The effects of nitrogen fertilizer and two drilling methods on the development, yield and grain quality of wheat (*Triticum aestivum* L. THELL)

By

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Abstract.

Agronomic practices influencing the establishment, development, yield and grain quality of wheat were investigated. The main husbandry treatments tested were drilling pattern (suffolk and band coulters), plant population density, rate and timing of nitrogen fertilizer, density x nitrogen and nitrogen x timing interactions. Crop growth analyses were used to provide information on the response of winter and spring wheat varieties to these various agronomic treatments.

Band coulter drilling resulted in a higher (NS) plant population m-2 and a significant ($P<0.05$) increase in total plant biomass m-2 than the suffolk coulter drilling system. However, individual plant dry weight, number of grains per ear, thousand grain weight and the final grain yield lowered (NS) by the former technique. It was concluded that band drilling was not advantageous for soil conditions at the Wye College Farm.

In the winter wheat trials of 1986/87 (experiment 2), plant populations within the range 200-500 seeds m-2 increased the total plant biomass but decreased individual plant dry weight due to lower numbers of tillers per plant. The number of spikelets per ear, number of grains per ear and thousand grain weight were decreased with increasing plant population density. Grain yield was higher (NS) with the medium density (350 seeds m-2). In the spring wheat variety (Axona) the number of spikelets per ear, number of grains per ear and the thousand grain weight were also decreased by higher plant population. However, the final combine grain yield was slightly increased (NS).

Application of N in the range 0-250kg/ha to winter varieties, and 80-170kg/ha to a spring variety increased total plant dry matter m-2 and per plant due to increased tiller formation. The final number of ears

m-2 as well as spikelets per ear also increased (NS) in the variety Axona. However, number of grains per ear and the thousand grain weight were decreased in both varieties. In the winter wheat variety Slejpner, grain yield increased up to 175kg/haN but decreased with the highest level of 250kg/ha. With the spring variety, grain yield was increased (NS) by additional N from 80-125kg/ha, but raising the N fertilizer level to 170kg/ha did not result in any increase in grain yield. However, grain protein content increased linearly with the additional N from 80-170kg/ha. Hagberg falling number also increased (NS) within the range tested in spring variety during 1989 growing season. Although higher levels of N fertilizer influenced grain yield and quality, its effect on the environment has also now become a topic of controversy, hence correct time of application is very important if this problem is to be averted.

Treatment with N at GS12-13 and GS14 in the spring wheat trials increased total plant biomass and the individual plant dry matter due to an increase in the number of tillers per plant. Number of ears m-2 and the number of spikelets per ear were also increased both in 1988 and 1989. The number of grains per ear as well as the final combine grain yield increased with the early application of N in 1988 but decreased in 1989. Late application of N at GS30 and GS32 increased (NS) the number of grains per ear and final grain yield in 1989. In contrast these variables decreased (NS) linearly with these treatments in 1988. Delayed application of N both in 1988 and 1989 increased thousand grain weight and grain protein content significantly ($P<0.05$). In 1989 treatment with N at the later growth stages (GS30 and GS32) resulted in a slight increase in Hagberg falling number. Timing of N at GS30 and GS32 on winter wheat during the 1988/89 growing season resulted in a significant ($P<0.05$) increase in grain yield over the control zero N input. However, application of N after GS21-23 had no effect on grain protein content, although it was increased when compared to the control treatment (N0).

Due to the dry and hot growing season in 1989, results were obtained and discussed from widely contrasting weather situation. This made treatment comparisons between seasons both difficult and stimulating.

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GENERAL INTRODUCTION.

General introduction.

The importance of wheat in world agriculture cannot be overestimated. Its cultivation probably began as early as 10,000 B.C, it continues to exceed other cereal crops in total production, and it ranks essentially equivalent to rice as the formost crop for nutrition of mankind (Olson, 1989). Wheat is the major food for about 35% of the world's people and is the staple diet of some 43 countries of the world. Pre-eminence of wheat for human consumption is due in considerable part to the unique properties of wheat protein which form gluten that permits the dough from mixed flour and water to retain gas needed for bread production. The protein component serves as an invaluable role in the diets of many people. Virtually all countries having less than 60 grammes daily protein intake per capita are found in tropical regions where wheat is not the staple food crop. Among the three major cereals, wheat diets would require no protein supplement, while modest protein supplementation is needed for rice and maize if all the daily energy requirements were provided by a cereal grain. The agronomy, quality and the uses of wheat as grain are extensively reviewed in this thesis (sections 1.7, 1.4 and 1.5).

Total world cereal production (million tonnes).

Crops.	Total production (mt).
Wheat	502
Rice	452
Maize	370
Barley	173
Sorghum	57
Oats	39

Source: EIU, World Commodity Outlook (1989).

This post-graduate study was undertaken during a period (1987-1989) when the European Economic Community (EEC) was trying to reduce the

total production of small grain cereals such as wheat. A reduction in the area of land (especially poorer grade 3 and 4 soils) under wheat therefore means that production systems that result in maximum grain yields per unit area must be available for more fertile sites. Thus, a means of establishment that would guarantee the best spatial distribution for maximum interception of solar radiation must be researched. Alternative seed drilling techniques that may provide even plant arrangement should be explored. With this objective in mind a different drilling method (band drilling) from that normally used (suffolk drilling) in the UK agriculture was tested (Plates 1 & 2).

It is also of parmount importance to now accept that grain yield is not the only characteristic which must be discussed in relation to the present EEC grain 'mountain'. Production systems that increase the quality of the grains must also be explored. In the past decade, the participation of UK wheat growers in the import of quality wheat has decreased drastically (see literature review pages 24-25). If this trend is to continue, then a change in direction in the present agronomic research on high yielding wheat production techniques is eminent. Agronomic practices such as the correct timing of fertilizer N application will hopefully result in increased grain quality (especially protein level). However, the environmental implications of split applications and higher levels of N must also be questioned. Application of N requires a judicious method in order to reduce the environmental hazards caused by nitrate leaching into drinking water and water courses. The ideal way is to apply the N fertilizer precisely when the crop needs it. Thus, timing of N application becomes an important topic for present and future research if environmental pollution caused by nitrate leaching is to be averted.

Present varieties of spring wheat are an ideal source of grains for breadmaking grists. Thus future wheat production systems should be

geared towards lower yielding, quality spring varieties. In addition to their potential as a source of quality grain, spring varieties also require less fertilizer N. This will help to reduce the continuous outcry from Environmentalists and 'Green Peace' about the present environmental problems attributed to so many UK farmers. In present UK agricultural production systems, spring wheat has been given less research attention despite its potential as a source of quality grain and its possible role in reducing pollution by nitrate levels. With these thoughts in mind the present Ph.D study was undertaken to explore agronomic practices that may result in increased grain quality without having a significant deleterious effect on grain yield. Different drilling patterns, plant populations, N levels and time of its application were tested. Detailed grain development and growth analyses to ascertain the impact of the treatments on grain quality were carried out. The experimental procedures used are fully described in the materials and methods (section 2.2, pages 61-69).

Plate 1. Crop establishment using the suffolk coulter drill.

(The photograph illustrates the 24 suffolk coulter rows. Plot width (3m) extends between the two small white markers).



Plate 2. Crop establishment using the band coulter drill.

(The photograph illustrate the 12-double band rows. Plot width = 3m).



SECTION 1.

LITERATURE REVIEW.

CHAPTER I.

Literature Review.

1.1.Botanical description and origin of wheat.

The wheat plant Triticum spp, is a member of the grass family; Gramineae. Wild and cultivated wheat belong to the genus Triticum. There are fourteen commonly recognised species of Triticum. The species are divided into three subgroups - "diploid, tetraploid and hexaploid" - based on the number of chromosomes in their reproductive cells. Almost all the world wheat is hexaploid, known botanically as Triticum aestivum L., and is the subject of this study.

Wheat is an ancient crop plant. Its cultivation probably began as early as 10,000 B.C., it continues to exceed other cereal crops in total production (Olson, 1989). Its grain may be either hard or soft in texture and its colour may be brownish, red or white.

The cultivation of wheat is thought to have originated in the Fertile Crescent of Middle East, bounded on the east by the Zagros Mountain system, on the north by the Taurus Mountains, and on the west by the Mediterranean. Today, approximately 241million hectares of wheat are planted in the world. In 1987, the world total production of wheat was 516.8 million tonnes, compared to 457.4 and 454.3 million tonnes for maize and rice respectively ranking second and third in the world production (FAO, 1987). Wheat is the major food for about 35% of the world's people, is the staple food of some 43 countries of the world, and it ranks essentially equivalent to rice as the formost crop for the nutrition of mankind (Olson, 1989).

1.2.Wheat production in the UK.

