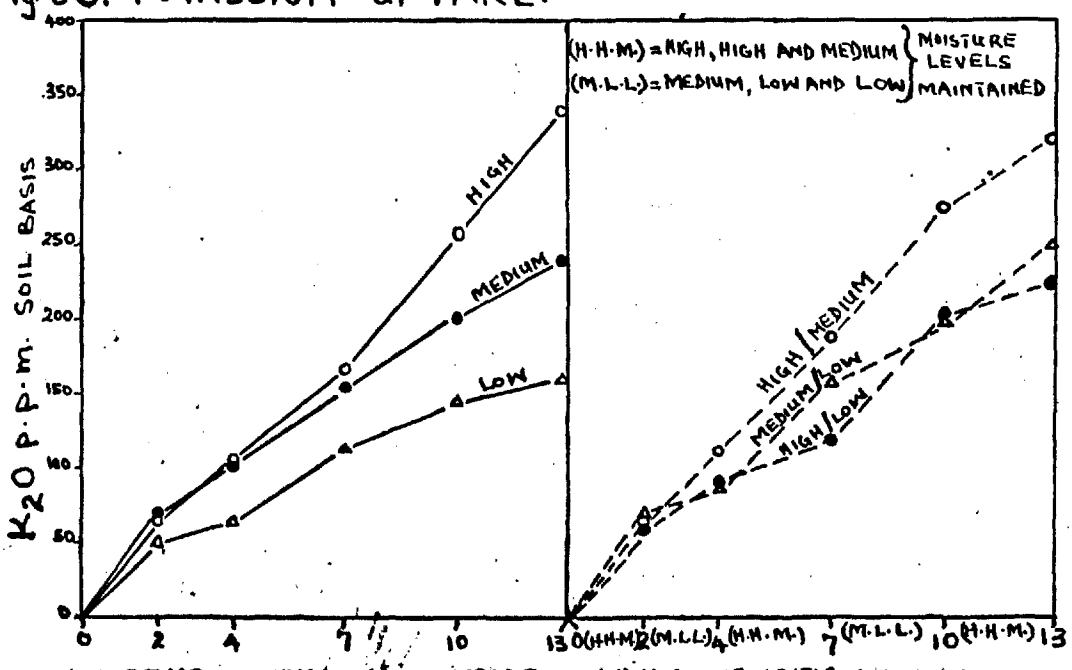


Fig. 80: POTASSIUM UPTAKE.



during the low moisture phases than during the high moisture phases.

4. Potassium uptake (Fig. 80).

There were no significant differences in the potassium uptake between the different soil moisture treatments in the first cutting after two weeks. Thereafter, the significance of the differences in potassium uptake between the different soil moisture treatments may be summarised as follows, using the usual notations:

At the second cutting done after 4 weeks:

H/M, H, M, H/L, M/L, L

At the third cutting done after 7 weeks:

H/M, H, M/L, M, H/L, L

At the fourth cutting done after 10 weeks:

H/M, H, M, H/L, M/L, L

At the fifth cutting done after 10 weeks:

H, H/M, M/L, M, H/L, L

Among the treatments where moisture levels were alternated, only the alternations of the high and the medium moisture levels with the low showed any pronounced change in potassium uptake as the soil moisture levels were changed. Alternation

of high with low moisture levels showed greater potassium uptake during the low moisture phases than during high moisture phases. Alternation of medium with low moisture levels showed greater potassium uptake during the medium than during the low moisture phases.

Generally, rye-grass performed better during the low than the high moisture phases when the high soil moisture level was alternated with the low moisture level. The performance of the rye-grass at the end of the experiment was generally best at the continuously high moisture level and worst at the continuously low moisture level. The performance of the rye-grass was equally good when the soil moisture level was maintained continuously at the medium or alternately raised to high or medium and reduced to low. When the high moisture level was alternated with the medium, rye-grass generally performed as well as when the high moisture level was continuously maintained, except in the case of phosphorus uptake where the performance under continuously high moisture level was much better than when the high moisture level was alternated with the medium.

(ii) Discussion.

The general increase in total dry-matter yields and nutrient uptake by rye-grass tops with increasing soil moisture level up to 80% m.w.h.c. when moisture levels were continuously maintained, agrees with results obtained by Schumaker and Davis (1961), Jenne et. al. (1958) and Low and Piper (1960).