In the United Kingdom, wheat is the most important crop. The market situation, and the improvement in yield due to advances in technology of wheat production encouraged an increase in the area sown over the past decade. For example, average yields of wheat increased from 4.1t/ha to 6.75t/ha during the period 1968 to 1989 (Table 1.1). The most significant improvements in productivity have been achieved in wheat production systems. From 1945, the mean rate of increase in the yield of winter wheat varieties has averaged 0.090t/ha/year, whilst for spring barley the corresponding figure is 0.057t/ha/year. More accurately, the rate of improved output should be divided into three periods, (Table 1.2). After rapid improvements especially in husbandry techniques following the end of World War 2, a yield plateau was reached during the sixties. In the 1988 growing season, the total land area under wheat cultivation was about 1.891million ha, with an output of about 6.13t/ha, and 1.895million ha of barley which yielded approximately 4.64t/ha (Harvest Review, 1988 & 1989). Table 1.3 shows wheat and barley production from 1969 to 1989 in the U.K.

1.3.EEC production.

Total EEC grain production has risen from approximately 138 million tonnes in 1983 to 155 million tonnes during the 1986/87. present average yields throughout the member countries (including Spain, Portugal and Greece) are around 5.8 and 5.0t/ha for wheat and barley respectively. In 1988 the total production from the EC-12 was 161million tonnes. It is estimated that by 1990, and with a virtually static demand, the EEC will have to store, on average 30million tonnes of cereal each year.

Table 1.1. Average and high yields (t/ha) of winter wheat and barley 1968 to 1989.

Year	W.Wheat		S.Barley.		W.Barley.	
	Average.	High.	Average.	High.	Average.	High.
1968	4.14	4.76	3.76	4.39	-	-
1972	4.27	5.02	3.64	4.27	-	-
1974	4.39	5.02	3.77	4.39	-	-
1976	4.50	5.25	3.90	4.50	-	-
1978	4.50	5.65	4.00	5.00	-	
1980	5.00	6.00	4.00	4.80	4.50	5.30
1981	5.25	6.25	4.10	4.80	4.70	5.30
1982	5.50	6.50	4.20	4.80	4.80	5.50
1983	5.75	7.00	4.30	5.00	4.90	5.70
1984	5.90	7.20	4.30	5.00	5.00	5.80
1985	6.30	7.70	4.40	5.30	5.30	6.50
1986	6.75	8.50	4.50	5.50	5.60	7.00
1987	6.50	8.00	4.50	5.50	5.50	6.75
1988	6.70	8.00	4.70	5.50	5.60	7.80
1989	6.75	8.00	4.70	5.50	6.65	6.75

Sources: Scarisbrick, D.H.; Chatham, C.J. and Hill, P. (1988).
NIX, J. (1989).

Table 1.2. National average wheat yields from 1946 to 85.

Year	Yield (t/ha)	Rate of increase (t/ha/year).
1946-61	2.31 - 4.21	0.119
1962-72	4.27 - 4.33	0.005
1973-81	4.27 - 5.59	0.147
1981-85	5.59 - 7.71	0.530

Source: Scarisbrick, D.H.; Chatham, C.J. and Hill, P. (1987).

Table 1.3. UK wheat and barley production 1969 to 1989 (area'000ha and yield t/ha).

		1969/70.	1977/78.	1983/84.	1984/85.	1985/86.	1986/87.	1987/88	88/89
Wheat.	Area	833	1,076	1,965	1,939	1,997	1,994	1,891	2,106
	Yield	4.04	4.90	6.80	7.71	6.97	5.99	6.13	6.55
Barley.	Area	2,413	2,400	1,967	1,978	1,917	1,830	1,895	1,662
	Yield	3.59	4.39	5.35	5.39	5.22	5.04	4.64	4.81
Total.	Area	3,246	3,476	3,932	3,917	3,868	3,824	3,786	3,768

Source: Harvest Review (1988 & 1989); Scarisbrick, D.H.; Chatham, C.J. and Hill, P. (1988).

1.4.Grain quality.

While high yields are particularly important to the grower, grain quality is also a major consideration. This is of vital importance if a premium price is paid above that obtained for normal feed grain. Breadmaking samples command the best premium. In the 1962 Edition of Flour Milling, Sir Joseph Lockwood defined the most important qualities of wheat for milling and baking as strength, colour, flavour and flour yielding properties. Strength being defined as "the capacity of wheat to produce bread of high volume especially when blended with 'weaker' wheat types".

Millers have been pressurised into increasing quantities of UK grown wheat and have therefore had to evaluate and define more clearly

their quality requirements. From a total wheat production in the UK (Table 1.3), only approximately 2.5million tonnes is suitable for breadmaking in most seasons. However, the total milling requirement is around 3.2million tonnes. Therefore, there is a considerable shortfall in the supply of home grown quality wheat.

There has been greater pressure on wheat growers to produce quality grain since cereal production in the UK became greater than requirements. In response to EEC import tariffs, developments in cereal processing have enabled more home-grown wheat to be used. These developments have led to more specific quality criteria being needed from a greater quantity of UK home-grown grain. The purchase of surplus production by the Intervention Board for Agriculture Produce (IBAP), and by wheat exporters has also been increasingly dependent on grain quality meeting high standards. There is thus, additional need for cereal growers, their advisers, the ancillary trades, research workers and educationalists to understand wheat quality characters and the factors affecting them.

The increasing requirements for home-produced cereals has necessitated the use of more intensive cultivation methods, and has led to the introduction of more sophisticated agronomic practices including a more extensive use of N fertilizer. Due to the increasing level of wheat production in Northern Europe, it is becoming increasingly important for farmers to produce wheat that is sufficiently high quality to meet the requirements of the end users. There are several quality standards that must be met in order for wheat grain to be accepted by the Intervention board. If farmers are able to produce wheat that meets or exceeds these standards, then financial premiums are often available (Dampney, 1987). The main quality characteristics of wheat for EEC intervention standards are: high Protein content, high Hagberg falling number and high specific weight.

1.4.1.Protein.

Grain N (or protein) content is one of the most important quality criteria and satisfactory levels must be achieved if a sample of grain is going to be accepted for milling. Analysis for grain N is used as a quick and easy means of assessing the protein contents of grains, since it is usually assumed that all N contained in the grain is present as protein that is of value in the breadmaking process. According to Duffus (1987), protein is a key determinant of wheat grain quality and some of the mechanisms involved in its synthesis and deposition are described in relation to grain quality parameters. The EEC intervention support for protein content in wheat grains in all years is 12% at 0% grain moisture content (NIAB, 1988).

High protein content (measured as %N x 5.7) is regarded as essential. However, protein content measured this way takes no account of the non-protein nitrogen (NPN) fraction, which even in grain from unstressed plant constitute from 5.8% of the total grain N (Byers, Miflin and Smith, 1983). It also takes no account of the distribution and composition of the individual polypeptides comprising the grain storage protein. Duffus (1987), suggested that relatively little is known of the biochemical pathways involved in the synthesis of protein from the nitrogenous substances entering the developing 'caryopsis'.

Protein content is amenable to management pratices. It is well known that N fertilizer levels and timing increase grain protein levels in wheat (McDonald, 1988). Use of N fertilizer has a marked influence on both grain yield and N content. For milling varieties of wheat, the fertilizer strategy must aim to achieve both high yields and high quality. N manuring investigations within ADAS have shown grain protein improvements of about 0.5% for each 40kg/ha increments of N used up to about 200kg/ha (Rule, 1987). Protein contents of 10.2, 14.6 and 16.1% at 14% moisture content of the grain for two soft American winter wheat

cultivars 'Blueboy and Arther' treated with 0, 112 and 224kg/ha in late spring were reported by Hucklesby, Brown, Howell and Hageman (1971); Stanford and Hunter (1973). Kosmolak and Crowle (1980), working in Canada found that N fertilizer applied within the range of 56 to 224kg/ha to five hard red spring wheat cultivars resulted in increased grain N at each level of N fertilizer application. However, flour yields were not affected by protein content. They also suggested that, protein content, which in wheat influences baking quality, was controlled more by environmental conditions, and N supply than by genotype. Large grain protein responses have been recorded with post-anthesis urea sprays, which presumably provide a ready supply of N for the swelling grain (Smith, Burn and Bartlett, 1987). It should be noted that small early application of N fertilizer tend not to affect grain N concentration (Vaidyanathan, Sylvester-Bradley, Bloom and Murray, 1987).

Compared to cereals, break crops often leave a greater residue of N in the soil which may increase the protein level of a succeeding cereal crop. Past experiments have shown that winter wheat grown after crops such as beans tended to have higher grain N than when grown after another cereal crop (Batey and Reynish, 1976). However, grain yield and N concentration in the grain are often found to be inversely proportional, so that the yield advantage of a first cereal crop would counteract an increase in its grain N concentration (Vaidyanathan et al. 1987). Average amounts of N fertilizer applied to winter wheat in England and Wales have more than doubled since long term rotational experiments were carried out. Crops now rely proportionally less on residues and more on N fertilizer for their N requirements.