Finn et. al. (1961) explained this by supposing that grasses tended to respond negatively to increased oxygen availability. This explanation might be valid for moisture levels up to 80% m.w.h.c. because Schumaker and Davis (1961) and Low and Piper (1960) found that dry-matter yields of western wheat-grass and rye-grass decreased as the soil moisture was further increased to levels higher than 80% m.w.h.c.

The similarity in the dry-matter yields and in total nitrogen and potassium uptake at the end of the experiment between continuously maintaining the high moisture level and alternating it with the medium moisture level may be due to the fact that in the cycles of alternations, the high moisture phases stimulated the performance of the rye-grass through the moisture effect while the medium moisture phases stimulated it through the possible greater availability of nitrogen than during the high moisture phases. This was possible since nitrification would be greater at the medium moisture level than at the high as shown in Chapter III. Thus during the alternations of high with medium moisture levels, the dry-matter yields and nitrogen and potassium uptake were each similar whether the phase was of the high or of the low moisture level.

The above observation may also explain why the rye-grass generally performed better when the high moisture level was alternated with the medium than when the medium moisture

level was continuously maintained. Whereas nitrification rate falls off with time at a constant soil moisture level, (Birch 1958) changing a high moisture level, which is unfavorable to nitrification, to a medium moisture level would stimulate greater nitrogen mineralization as shown in Chapter III during the medium moisture phases. The effect of this in stimulating the growth and performance of rye-grass coupled with the better performance during the high moisture phase would ensure better performance of the grass than when the soil moisture level was continuously maintained at medium.

This whole concept may also explain the similarity in the performance of rye-grass when the soil moisture was continuously maintained at medium and when it was alternated between medium and low. Since the nitrification during the medium phases of the cycles would be increased due to the drying effect of the low phases, compared with the corresponding nitrification when the moisture level was continuously maintained at medium, it would compensate for the reduced nitrification during the low phase. Thus better performance of rye-grass in the medium and worse performance in the low moisture phases during alternations than in the corresponding periods when the soil was continuously maintained at the medium moisture level would ensure equal performance under the two treatments by the end. This would also result in a better performance than when the soil was continuously maintained at the low moisture level.

The performance of the rye-grass during the alternation of the high and the low moisture levels was as good as the performance when the soil was continuously maintained at the medium moisture level. This might be expected since during the alternations, the crop has alternate phases of growth stimulating and retarding conditions. Their summation produced an overall performance which was as good as the performance at the continuously maintained medium moisture level. Since the low moisture phases stimulated performance more than the high moisture phases, factors other than the moisture itself must be operating. It might be that the sudden changes in the redox potential involved here had a bearing on the physiological activity of the rye-grass plants, and through this on the uptake of nutrients.

In this connection it is observed that it was only in phosphorus uptake that continuously maintaining the moisture level at high was better than alternating high with medium moisture levels, which was in turn as good as all other treatments except continuously low moisture level. It would seem that during the medium moisture phases (high redox potential) the iron and phosphorus mobilized during the high moisture phases were precipitated whilst under continuously high moisture level, (low redox potential) phosphorus was always mobilized (Shapiro and Armiger (1958)). This alternation of mobilization and precipitation probably caused a reduction in phosphorus uptake compared with a continuous mobilization.

Since differences in nutrient uptake became significant much earlier than the differences in dry-matter yields,

it would seem that the soil moisture treatments affected the performance of the crop more through the metabolism of nutrients than through the growth of the rye-grass. The results may explain why continually varying soil moisture conditions (short dry and rainy periods) may not substantially affect the growth of crops in the field. They also show that when nutrient uptake by the crop is hampered by the adverse soil moisture conditions of one phase, there is an increased uptake of nutrients by the crop during the favourable soil moisture conditions in the following phase. The crop may thus perform as well as if it had been grown under continuously favourable soil moisture conditions.

This general behaviour of the crop may be compared to the behaviour of micro-organisms whose population and activities increase on their being returned to favourable soil conditions (including moisture) after having been subjected to adverse conditions. The crop thus seems to recover from a lull in metabolic activity when favourable soil moisture conditions replace adverse conditions just as micro-organisms more than recover their activities after a partial sterilization treatment.

Conclusion.

(A) The effect of alternate wetting (to three moisture levels , 20%, 50% and 133% of the maximum water holding capacity) and air-drying on the mineralization of nitrogen and the availability (Morgan's extract) of phosphorus and potassium

in soil 9 and 2 was studied with incubation during the wet phase. (B) The effect of alternate raising and lowering the soil moisture levels compared with maintaining them continuously at 20%, 50% and 80% of the maximum water holding capacity on the performance of rye-grass in soil 2, was also studied.