Although it has been found in most cases that baking quality improves on raising the flour protein, there are indications that on some occasions baking quality may not increase in proportion to protein content. The reasons for these occasional discrepencies in the

correlation between protein levels and baking quality have not been fully elucidated. Many writers have associated this behaviour with sulphur deficiency. Which has been shown to reduce protein molecular weight and increase the level of non-protein N (NPN). Under sulphur-deficient conditions the yield and amino acid composition of grain legumes as well as cereal grains is adversely affected (Randall, Thomson and Schroeder, 1979). A decrease in sulphur - amino acids (cysteine and methionine) content of cereal grains used for breadmaking affects the ability of bonds in sulphydryl and disulphide groups to break and reform during rising of dough. Thus, the availability of sulphur - amino acids in grains used for breadmaking influences the elasticity of dough.

1.4.2.Hagberg falling number.

This is a measure of the alpha amylase activity of the grain, the enzyme which converts starch to sugar and 'dextrins'. For breadmaking, millers seek a high falling number, i.e low alpha amylase, since the activity of this enzyme in the grain results in bread with excessively dark crusts and sticky crumb texture. Ideally, varieties should be chosen with good scores for resistance to sprouting in the ear because, as soon as germination begins alpha amylase is produced and falling number is lowered. The minimum requirements for the EEC Intervention Board for Agriculture Produce range from 220 to 250. The character is genetically linked, but is subject to considerable environmentally induced variation (NIAB, 1988). Wet humid conditions in the period before harvest can lead to sprouting in grains, thus leading to a product which may not be suitable for milling and which, if high alpha amylase is present, will give rise to loaves which are difficult to slice.

Little is known about the effects of N fertilizer on falling number. McDonald (1988) reporting results from field trials carried out

on sandy soils at the Gleadthorpe Experimental Husbandry Farm, showed that falling number increased from 250 to 350 with increased rates of N fertilizer application from 80 to 240kg/ha. Increase in falling number from the application of higher levels of N fertilizer resulted from reduced grain alpha amylase activity by delaying grain maturity hence, matured in late dry summer period of August (McDonald and Vaidyanathan, 1987; Smith, et al. 1987; Gooding, Kettlewell and Davies, 1986). This contrasts with that of work by Brun (1982), where high N fertilizer application caused lodging and reduced falling number. Why N fertilizer application should increase falling number is not fully resolved.

1.4.3.Specific weight.

Specific weight is a function of surface roughness, grain sizes, grain density and grain shape (packing properties). The minimum requirements for intervention standard is 76kg/hl. This is another key quality standard for a breadmaking wheat. Seasons, variety, as well as husbandry inputs have a very large influence on the extent of grain 'fill' and the final specific weight of the grain. Many writers have used thousand grain weight to describe the specific weight of wheat grains. Kosmolak and Crowle (1980), working on spring wheat variety Neepawa in Canada, showed that thousand grain weight and specific weight were postively correlated when crops were treated with different levels of N fertilizer. But, Gallagher, Doyle and Dilworth (1987); Sylvester-Bradley, Marriot, Hayward and Hook (1987) recorded no relationship between thousand grain weight and specific weight in winter wheat cultivars Norman and Moulin.

Increased number of grains per ear resulting from N fertilizer application may affect the specific weight as the extra grain is usually smaller. If grain shape and smoothness remain relatively constant over the N fertilizer response curve, then increasing N fertilizer will

increase specific weight by increasing grain density even though the grains might become smaller (Withers, 1987). Pushman and Bingham (1975), found that specific weight was significantly postively correlated with grain density and grain protein content. They concluded that low specific weight (75.3 & 74.9kg/hl) was associated with the high-yielding varieties, e.g. Maris Huntsman and Maris Nimrod due to unusual grain shape, which affected the packing efficiency. Smith, Burn and Burtlett (1987), using 1000grain weight as a measure of specific weight reported that a higher value was detected from nil N fertilizer treatment when numbers of ears were depressed. However, 1000grain weights are not necessarily paralled by equivalent trends in specific weight values, since these are a measurement of packing density and the shape of the grains. In a trial with Triticale, Naylor (1987) found no effect of an increase in the rate of N fertilizer on the specific weight.

Specific weight is influenced by the light interception, utilization efficiency of the intercepted light, and partitioning of the plant dry matter to the grain. Dry matter partitioning into the grains has played a role in spring wheat improvement in recent years, even though wheat breeders have not selected directly for this trait (Deckerd, Busch and Kofoid, 1985).

1.5.Uses of wheat in the UK.

Table 1.4 shows the flour requirement of the United Kingdom and sources of supply. Bread and biscuits are the principal foods made from wheat flour. Flour quality requirements can be divided into: Milling and Baking qualities.

1.5.1.Milling quality.

This refers to the ease of separation of white flour from the germ and bran (pericarp and outer layers of the seed). 'Milling value' is a measure of yield, grade and colour of flour obtained from sound wheat.

1.5.2.Bread baking quality.

Wheat is the only cereal which produces flour suitable for bread making because the dough produced has elastic properties; due to the 'gluten' (hydrated insoluble protein) present. To provide large soft, finely textured loaves, the baker requires flour with a large amount of good quality gluten (at least 11.6% on dry matter basis in the grain). This is produced by strong-textured wheats. Such varieties include Mercia, Avalon, Brimstone, Alexandria, Axona, Tonic, and Jerico. A good dough will produce a loaf of about twice its volume. The amount of water absorption by flour is also important in breadmaking. High water uptake by damaged starch granules of hard wheats means more loaves, which keep fresh longer, from each sack of flour.

1.5.3.Biscuit baking quality.

A very elastic type of gluten is not required for biscuits which should remain about the same size as the dough, 'weak' textured wheat varieties such as Longbow, Brigand and Norman are suitable for biscuit making. Poorer quality grains from varieties such as Slejpner and the by-products of flour production such as bran and various inseparable mixtures of bran and flour (e.g. weating), are fed to pigs, poultry and other livestock.

Table 1.4. Flour requirements in the UK and sources of supply (million tonnes).

Types of flour and quality equivalent	Wheat		Homegrown	Imported	
				Strong	Weak
Bread	2.44	3.3	1.5	1.3	0.5
Biscuit	0.41	0.55	0.5	-	0.05
Household	0.83	1.15	0.4	0.2	0.55
Total	3.68	5.00	2.4	1.5	1.10

Sources: Lockhart, J.A.R. and Wiseman, A.J.L.(1980)

1.6.General husbandry.

1.6.1.Land preparation.

The general practices of preparing land for seeding to wheat are ploughing, discing and harrowing. These operations are performed in standard ways by a range of commercial equipment. It is not necessary to prepare a very fine seedbed. Soil conditions with small clods prevent 'soil capping' in a mild wet winter and protect the base of the plants from cold frosty winds. However, under dry, and large clod conditions it is difficult to achieve an even planting depth. Medium season seeding (usually mid October) in most localities is usually favoured. Wheat sown after mid-November generally suffers more winter injury, tiller less, and may ripen later the next season. Wheat sown too early is prone to leaf diseases such as mildew (Erysiphe graminis), and may joint in the fall before winter. However, the time for seeding winter wheat varies from late september to early November, with early to mid-October being the best time. On many farms sowing earlier than the optimum seeding time has become common practice, (especially following oil seedrape) in order to take advantage of favourable soil moisture and temperature conditions.

Spring wheat are usually sown during late February to mid-April, with mid-March the most favourable time. However, drilling date is frequently delayed in cold springs especially on heavy clay soils. For example, experiment 1 was not drilled in 1988 until mid-April due to cold, wet weather. Recently, there has been a move towards autumn sowing of spring wheat. Early seeding of spring wheat usually results in the highest yields and improved quality (McDonald, 1988). Early-sown spring wheat is most likely to escape injury from drought and diseases such as Septoria nodorum, which become more prevalent as the season advances.

1.6.2.Plant establishment.

Laboratory testing has shown that germination of wheat seeds will occur between 4 and 37 degrees centigrade with 20-25 degrees centigrade considered optimal. Seeds are usually sown at a moisture content of 14%. Imbibition take place in the soil and the percentage moisture content of the seed rapidly increases. The minimum moisture content for germination is 35-45% of the seed weight, and the rate of germination is increased as moisture increases above this level (Evans, Wardlaw and Fischer, 1980).

Following germination, the seminal roots extend into the soil and the coleoptile penetrates to the soil surface and elongates. The second internode, enclosed within the coleoptile, also elongates. Once emergence has taken place the coleoptile and the internode stop elongating and the growing first leaf bursts through the coleoptile tip (Peterson, 1965). This main shoot normally continues to produce leaves with negligible internode elongation until the apex enters the reproduction phase. Meanwhile, buds develop in the axil of the leaves and sometimes of the coleoptile. Emerging tillers then enter a point of rapid growth while other tiller buds continue to grow slowly. Kirby and Faris (1970) considered, that a tiller bud of barley, (Hordeum valgare

L.) may develop at once after seedling establishment, but data of Williams and Langer (1975) indicate that this is not true for wheat.