(A) 1. When 20% or 50% was alternated with air-drying NH_4-N decreased during the wet phase and increased during the dry phase. This was probably due to the nitrification during the wet phase and the accumulation of ammmonia during the dry phase when nitrifying bacteria were inactive.

2. Also, when 20% or 50% was alternated with air-drying NO_3-N increased during the wet phase and decreased during the dry phase until a maximum value was reached at the end of a wet phase. The increase was probably due to nitrification of accumulated ammonia and that derived from organic matter decomposition during the wet phase. During the dry phase the decrease in NO_3-N was probably due to microbial immobilization.

3. After a maximum NO_3-N level had been reached in soil 2, NO_3-N decreased and remained constant despite further wetting and drying. This may be due to the high level of mineral nitrogen causing nitrogen immobilization to predominate over mineralization.

4. When 133% was alternated with air-drying, NH_4-N remained high and NO_3-N remained low despite wetting and drying. This was probably due to the fact that nitrifying

bacteria were inactive at both water-logging and air-drying.

5. NO_3-N was generally higher at 50% than at 20% during the wet phases but similar during the dry phases. This was probably due to a greater microbial activity at 50% than at 20%.

6. Each wet phase increased NO_3-N more than the previous one until the maximum NO_3-N was attained, when 20% or 50% was alternated with air-drying. This was probably due to the partial sterilization effect of the intervening air-dry phases and the decomposition of the dead cells of the micro-organisms of the previous wet phase.

7. When 20% ar 50% was alternated with air-drying the available phosphorus increased during the dry phases and decreased during the wet phases in soil 9 (low original available phosphorus). In soil 2 (high original available phosphorus), the reverse was the case. The three cycles of alternate wetting and air-drying caused ultimate phosphorus release in soil 9 and phosphorus fixation in soil 2. This might be due to an equilibrium state in soil phosphorus.

8. When 133% was alternated with air-drying, phosphorus was greatly mobilized during the wet phases and fixed during the dry phases. This might be due to the reducing conditions under 133% causing a reduction of insoluble ferric phosphates to soluble ferrous phosphates. The reverse process occurred

during the dry phases but because ferric compounds other than phosphate were reduced during the wet phases, more phosphorus was fixed than mobilized.

9. When each of the moisture levels 20%, 50%, or 133% was alternated with air-drying, available potassium decreased in the wet phase and increased in the dry phase of the first cycle, but thereafter, the available potassium decreased continuously despite alternate wetting and drying. This might be due to the presence initially of clay minerals with expanding lattices which were later changed to those whose lattices did not expand as a result of trapping potassium ions within the lattices.

10. In the first cycle, the fixation during the wet phase and the release during the dry phase increased with increasing moisture level of the wet phase but thereafter the differences in potassium fixation between the moisture levels of the wet phases were non-significant. This strengthened the argument for the possible presence initially of clay minerals with an expanding lattice later being converted to those whose lattices did not expand on hydration.

(B) 1. When the high or medium moisture level was alternated with the low, rye-grass performed as well as under continuous medium moisture level better than under continuous low moisture level and worse than when the high moisture level was alternated with the medium. Under the last condition, rye-grass performed

as well as under continuous high moisture level except for phosphorus uptake where the latter treatment was better.

2. A greater proportion of the effects of these moisture treatments on rye-grass performance was due to their influence on nutrient uptake rather than on dry-matter yields.

3. Even so, when the nutrient uptake was hampered by unfavourable soil moisture conditions of any phase during the alternations of the moisture levels, there was an increase in nutrient uptake during the favourable conditions in the subsequent phases, thus compensating for the deficit obtained in the unfavourable phase. This effect is similar to the recovery of micro-organisms given favourable conditions after their activity has been reduced by an unfavourable treatment e.g. partial sterilization.

CHAPTER X

GENERAL SUMMARY AND FINAL CONCLUSIONS

GENERAL SUMMARY

Carbon and nitrogen mineralization, and the Morgan's extracted phosphorus and potassium were determined at three-weekly intervals in soil 2 maintained at constant moisture levels between air-dry and 133% m.w.h.c. during incubation for 12 weeks and in the same soil whose moisture levels below and above 50% m.w.h.c. were changed to 50% and moisture levels up to 50% were changed to 133% m.w.h.c. half way through the 12 weeks.

When the soil moisture was maintained at constant levels, carbon and nitrogen mineralization increased with increasing moisture level up to about 60% m.w.h.c. for carbon and 40% to 50% m.w.h.c. for nitrogen. Thereafter, carbon and nitrogen mineralization decreased generally with increasing soil moisture level. This was supposed to be due to the effect of the deficit in soil moisture limiting microbial activity for the lower moisture levels and to the effect of excess soil moisture in limiting microbial activity through the restriction of the availability of oxygen.

Moist fixation of phosphorus and potassium was observed for moisture levels up to 70% m.w.h.c. Thereafter phosphorus was mobilized with a further increase in soil moisture level whilst potassium was fixed further. The phosphorus fixation at moisture levels up to 70% m.w.h.c. were probably due to the presence of hydrated iron and aluminium oxides which would fix

phosphorus under moist conditions whilst the mobilization of phosphorus at the higher moisture levels was due to the reduction of insoluble ferric compounds including phosphates to soluble ferrous compounds. The moist fixation of potassium was probably due to the fact that the soil was limed annually prior to sampling and moist fixation of potassium is known to be caused by lime additions.

When the original soil moisture levels were changed to 50% from below and above 50% m.w.h.c., carbon and nitrogen mineralization increased compared with that in soil left at the original moisture level. This was thought to be due to the partial sterilization effect of the adverse moisture levels below and above 50% m.w.h.c. prior to the change in moisture levels. Phosphorus and potassium did not change much when moisture levels below 50% were changed to 50% m.w.h.c. but when moisture levels above 50% were changed to 50%, the fixed potassium was released and the mobilized phosphorus fixed.

Following this, carbon and nitrogen mineralization was determined at three-weekly intervals when soil 1 was brought to different pH levels (4.7-7.8) by the addition of aluminium chloride or calcium carbonate, and maintained at different moisture levels during incubation. It was found that as before the carbon and nitrogen mineralization

increased with increasing moisture level to between 50% and 70% and then decreased with a further increase

in soil moisture level only when the soil pH was above 5.80. At the low pH (4.72) the soil moisture level had no differential effect on carbon and nitrogen mineralization. Micro-organisms functioning at this low soil pH were probably not affected by moisture levels used.

When carbon and nitrogen mineralization and available (Morgan's extracted) phosphorus and potassium were determined in soil 1 in the presence of added oat straw and compost, differences between the different soil moisture levels (20%, 50% and 133% m.w.h.c.)) in carbon mineralization were significant only in the presence of oat straw, which contained a high proportion of easily mineralizable organic carbon compared with soil humus or compost. Under anaerobic conditions (133% m.w.h.c.) the mineralization of carbon was however similar and low for the straw, compost and soil alone indicating that even when easily mineralizable organic carbon is present respiration may be low under anaerobic conditions.

Under the organic matter treatments, lag periods occurred before nitrogen accumulation was obtained at all moisture levels. This lag phase might be due to immobilization of nitrogen at the aerobic moisture levels, and immobilization plus possible denitrification under waterlogging. Also at the aerobic moisture levels phosphorus, and at all moisture levels potassium, derived from the

organic matter were fixed probably by micro-organisms whilst at 133% phosphorus was as usual mobilized, more so in the presence of the added organic matter than in the soil alone. More organic acids derived from anaerobic decomposition of the added organic matter was probably responsible for this result.

Total nitrogen balances were studied at 20%, 50% and 133% during incubation of soil 1 with added organic matter at different soil pH levels (4.7-8.0) and added inorganic nitrogen. In the absence of added inorganic nitrogen, addition of organic matter stimulated atmospheric nitrogen fixation presumably by providing energy material. When the added organic matter was low in total nitrogen (oat straw) atmospheric nitrogen fixation increased with increasing moisture level but when high in total nitrogen (composted oat straw), atmospheric nitrogen fixation decreased with increasing moisture level. In the presence of added inorganic nitrogen, loss of nitrogen from NH_4-N increased with increasing pH and at the high pH increased with moisture level and was further stimulated by organic matter addition. Loss of nitrogen from NO_3-N however increased with moisture level, was further stimulated by the addition of organic matter (more so by straw than by compost) and tended to be at a maximum at a pH 6.40.

Under growing rye-grass and rice plants, the nitrogen lost in the early part of the growth of the rye-grass

was recovered in the later part when algae had developed on the surface of the soil. The extent of nitrogen fixation by these algae increased with increasing soil moisture level during the crop growth.