Emergence rate in wheat shows some genetic variation. For example, it is postively correlated with coleoptile length and plant height, and was a problem initially with dwarf wheats. Selection for long coleoptiles has been only partially effective in improving their emergence (Allan, Vogel and Peterson, 1962).

From the start of germination until exposure of the first green leaf to light, growth is dependent on reserve carbohydrates in the endosperm, more than half of which are utilized by the seminal roots (Williams, 1960). Wheat is typical of all monocotyledonous cereals and has a large endosperm reserve (80-86% by weight) which consists largely of starch (Harper, 1983). The larger the seed, the greater the endosperm reserves. However, protein content rather than seed size may be the main factor influencing seedling establishment and development. Crops from high-protein seed (12-14%) induced for example, by some agronomic treatments such as rate and timing of N fertilizer may establish and grow faster (Lowe, Ayers and Ries, 1972). On soils short of nitrogenous nutrients, N-rich seeds establish seedlings better than N-poor seeds (Briggs, 1978). Seeds with high protein content respire faster than seeds of equal size having a low protein content (Harper, 1983).

A major objectives before sowing is to find laboratory tests that will decide whether drilled seeds will emerge quickly, and successfully established under a range of soil conditions. Larger seeds from a particular seedlot may be more vigorous (higher 'seed vigour'). In barley seeds, Briggs (1978) reported that, large seeds which contained more nutrient established better under unfarourable conditions.

1.7.Crop agronomy.

1.7.1.Spatial arrangement.

Wheat is traditionally sown in a random (poisson) arrangement along rows a fixed distant apart,usually about 18cm. The purpose of the sowing process is the distribution of a defined quantity of seed over a given area and finally their placement at a known depth in the seed bed. Distribution patterns realised depend on the different sowing techniques. According to Speelman (1975), broadcasting proved to be superior to 'normal' drilling as it gives greater 'distances' between plants. However, depth control is generally poorer and as a result field germination is usually lower by 10-20%.

The development of new implements for broadcast sowing or the use of adapted coulters such as the 'band coulter', which give good depth control, are being investigated. The band coulter spreads the seeds throughout the full row width. The system has been called 'controlled broadcasting'. It provides the benefits of broadcasting without the problems of uneven and shallow drilling. However, despite the agronomic importance of spatial arrangement the literature on the subject is sparse, because of insufficient research work on this aspect of crop production.

Several authors have examined the effects of neighbouring plants. For example Mead (1966, 1968) found within a single row, that plant to plant interaction extended beyond the nearest neighbour. He used a polygon analysis to examine the effect of nearest surrounding neighbours within random plant arrangements, and the correlation of plant weight with the mean weight of its neighbour using barley variety Eegular. He concluded (i) that plants in addition to the immediate neighbours might affect the plant indirectly, (ii) that the size of a neighbour will affect its influence on the plant, and (iii) that the positions and

sizes of distant surrounding plants will affect neighbours and through them the original plant. Mule and Heege (1981) also reported that the seed spacing of winter wheat over an area (not in rows) could be described by the mean distance to the nearest neighbour.

In Australia, Kemp, Auld and Medd (1983) working with spring wheat cv. Condor at different densities (40, 75 & 200 plants/m2), in rectangular and square arrangements, found that as the arrangements tended towards 'square' that grain yields from the 40 and 75 plants/m2 were equal to those obtained from the high density (200 plants/m2). They suggested that this occurred either due to reduced interference between plants or improved utilization of 'space'. The increased yield from the low densities was attributed to (i) plants in the square arrangements were able to grow for a longer period before encountering the 'space' occupied by neighbouring plants, (ii) the extent of crop growth required for plants to exploit all available 'space' in squares was less than in the case of rectangular spacing. Hence, all available 'space' could be exploited earlier.

An early tillering advantage was noted within the square arrangements. Plants in the low density (40 and 75 plants/m2) square arrangements had an average of 13% more tillers per plant that produced ears compared with the rectangular arrangements (Kemp et al. 1983). This early greater number of tillers was a major factor which contributed to the final differences in grain yields. Similar results have been found from research on some perennial crops. For example with apple trees Cripps, Melvile and Nicol, (1975); Christensen, (1979) have shown that square arrangements in orchards outyielded rectangular for at least 8 years.

Soetono (1975) reported that both population density and plant arrangement influenced the size and variability of barley in the population and hence the frequency distribution of weight, height and

tiller number. In Mexico Fischer, Aguilar, Maurer and Rivas (1976), working with winter wheat cultivar Sonora found no effect of plant arrangements at high density (300kg/ha seeds). In another study using spring barley, Evans (1977) reported that at high density (500kg/ha seeds), plants arrangements made no difference compared to low density (300kg/ha seeds).

1.7.2.Competition.

Competition can be defined as the struggle between individuals within a population for available resources, when the level of resources is below the combined needs of the members of the population. The resources involved in crop growth are primarily light, water and nutrients. A vast number of model experiments have being carried out on plant competition in glass houses and growth rooms. The results of many of these experiments are mainly descriptive and the conclusions reached are sometimes hypothetical and are mostly based on assumptins. In the field, it is even more difficult to define and determine the effect of 'competition'. Increases both in the light environment and the volume of soil available to individual plants prevents full differentiation between competition for light, water or nutrients. These interacting factors cannot be controlled precisely under field conditions. For this reason, the results obtained from plant competition studies carried out in the field are very difficult to explain and interpret with precision. The implications of plant competition on the physiology of field crops are rarely known. However, many workers including Puckridge and Donald (1967); Puckridge (1968); Fisher et al. (1977); Dawrwinkel (1978, 1979 & 1980); Ellen (1987) have tried to describe the effect of plant competition in field situations. This section of the review summarises some of the findings of these workers. The discussion sections of chapters 2 and 3 will consider the results of experiments 1 and 2, in which some practical aspects of competition were studied.

Intensive crop management systems which are designed to reduce the cost per unit area of production require a knowledge of the optimum plant population for a given environment. Optimum yields on an area basis should arise from plant densities that minimize inter-row and intra-row competition, (Donald, 1968). Darwinkel, ten Hag and Kuizenga (1977), working with winter wheat (cv. Lely) in the Netherlands, found that with early sowing (early to mid September) seed rate had no effect on grain yield, due to mutual compensation of changes in the yield components. But, with late sowing (November) a higher seed rate increased the number of ears so that a higher grain yield was achieved. In experiments with barley crop, where the plant density was varied, it was found that over a wide range of densities (50 to 800 plants/m2), yield changed relatively little (400 to 380g/m2) (Kirby, 1967, 1969).

Wheat grain yield is the product of three components: ears per unit area, grains per ear, and weight per grain. Increasing seeding rates can increase ears per unit area but reduce the other two yield components; grains per ear and grain weight, (Darwinkel, et al.1977; Darwinkel, 1978; Puckridge and Donald, 1967; Steel and Torrie, 1980). Compensation occurs among yield components and tends to minimize yield loss when one component is reduced, but such compensation may not be complete. Therefore in crop density studies, all yield components must be considered, rather than studying each component individually (Darwinkel, et al. 1977; Puckridge and Donald, 1967; Steel and Torrie, 1980). The number of ears per unit area is dependent on the number of main stems and the number of reproductive tillers per plant (Power and Alessi, 1978). Greater numbers of tillers per plant are produced at low plant densities, and more tillers per unit area are produced at higher plant densities (Power and Alessi, 1978).

Maximum tiller number per unit area for a specific environment will be attained more rapidly as plant population increases. At high plant

densities (1078 plants m-2), the percentage of tillers that survived to produce ears was low (Puckridge, 1968), but 100 percent tiller survival is not likely even at low plant densities (Puckridge and Donald, 1967). Increasing the plant population decreased grains per ear (Darwinkel, 1978; Darwinkel, et al., 1977; Puckridge and Donald, 1967; Steel and Torrie, 1980). Weight per grain also decreased from 34.2 to 31.7mg as plant density increased from 184 to 1078 plants m-2, but effect on weight per grain was less than on grains per ear. The most probable simple explanation is that the amount of photosynthetically active radiation (PAR) intercepted by a single plant at the high densities (1078 m-2) is comparatively small, while at low densities (184 m-2) PAR is available per plant. Also, there must be reduced interplant competition for moisture and nutrients at lower plant densities, but in the above and many similar studies these factors are rarely quantified.

It is well known that ear size is inversely related to ear density. The greater the ear density, the less 'space' is available per tiller, this reduces photosynthesis in every tiller. Thus, fewer assimilates are available for ear growth, ear development is hindered and the ears are smaller. At higher ear densities an increasing part of the dry matter produced was found as a supporting tissue in stems only (Darwinkel, et al. 1977). In this study fewer spikelets were initiated and the number of grains per fertile spikelet decreased as the available space per tiller decreased caused by an increase in plant densities from 130 to 360 plants per m2. At high ear densities (2500, 2475 & 2220 m-2) Fisher et al. (1977) found that, there was reduced carbohydrate reserves in the earbearing tillers before anthesis because crop respiration was increased which reduced grain filling. These authors also found that, total grain yields increased as the number of grains increased up to a level of 30,000 m-2, although grain weight decreased.

Darwinkel (1978 & 1980) summarised the effect of plant density on some crop characteristics. The results are presented in Tables 1.5 & 1.6. He reported that at 800 plants m-2 almost all the primary and secondary tillers produced died and so the surviving ears originated from the mainstems only.

Table 1.5. Yield and some crop characteristics at different plant density in winter wheat cv. Lely.

Plant /m2.	Tiller formed/m2.	Ears /m2.	G. Yield (g 85%DM)/m2.	Total yield (g 85%DM)/m2.	G. Wt (mg).	Harvest index.
5	145	118	282	707	40.3	39.9
25	492	272	644	1531	41.7	42.1
50	691	322	720	1647	44.6	43.7
100	977	430	843	1968	44.1	42.8
200	929	490	834	2024	42.3	41.2
400	1232	582	848	2181	41.0	38.9
800	1780	777	890	2376	39.0	37.5

Source: Darwinkel, A. (1978).

For many crops the effects of plant density on yield are generally attributed to interplant and intraplant competition for light, water and nutrients (Darwinkel, 1978). Within the plant, competition for assimilates between stems and ears may as well largely influence ear development (Gallagher et al. 1976). With increasing densities interplant competition occurs earlier. Whilst at low plant densities a prolonged tillering period usually results in more tillers per plant. At high densities, for example 800 plants m-2 (Table 1.5), early interplant competition affects not only the number of tillers but also the tiller size. This also caused lower grain weight, and it was inferred that increased interplant competition restricted the supply of carbohydrates required for grain filling. Increasing plant from 5 to 800 m-2 reduced the number of tillers per plant from 29 to 2.2 (Table 1.5), but the total numbers of tillers was highest at 800 plants m-2. Darwinkel concluded that limitation in tiller formation at higher plant densities

indicates early plant competition for PAR. Therefore, fewer assimilates are available for the growth of mutually competitive organs such as leaves, roots and the stem-apices. At low plant densities e.g 5 to 150 m-2 (Tables 1.5 & 1.6), later emerged tillers produced ears, but at higher densities ear formation was restricted to older earlier emerged tillers and mainstems. At higher densities the early occurrence of competition is expressed by lower tiller initiation and higher tiller mortality.

Table 1.6. Yield, yield components and some crop characteristics of winter wheat cv. Lely at various plant densities.

	Density (plants m-2).							
	50	100	150	200	300	400	500	600
Yield components.								
No. of shoots /plant.	15.1	13.1	9.7	10.3	8.3	7.0	5.9	5.4
No. of ears /plant.	10.1	6.1	4.3	3.4	2.5	2.0	1.7	1.4
No. of ears /m2.	506	600	647	674	755	803	859	837
% shoot fertility.	67	46	44	33	30	29	29	26
No. of spikelets /ear.	20.6	20.8	20.8	20.9	21.2	21.1	20.6	20.3
No. of fertile spikelets/ear.	16.4	16.5	16.3	16.0	15.6	15.5	14.6	14.5
No. of grains /fertile spikelet.	2.32	2.25	2.32	2.13	2.04	1.99	1.90	1.90
No. of grains /ear.	38.0	37.1	36.2	34.1	31.9	31.0	27.7	27.6
1000grain weight (g 85% DM).	44.6	42.5	41.8	42.0	41.4	40.3	39.9	39.2
Grain yield/ear (g 85% DM).	1.70	1.58	1.51	1.44	1.32	1.25	1.11	1.08

Source: Darwinkel, A. (1980).

In another experiment Darwinkel (1979) reported that, increasing the ear density from 350 to 700 ears m-2 decreased the number of spikelets initiated by 13%, the number of fertile spikelets by 21% and the number of grains per spikelet by 30%. Within this range of plant

density the harvest index decreased from 43.5 to 37.5. Consequently the difference in number of grains per ear between both densities was nearly 40%. At higher densities a greater proportion of the dry matter produced is used for the growth of straw and chaff when grain yield approaches an asymptote (Darwinkel, 1978 & 1979). When increasing density from 5 to 800 plants m-2, ear sizes and grain yield per ear decreased (Table 1.6). By comparison straw length and total biological yield increased. Consequently the harvest index was reduced (Table 1.5).

It has been reported by many writers including Fischer et al. (1977); Darwinkel (1977, 1978 1979 & 1980), that reduced productivity of tillers in dense crops results from several causes: fewer assimilates are produced per tiller, fewer storage resources (sink) are available to be filled and the partitioning of dry matter between grains and the rest of the plant organs is unfavourable.

Ellen (1987) reported that, with higher plant density the smaller the leaf area per plant, but with more plants m-2 the faster a closed canopy (LAI = 3) is attained. He concluded that increasing the seed rate from 45kg/ha to 125kg/ha decreased the mean specific leaf weight (SLW) from 5.7mg cm-2 to 5.3mg cm-2. But did not say whether the total grain yield was affected with this increase in plant density. At high plant densities competition for light greatly affects ear development from early growth stages (double ridges) onwards (Puckridge, 1968). The higher interplant and intraplant competition during the growing period could hamper the enlargement of spikelets initiated in the later formed tillers, therefore, reduced the final grain yield.

This review shows that plant competition studies is not based on a precise scientific principles. The first year experiment during 1986/87, was aimed to study the effect of drilling patterns over a range of plant densities with a view to assess the effect of plant competition on the growth, development and yield of winter wheat. At the end of that first

year, it became apparent that such findings were not worth continuing. This was because the hypothesis upon which the initial objectives of the experiment was based did not produce a positive trend. Thus, the possible yield increase which was alleged to be associated with drilling using the band coulter was not detected as earlier on suggested by Butterworth and his colleagues in Berkshire (unpublished data). More over, it became extremely difficult to carry out a detailed field studies on the effect of plant competition over a large unit area of land. These necessitated a re-directioning of the design of the subsequent experiments. Which encompasses studies on grain quality of winter and spring wheat varieties, and the agronomic practices influencing it.

1.7.3.Rate of nitrogen.

Reported investigations on the N requirement for winter wheat are numerous. Lessells and Webber (1965) have shown that the average response of winter wheat to N in 114 experiments carried out by the National Agricultural Advisory Service in the United Kingdom from 1957 to 1963 was 11kg grain per 1kg of N fertilizer applied. In trials by Harris (1974) and Selman (1975) during 1964-1970, on winter wheat a top-dressing of 113-115kgN/ha gave the maximum response. In other trials with three varieties of winter wheat (Maris Fundin, Hobbit and Maris Huntsman), with N fertilizer ranging from 0 to 210kg/ha during 1975 to 1976; dressings of 100 to 180kgN/ha increased grain yield from 5.8 to 7.0t/ha. However, grain yield decreased to 6.5t/ha when N fertilizer was increased to 210kg/ha (Pearman, Thomas and Thorne, 1978; Widdowson, Johnson and Penny, 1980). In subsequent experiments, Widdowson et al. (1987) reported that about 215kgN/ha could be taken up by the crop to produce a maximum yield of 11t/ha. These authors concluded that N uptake by the crop depended on the sowing date, soil type, cropping history, amount of N fertilizer applied to the soil, the

stage of development of the crop, and even variety. For example, the newer semidwarf wheat cultivars are more responsive to N than the taller types (Blackman, Bingham and Davidson, 1978; Pearman, Thomas and Thorne, 1978), because of insusceptibility to lodging. Clearly response must be discussed in relation to a wide range of environmental, husbandry and physiological factors.

The application of N fertilizer affects the development of the crop in several ways. High N fertilizer application helps the survival of late tillers and hence the ear density is increased (Batey and Reynish, 1976; Bowerman and Clare, 1976). In high input systems, large amounts of N fertilizer will only be profitable if supplementary inputs such as growth regulators, fungicides and pesticides are modified (Dilz and Schepers, 1974; Dilz et al., 1982; Sturm and Effland, 1982). For example, it has been shown that for Avalon winter wheat, the yields with (prophylactic) or without fungicides were 98% and 112% of the control treatments (NIAB, 1988). The mode of N fertilizer dressing must closely follow the N demand of the crop during growth and development.

The response of wheat to N fertilizer top-dressing is influenced by a number of factors. Need for N is greater in continuous cereals or in an arable rotation than following newly broken pasture (Lesslls and Webber, 1965). The use of crops such as legumes and Brassica forage crops in the rotation reduces the need for N (Singh, 1983). Bowerman and Clare (1976) have shown that the yield of winter wheat following a bean crop was equivalant to that obtained with a top-dressing of 75kgN/ha. The recommendation for N fertilizer to winter wheat is usually less after a non cereal break crop (MAFF, 1985) despite the greater yields achieved by first wheats.