When no nitrogen was applied rye-grass and rice tops performed nearly as well at all moisture levels (20%, 50% and 80% m.w.h.c. for rye-grass and "upland" and water-logged moisture conditions for rice). When nitrogen was applied, dry-matter yields and nitrogen, phosphorus and potassium uptake increased with increasing moisture level, NO_3-N application resulting in a better performance by rye-grass than did NH_4-N. NO_3-N stimulated higher dry-matter yields but a lower phosphorus uptake by rice tops than did NH_4-N.

Since the rice tops performed equally well, when no nitrogen was added, at the "upland" and water-logged moisture levels (submerged under 1 cm. of water) the possibility of greater heights of submergence producing a better performance of whole rice plants was examined in soils 1 and 2. It was found that the performance of whole rice plants became progressively better as the height of the water of submergence increased up to 5 cm. It was further found that as height of water increased the contribution of the roots to the performance of the whole plant also increased. Thus under this height of water of submergence, rice seedlings were found to perform better under water-logging than under "upland" soil moisture level

provided the soil was not in a very advanced state of reduction during water-logging prior to the transplating of the seedlings.

Attention was then turned to the effect of soil drying on nutrient metabolism during subsequent wetting. It was found that carbon and nitrogen mineralization increased on wetting and incubation of soils 1, 3, 4, 5 and 6, when the soils were previously air-dried compared with no drying and this increase in carbon and nitrogen mineralization increased with increasing period of air-dry storage prior to wetting. This was probably due to the partial sterilization effect of the drying.

Under growing rye-grass in soils 7, 8 and 9, however, this effect of air-dry storage was not manifested in the uptake of nitrogen by the grass although potassium seemed to be released to the crop by the air-drying of soil 9 (low Morgan's extractable potassium) and seemed to be fixed against crop uptake in soil 8 (high Morgan's extractable potassium).

The partial sterilization effect of air-drying might also explain the greater nitrification obtained in each successive wet phase when soils 2 and 9 were alternately incubated wet at aerobic moisture levels and then air-dried. Thus the partial sterilization effect arose from the intervening air-dry phases. Under these alternate wetting and air-drying treatments, NH_4-N decreased and NO_3-N increased during the wet phases whilst during the dry phases, the reverse was the case.

This, plus the fact that when water-logging was alternated with air-drying NH_4-N remained continuously high and NO_3-N low, indicated that nitrifying bacteria were inactive at both air-dry and water-logging moisture regimes whilst ammonifying micro-organisms were active at all moisture regimes from air-dry to water-logging, thus causing ammonia to accumulate whenever it could not be nitrified.

Furthermore, when the aerobic moisture levels were alternated with air-drying, phosphorus was released from the soil 9 (low phosphorus status) but was fixed in the soil 2 (high phosphorus status). Phosphorus was greatly mobilized during the wet phases and fixed during the dry phases when water-logging was alternated with air-drying. Alternate wetting and air-drying at the end of three cycles however, caused a fixation of potassium in soils of both low and high potassium status.

Following this, rye-grass was grown in soil 2 under constant soil moisture levels of 20%, 50% and 80% m.w.h.c. and under regimes where moisture was alternated between these levels. The grass performed progressively better as the constant moisture levels increased. This was in contrast with results obtained earlier with soil 1 where the performance of rye-grass was similar at all moisture levels and confirmed the suggestion that the low nitrogen status of soil 1 was responsible for the lack of difference in the performance of rye-grass at the different moisture levels.

The performance of rye-grass when the high was alternated with the low moisture levels was as good as when a constant high moisture level was maintained and better than when a constant medium moisture level was maintained. The latter was better than when a constant low moisture level was maintained and was as good as when the medium or high was alternated with the low moisture levels. During the alternations of the moisture levels, rye-grass performed better during the more favourable phases than during the corresponding period at the constant favourable moisture level, thus compensating for the deficit in the performance during the less favourable moisture phases. This effect of unfavourable moisture conditions is similar to the partial sterilization effect of air-drying soils on subsequent microbial activity.

FINAL CONCLUSIONS

After studying the effect of soil moisture on nutrient metabolism in incubation and pot tests, the main conclusions reached were as follows:

Microbial activity, as measured by organic matter decomposition in soils occurred even below the permanent wilting moisture percentage. Carbon and nitrogen mineralization increased with increasing moisture level up to about 60% m.w.h.c. and then decreased with a further increase in

moisture level. Soil moisture was thus a controlling factor in organic matter decomposition up to about 60% m.w.h.c., whilst its effect at higher moisture levels was mainly through its restriction of oxygen availability.