Nitrogen fertilizer response is largely governed by the supply of N from the soil, which often includes residues from previous fertilizer applications. This can be crudely estimated using some known and

partially predictable factors, such as past cropping and fertilizer use, rainfall, soil texture and depth. Systems for predicting leaching of residual N and N fertilizer response can take account of some or all of these factors. However, many site factors such as early spring weather when N fertilizer top dressing is carried out cannot be readily predicted. Cold spring soil temperatures reduce the rate of mineralization and the release of available nitrate ions, and aid losses through leaching (Needham and Boyd, 1976).

The response of winter wheat to N fertilizer is notoriously variable. These variations have been attributed to differences in weather, soil, variety, yield and husbandry factors but had so far eluded accurate prediction (Sylvester-Bradley, Dampney and Murray, 1984). The factors affecting the uptake of N by a crop are imperfectly known, though soil water availability, soil temperature, soil organic matter content and concentration of N in the soil solution must be involved (Jackson and Sims, 1977).

An excellent summary of the response of winter wheat to a range of N fertilizer levels in 142 experiments conducted on wide range of soils between 1975-1981 has been presented by Sylvester-Bradley, Dampney and Murray (1984). With exception of trials at Experimental Hubandry Farms, all investigations used commercial farm crops. A curve was fitted to the crop yields from each trial, and where possible the level of N (N optimum) beyond which additional N fertilizer would not repay its costs was calculated. N optimum was defined as the level of applied N fertilizer at which the rate of response reached 3kg of grains per kg of N fertilizer applied. In another trial Sylvester-Bradley and George (1987) suggested that, at the UK price rate of 115pounds/tonne (33.3p/kg) of N fertilizer (Nitram, 35%N), application of 50kgN/ha above the optimum level could still be economically viable. However, this was only justified where a premium was paid at high protein levels (from 12%

and above), resulting from the additional N above the level recommended for optimum yield.

MacNeidhe (1985) found that a top-dressing of 130kgN/ha applied as a single dressing in March gave the largest yield of grain (8t/ha) in winter wheat cv. Armanda, grown on peat land in Lullymore, Ireland. 100 and 160kgN/ha gave yields of 6.5 and 6.8t/ha, respectively. The larger yield from 130kgN/ha was due mainly to a greater ear density per unit area and 1000grain weight. The larger dressing of 160kgN/ha reduced the grain number per ear and the grain weight and this contributed to the lower yield (Table 1.7). Grain weight is decreased particularly in seasons when the rainfall is above average due to N leaching (Batey and Reynish, 1976; Bayles, Evers and Thorne, 1978; Pearman, Thomas and Thorne, 1978). The decrease in grain weight resulting from N leaching was larger (797 versus 931g m-2) in sandy than in clay soils (Thorne et al. 1988). This suggested that more N was lost from the former than from the latter.

Table 1.7. Effect of increasing amount of N on fertile tillers per plant, plant height, grains per ear, ears m-2, 1000grain weight and grain yield of winter wheat (cv. Armanda).

N applied kg/ha	Fertile Tl./Pl	Pl.ht. (cm)	Grains /ear.	ears /m sq	TGW(g) 85%DM.	GY(t/ha) 85%DM.
0	1.3	51	30.1	453	46.4	1.91
60	2.5	63	36.1	549	45.0	5.15
100	2.8	64	36.0	518	43.4	6.50
130	3.0	64	35.4	529	48.0	8.01
160	3.0	66	31.9	508	47.3	6.80
SE(df=15)	0.35	0.6	1.1	75.1	4.5	0.45

Source: MacNaeidhe, F.S (1985).

Beveridge, Jarvis and Ridgman (1965), found in glass house studies that, response of wheat grain yield depended on the number of tillers produced, and the earbearing tillers. N fertilizer application also increased other yield components such as, the number of grains per ear

and the 1000grain weight. Results of detailed field and other experiments in which N fertilizer was applied to winter wheat demonstrated that response of grain yield to N did not necessarily reflect the response of individual yield components. Obviously grain yield cannot be completely independent of plant population and the components of individual plants, but it is the sum of the contributions made by various yield components under the environmental conditions, including N supply prevailing at each stage of growth.

Spiertz and Ellen (1978) in the Netherlands reported, that additional N delayed senescence of the top leaves by 8 to 10 days and considerably increased the amount of N available in the leaves for redistribution to the grains . They also found that, the major part of the positive effect of additional N on the number of grains per spikelet was attributable to a greater number of grains in the lower and central part of the ear. High grain yields (10t/ha) required a total of 250 - 260kgN/ha supplied by soil and fertilizer in studies by Darwinkel et al., 1983; Spiertz and Ellen, 1979). However, high rates of N fertilizer must be carefully applied as split applications to prevent a high incidence of lodging, diseases and pests (Darwinkel, 1980).

Yield and grain N level have a major influence on overall value when crops are grown for milling. It has been reported that increase in the grain protein content resulting from high levels of N fertilizer decreases the level of sulphur relative to N (Timms, Bottomley, Ellis and Schofield, 1981). This has mainly been attributed to a decrease in the emission of sulphur dioxide from chimneys. Since 'S' amino acids are important for gluten elasticity, low sulphur content prevents the dough from rising during Kneading. Therefore, if the practice of applying large amount of N fertilizer continues some application of sulphur containing fertilizer such as ammomium sulphate may become necessary.

1.7.4.Time of nitrogen application.

The best timing for N fertilizer application is governed by the climate, and the type of wheat grown. In very humid regions where rainfall during the growing season substantially exceeds evaporation and plant water use, it may be necessary to apply some N fertilizer at sowing, with the remainder being supplied later in the season to minimise leaching and denitrification losses. In USA Olson (1989) reported that, pre-sowing or sowing time application of N fertilizer may yield results. However, this is not normally practiced in the UK. In this country N fertilizer applications to winter cereals are carried out in the spring, after crop recovery from the cold winter treatment.

N fertilizer applied during the autumn is prone to losses by leaching in very wet winters, which therefore makes application at this time uneconomical and environmentally not acceptable. Johson (1984) had reported an average losses of N through leaching of 40, 25 and 9%, when N fertilizer was applied in February, March and April.

From the standpoint of yield alone, an early application before or during tillering stage of the crop may result in increased yield. But maximum grain protein yield usually accompanies later application at or after the start of stem extension (Experiment 1)

Farmers have shown considerable interest in the timing of N fertilizer application, including application around anthesis (Laloux et al. 1979). N fertilizer applied at this growth stage may increase the life of green leaves, prolong photosynthesis, and increase grain yield (Spiertz and Ellen, 1978). Natr (1972), reviewing experiments made mainly in controlled environments, concluded that photosynthesis was very sensitive to the level of N nutrition and that, decreasing the N content of the leaves resulted in a lower rate of photosynthesis. Holbrook, Osborne and Ridgman (1982), concluded that, the effects of

time of application cannot be predicted by field trials until much more basic scientific work on the movement of N in soil and plants and its role in grain filling has been done.

The time of application also affects the response to N. Autumn applications are not as effective as spring applications (Harris, 1974; Lessells and Webber, 1965). For the majority of soils, early spring application (early to mid-March) gives a lower yield compared with later spring application (end of March to mid-April), Bremner (1969); Harris (1974); Lindsay Easson (1980). Late application (early May) of N fertilizer results in the survival of a greater number of the late tillers, and thus, ear density is increased (Lindsay Easson, 1980). Later produced tillers develop quickly and consequently, produce fewer spikelets (Darwinkel, 1978; Power and Allessi, 1978). Tiller and ear survival is thus not the only aspect that need consideration, but ear size of these surviving tillers is also important.

On a peat soil in Ireland, which is warmer and wetter in the spring than South East England a February dressing of N fertilizer to winter wheat gave a vigorous growth of tillers up to early July. But, around mid-July the crop began to mature, while growth continued to late July with a late-March dressing. The number of ears m-2 was greater (468 m-2) with N fertilizer dressing in mid-March than the application in February which gave 385 ears m-2 (MacNaeidhe, 1985). Bremner (1969) also recorded an increase in the number of tillers and earbearing tillers with a mid-March application of N fertilizer. Maclaren (1981) reported that when N fertilizer was applied at more than one time, with the first application at Zadoks growth stage 14, the maximum number of emerged tillers was higher (1172 m-2) than when the first N fertilizer application was made at Zadoks growth stage 16 which resulted in 1075 tillers m-2. But, the final number of ears was not significantly different (462 versus 468 m-2).

Langer and Liew (1973) suggested that N fertilizer given at ear emergence could not affect the size of the flag leaf, but prolonged its life by about 20 days. Whereas N fertilizer supplied at the double ridge stage increased both the leaf area and the longevity.

In an experiment on winter wheat cultivar Armada MacNaeidhe (1985), reported that the time of N fertilizer application had no effect on the number of grains per ear. But 1000grain weight was increased from 51.4g to 52.2g when application was delayed until the middle of March. This result is in line with that of Harris (1974). Langer (1979) working in New Zealand found an increase in the number of grains per ear with late-March application of N fertilizer. Whereas Ellen (1987) in the Netherlands recorded a decrease in the number of grains per ear with a late-March application of N fertilizer.

In trials reported by Sylvester-Bradley and Dampney (1984) conducted from 1977 to 1979 in England, a delay of N fertilizer application from Zadoks growth stage 37 to 39 until Zadoks growth stage 45 to 50 caused a yield reduction in 65% of the trials but only 9% were statistically significant. They concluded that, the economic implications of varying the timing of N fertilizer application are considerably less than of varying the total amount of N fertilizer applied. These authors also suggested that, yield differences due to the use of either early or late application of N fertilizer were usually less than 0.5t/ha. However, their results mainly refer to trials using winter not spring wheat varieties.

The N requirements of spring wheat are regarded as being moderate to low. Most of the recommendations for spring wheat dressing are based on the levels applied to spring barley (Archer, 1985). More over, results on the response of spring wheat have not been studied in detail. This makes it very difficult to review the literature on this subject. However, with the current EEC 'grain mountains' which call for quality

increase as opposed to yield, this crop may become very important in the UK, Since a higher proportion of spring wheat is sold for milling compared to winter wheat. Also, the total variable costs of production for winter and spring varieties used for milling purpposes are 230 and 160pounds/ha respectively (Nix, 1989). The increase in the cost of production of winter varieties resulted from the extra dose of N fertilizer and other miscellineous operations e.g the additional cost for fertilizer application and fungicide sprays which are normally applied twice or more before crops are harvested.

In recognition of this, experiments 1, 2, & 3) reported in the subsequent chapters were designed to study the effect of the rate and timing of application of N fertilizer on the yield and quality of wheat. In these experiments quality wheat varieties Axona (expt. 1) and Avalon (expt. 3) spring and winter wheats respectively were grown. Details of the experimental treatments are described in the sections on material and methods.

1.8.Physiology.

Crop physiology encompasses a vast number of different factors. These involve among other things, the study of plant canopy structure and the modelling of plant growth with a view of explaining the yield variations that result from these. Close correlations are commonly found between the physiological studies and crop yield, yet a quantitative understanding of these factors remain essentially at the emperical level. Most field agronomic trials suffer in this regard from being too emperical. For example, N is an essential component of the biochemical constituents that drive yield-producing processes, but, detailed relationships to quantify the effect of N on crop productivity have been difficult to develop and apply in the field. Agronomic assessments of the effect of N using growth analysis techniques describes rather than

explains finely tuned physiological processes.

The physiology of wheat plant is well documented in scientific papers (Simons, 1982; Klepper, Rickman and Perterson, 1982; Kirby and Appleyard, 1984), the text book: 'Crop Physiology' edited by Evans (1980). In view of the above, this review is concentrated on physiological aspects of the yield components because these were assessed in the trials described in this thesis. Sections on root and leaf growth are included (but not discussed in depth) because of their importance in nutrients uptake and photosynthesis which are the source of assimilates for crop growth and development.

1.8.1.Growth and development.

It is important to differentiate between the growth of a plant and its development. This would aid in deciding on appropriate time for the application of any agronomic treatment. Plant growth is considered to include both cell division and cell enlargement and results in an increase in plant size as well as weight. The increase in weight can be determined from the change in dry matter in a given time period of growth. Plant development on the other hand may be defined as the sequence of ontogenetic events, involving both growth and differentiation, leading to changes in function and morphology. It is an enormously complex process, involving controls at the molecular (nucleic acid) organelle and cellular levels, the activation and repression of genes and determination of divergent patterns of differentiation leading to organ function, biochemical differentiation, maintenance of the balances between organs (e.g. roots and shoots), maturation and senescence.

1.8.2.Root growth.

Two distinct root systems develop in wheat: the seminal roots arising directly from or below the seed, and the adventitious roots that arise from the nodes of the stem above the seed. Each tiller normally develops its own system of adventitious roots and each root system normally supplies the tiller to which it belongs with nutrients (Boatwright and Fergerson, 1967). Functionally there seems to be little difference between the two parts of the root system although they show quite distinct distribution patterns. In the field, growth of the root system continues until heading, when it may cease, and roots may even degenerate during grain development (Asana and Singh, 1967).

It is very difficult to carry out studies on root growth in a field experiment. Root extractions are time consuming and studies in situ require expensive and sophisticated equipments. Most of the studies on root development had been done either in a 'Nutrient Film Technique' (NFT) or in pot experiments in glass houses. Under such conditions, root development is restricted and results can hardly be applicable in the field situations.

1.8.3.Leaf growth.

Leaf arrangement is an important aspect of canopy structure. Leaves formed prior to floral induction, originate close to the apex, but following induction the stem internodes elongate, and the leaves are separated further in the vertical plane, giving more effective light distribution within the canopy. Maximum leaf area per culm is attained before heading when the flag leaf has fully emerged (Watson et al. 1963; Fischer and Kohn, 1966; Puckridge, 1971). Like root growth, many studies on leaf initiation and development have been mostly carried out under controlled environment such as the glass houses and in growth rooms. In most cases growth environments such as temperature and humidity are

adjusted to be constant or flactuative, depending on the objective of the experimenter. Thus results are difficult to project and link with field situations. These academic studies have few practical implications for field agronomic trials such as those described in this thesis.

1.8.4.Tillering.

Following germination, lateral bud primordia are initiated at the shoot apex. The first bud to grow depends on planting depth and temperature. At a depth of about 5cm the third axillary bud is often the first to grow, but in shallow planting, Rawson (1971), found that, up to 90% of the coleoptile buds may produce tillers in some varieties of wheat, although a reduced number of these survived to maturity.

Alterations in environmental conditions appear to have comparatively little effect on the initiation of tiller buds at the apex, but have a marked effect on the subsquent growth of these buds. During its initial growth the tiller is enclosed in the sheath of the subtending leaf and is entirely dependent on the main shoot for its supply of carbohydrates and nutrients; tillers do not become independent of their parent shoots until they have developed about three mature leaves, when adventitious roots may form at their base. Tillering is favoured by high light intensity (Khalil, 1956; Friend, 1965b, 1966) and nutrition (Asana et al. 1966). The rate of tillering for temperate cereals are found to be maximum at 25°C according to Friend (1966), but Rawson (1971) found greater number of tillers at lower temperatures under an Australian conditions.

The onset of stem elongation following flower initiation usually causes a temporary ceasation of tillering (Jewiss, 1972). The tillers which fail to reach maturity may be considered as lost capital. However, some tillers although not completing their development, may be of some value in ensuring a continuing supply of nutrients to the ear-bearing

shoots during later stages of development (Palfi and Dezsi, 1960; Rawson and Donald, 1969; Lupton and Pinthus, 1969). By comparison, Batey and Reynish (1976), reported a decrease in number of grains and grain size resulting from tertiary tiller production in study on winter wheat testing five rates of N fertilizer in Southern England.

1.8.5.Reproductive development.

Timing of the reproductive cycle in wheat is an important determinant of yield. If inflorescence development begins too soon, there may be extensive injuring as a result of late spring frost to young ears. On the other hand, if it is too late, or too slow, grain filling may be cut short by high temperatures and water stress in summer. Control of the reproductive cycle is mostly gained by varietal responses to vernalization and long days before inflorescence initiation.

Morphogenesis of the wheat inflorescence has been described by Bonnett (1967) and its histogenesis by Barnard (1955), while Williams (1960) presented a detailed quantitative description of inflorescence development. The period from inflorescence initiation to anthesis may vary from two weeks to several months in duration, depending on cultivar and environment. Normally, the time of initiation must not be too early, if the developing ear is to escape frost injury. However,grain filling ideally begins as soon as canopy photosynthesis attains its maximum value. One objective of breeding programmes might be to increase the rate of inflorescence development (minimize its duration), since there appear to be heritable differences in this rate (Pinthus, 1963). To do so, however, could be counter-productive, in that it could adversely affect the number of spikelets per ear, and perhaps also fertile florets per spikelet, which are frequently powerful yield determinants in wheat. The consequence would result in less number of grains per ear, hence

reduction in final grain yield.

1.9.Yield and yield components.

Wheat grain yield is the product of the following yield components: plant per unit area, ear per plant, grain per ear and grain weight. The genotype-by environment interaction likely dictates which component accounts for the variations observed in yield (Darwinkel 1983; Gales 1983).

1.9.1.Plants per unit area.

A principal agronomic objective is to establish sufficient plants per unit area to produce maximum economic yield at harvest. High yields of winter cereals have often been associated with seed rates which achieve plant populations in the range from 400 to 500 m-2 (I.C.I, 1980). Poor seed emergence and seedling establishment which result in low (<100 m-2) autumn plant populations would require plough out and re-drilling.

The seeding rate, plant spacing and distribution in a given area have marked effect on the number of plants per unit area (Darwinkel, 1978; Kuizenga et al. 1977). High seeding rates can increase plants per unit area, but may reduce the other yield components: ears per plant, grains per ear and grain weight (Darwinkel, 1978; Kuizenga et al. 1977; Puckridge and Donald, 1967; Steel and Torrie, 1980).