In the presence of added organic matter (oat straw and compost) there was always a lag before mineral nitrogen accumulation occurred in the soil, the lag period being shortest at about field capacity and longest under water-logging. The lag was probably due to microbial immobilization.

In soil of low pH (4.70), soil moisture levels between 20% and 133% m.w.h.c. had no differential effect on carbon and nitrogen mineralization but as the soil pH increased up to 7.70, carbon and nitrogen mineralization increased with moisture level to about 60% m.w.h.c. and then decreased as usual with further increases in soil moisture level.

In the absence of added inorganic nitrogen, addition of organic matter of low nitrogen content during incubation generally stimulated atmospheric nitrogen fixation, more so at the higher than at the lower moisture levels and especially at a soil pH around 6.50. When inorganic nitrogen fertilizers were applied it was observed that nitrogen losses from added nitrate-nitrogen became serious only when the soil moisture level and nitrate and organic matter additions were high, whilst losses from added ammonia nitrogen became serious only at soil pH levels; at high pH ammonia losses were stimulated by high soil moisture levels and the presence of added organic matter.

Under rye-grass and rice crops, losses of added nitrogen at higher moisture levels in the early stages of growth might be mitigated by the development of algae which are capable of fixing atmospheric nitrogen.

Although there were variations in the Morgan's extracted phosphorus under aerobic soil moisture conditions and in extracted potassium under all moisture conditions during incubation, these variations were not clearly reflected in the uptake of these nutrients by rye-grass or rice under similar soil moisture conditions. Instead, their uptake tended to follow trends similar to that of dry-matter yields. During incubation at high soil moisture levels, phosphorus was generally greatly mobilized. The lack of a luxury consumption of this mobilized phosphorus by rye-grass or rice compared with the luxury consumption of potassium where it was added in nitrate nitrogen treatments would indicate that the mobilized phosphorus was not all available to the plant although it might prevent phosphorus deficiency.

When rye-grass was grown at soil moisture levels between 20% and 80% m.w.h.c. and rice at "upland" and water-logged soil moisture regimes, the crops performed better at the higher than at the lower moisture levels provided the general nutrient status of the soil was adequate. Thus where rye-grass was grown in a soil of low nitrogen status, it performed better at the higher than at the lower moisture

levels only when nitrogen fertilizers were applied but where it was grown in a soil of high nitrogen status it performed better at the higher than at the lower moisture levels without nitrogen application.

In the case of rice, however, the performance became progressively better as the height of the water of submergence increased, the roots contributing more to the whole plant performance under water-logging than under "upland" soil moisture condition. This led to the suggestion that the secret of the general better performance of rice plants under water-logged than "upland" moisture conditons might lie in the greater root development in response to the low oxygen pressure or some growth promoting substances derived from the complex anaerobic processes, bearing in mind that the development of rice seedlings might be hampered by a very advanced state of reduction in water-logged soils prior to transplanting.

When a soil moisture condition which hampered microbial activity or crop performance was changed to a more favourable one, microbial activity or crop nutrient metabolism increased compared with that prevalent under a continuously favourable moisture condition. Thus raising the soil moisture level from below 20% and lowering it from above 50% to 50% m.w.h.c. caused greater increases in carbon and nitrogen mineralization than maintaining the moisture level continuously at 50% m.w.h.c.

Air-dry storage of soils prior to wetting and incubation caused greater increases in carbon and nitrogen mineralization than no drying and when soils were alternately incubated at aerobic moisture levels and air-dried, every wet phase increased nitrification more than did the previous one. When rye-grass was grown under alternating moisture conditions, it performed better during the favourable phases than in the corresponding period under the continuous favourable condition.

The above observed results were possibly due to a partial sterilization effect of the adverse moisture condition as far as incubation tests were concerned. An effect similar to this seemed to apply to the rye-grass as well and may apply to other crops since Forward (1953) showed that the respiration of potato tubers increased on restoration of aerobic conditions, compared with that prevalent under continuous aerobic conditions, after storage under an atmosphere of nitrogen. It would seem therefore that variations in the soil moisture regime including spells of unfavourable moisture conditions affected the metabolism of nutrients in the soil and in plants through this phenomenon.

In general, useful as soil chemical analysis might be as a method of evaluating the availability of nutrients to crops, the soil nutrient status determined under the various moisture conditon by chemical tests did not truly

reflect the availability of the nutrients to rye-grass and rice. In this connection the study of the partial sterilization effects of air-dry storage of soils prior to wetting compared with no drying on the availability of nitrogen did not seem to have a practical applicability.

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