1.9.2.Ears per plant.

Ontogenetically, numbers of ears is the first yield component to be fixed, and thus, assumes particular importance. High yields result from winter wheat crops with the high (>500 m-2) number of ears at harvest; in conjunction with high 1000grain weight (>50g) and high number of

grains per ear (>44 grains/ear).

The number of ears per plant is dependent on the number of mainstems that produce reproductive tillers. Power and Alessi (1978), studying winter wheat varieties Waldron and Ciano under field condition in USA in two consective years found that, the chance of tiller number three surviving to maturity was greatly increased as N fertilizer rates increased from 0 to 270kg/ha. They concluded that N fertilizer enhanced tiller survival and N fertilizer deficiency during early stages of tiller development (GS30) seemed particularly detrimental to tiller survival. N fertilizer applied at the onset of stem elongation (GS30) promoted ear formation because the fertility of the initiated tillers increased, but posponing the N fertilizer supply until GS39 would decrease the number of ears m-2 (Darwinkel, 1983).

1.9.3.Grains per ear.

Number of grains per ear is considered to be a limiting factor for maximum grain yield (Fischer, 1975; Thorne et al. 1968). In field experiments, Fischer et al. (1976); Puckridge and Donald (1967); Willey and Holliday (1971) found that increase in grain yield was correlated with increasing number of grains. However, studies by Darwinkel (1978; 1983) and Nerson (1980) demonstrated that increased number of grains per ear cannot fully compensate for deficient ear populations. Very high numbers of grains for example 36,910 m-2 can only be achieved in dense crops (800 plants m-2), in which grain weight was decreased because radiant energy for individual grain filling will be limited (Darwinkel, 1978).

Fischer et al. (1977) found that, grain yields were increased as number of grains increased up to 30,000 m-2 although grain weight gradually decreased from 45.4mg to 38.6mg. High numbers of grains were achieved using high ear densities (2070 m-2). Number of grains per unit

area can be increased by the application of N fertilizer at stem elongation by increasing the numbers of surviving ear-bearing tillers (Darwinkel, 1983).

1.9.4.Grain weight.

Final grain weight depends on the extent of plant assimilation during grain-filling, and this is closely related to the area and duration of green leaves. Wheat grain weight is partly determined in the pre-floral period, for instance by the size of the photosynthetic area, but mostly in the post-floral period by the rate and duration of grain growth. A detailed description of the contribution by each leaf to the total pool of assimilates available for growth and translocation at different stages is presented by Rawson and Hofstra (1969) working in Australia with a cultivar 'Sunset'. They concluded that the lower leaves mainly contribute their assimilates to the roots and side-tillers, while the top leaves, especially the flag leaves, provide the assimilate requirements of stems and grains.

Wheat grain weight may differ from one growing season to another, and from a particular environment to another. Table 1.8 presents the variation of thousand grain weight across the regions of the UK, from 1986 to 1988. These values exclude the results for Northern Ireland and Wales. The 1986 harvest season recorded the highest mean value, 46.7g compared with 43.2g and 42.8g for the 1987 and 1988. On regional bases, the mean value for Scotland is higher than the rest of the regions, probably due to longer period of grain filling resulting from lower temperature. By comparison, winter wheats have bigger grain sizes than the spring varieties. The main reason for the differences is due to the duration of grain development period which is longer for the former compared to the latter. In the 1988 harvest season for example, Longbow and Norman (winter varieties) recorded thousand grain weight of 49.1g

and 48.6g, compared to 40g for Axona (spring variety) at 15% moisture content (HGCA, 1988).

Table 1.8. Mean thousand grain weight of wheat from different regions in the UK from 1986 to 1988.

	Thousand grain weight (g) at 85%DM.		
All varieties.	1986	1987	1988
Eastern	47.2	41.3	42.8
Northern	50.5	49.2	41.9
Scotland	51.5	47.1	47.5
Northern Ireland	-	-	-
South Eastern	43.5	40.2	42.6
South Western	45.5	43.9	42.5
Midland & Western	44.4	44.2	42.5
Wales	-	-	-
United Kingdom	46.7	43.2	42.8

Source: Home-grown Cereal Authority (1988).

SECTION 2.

EFFECTS OF RATES AND TIMING OF NITROGEN ON SPRING WHEAT (VR.AXONA).

CHAPTER II. EXPERIMENT 1. 1988/1989.

Effects of rates and timing of nitrogen on spring wheat (vr. Axona).

2.1.Objectives.

There has been increased usage of UK grown milling wheat since 1974 (HGCA, 1989). However, one must remember that breadmaking flours are mostly milled from blends of homegrown wheat with imported high quality wheat, such as Canadian spring wheat. In UK Agriculture, spring wheat production has not been given much attention. Despite its potential as a high quality wheat, it has received less priority by cereal research scientists and commercial wheat growers. This is because in the past, most wheat producers laid greater emphasis on the production of high yielding winter varieties. On the other hand, production systems for milling grain were often neglected. With the current over production of wheat grains in the EEC, and, the premium paid on quality wheat acceptable into the Intervention, there is now a brighter future for spring wheat production in UK Agriculture.

To produce a milling wheat that is of an acceptable standard, the agronomic principles influencing increase in wheat quality and an economic yield are of paramount importance. This knowledge requires a systematic study of input applications and the subsequent effects of these on the agronomic and quality performance of the crop. If the levels of wheat exports from the UK are to increase the overall quality must be improved. Most of the wheat presently exported has been of animal feed quality, but for homegrown wheat to compete within international markets it has to be more suitable for human consumption.

Protein, as well as being nutritionally important forms the essential structural element in breadmaking because it is protein as gluten which holds the carbon dioxide gas produced during fermentation. Experiment 1 was designed to study the effects of two drilling patterns, different seed rates (in 1988), different fertilizer nitrogen levels and time of application on the growth, development, yield and quality of the spring wheat variety-Axona. The main objectives were to:

i. assess 'best' growth stage for nitrogen fertilizer application in relation to grain protein content.

ii. determine the response of this crop to three nitrogen levels and timings. This was achieved using growth analysis during the vegetative and reproductive phases of development.

iii. explore interactions between the levels of nitrogen fertilizer and time of application on the physiology of the crop and attempting to relate it to the yield, yield components and some breadmaking quality attributes.

iv. monitor grain filling and protein deposition into the grains during grain fill in relation to to the levels of nitrogen and its time of application.

v. determine whether different cultivation systems could combine with the input applications to increase grain yield.

2.2.Materials and methods.

Spring wheat (Triticum aestivum L.) variety Axona, is high yielding (110) has high breadmaking quality (6) and stiff straw (8). An explanation of the score values given in parentheses is given in Table 2.1. Which summarries the NIAB recommended list of spring wheats for 1988 and their quality characteristics. Other descriptive characters for these varieties are given in the complete NIAB Table (NIAB,1988). The crop was grown after forage maize at Wye College Farm in Burgate field

on a heavy gault clay in 1988, and after spring barley on a lighter clay loam soil in lower Orchard field in 1989. From soil analyses, the experimental fields at Burgate and lower Orchard were found to have pH values of 8.2 and 7.9 respectively.

The experimental design in 1988 was a split-split-plot factorial combination of 2 x 2 x 3 x 3 in randomisation with two drilling patterns, two plant population densities three levels of nitrogen fertilizer and timings as the main factors in four replications. In 1989, a 2 x 3 x 3 factorial was drilled because plant population density was not studied. Four replications were used in both years. The omission of the density treatments during the second season reduced the number of plots to 72 in 1989, compared to 144 in 1988. In both seasons, sub-subplots measured 3m x 7m. The three levels of nitrogen fertilizer and timings are referred to as N1, N2 and N3 and, T1, T2 and T3 respectively throughout the text of this thesis (Table 2.4). The degrees of freedom (df) for the two analyses of variance (ANOVA) are presented in Tables 2.2 & 2.3. In each of the years, the experimental sites were completely surrounded by a commercial crop of Axona.

All plots were treated with 20 and 67kg/ha of phosphatic and potassium fertilizers in the seedbed on March 1st and February 2nd in 1988 and 1989 respectively. Seeds were drilled using a 3m width Amazone drill with either a Suffolk coulter of 12cm inter row spacing or a Band coulter. The experimental treatments are described in Table 2.4. The varying amounts of nitrogen fertilizer were separately weighed and then applied manually to the experimental plots.

2.2.1. Husbandry practices.

The site at Burgate was sprayed with 'Muster' (glyphosate better known as Roundup) and Gramoxone (paraquat) at the rate of 4.0l/ha and 3.0l/ha on September 26th,1987 and December 13th, 1987 respectively, to

improve the stubble burn and destroy volunteer weeds especially Couch grass (Elymus repens). At lower Orchard site in 1989 no pre-drilling herbicide was applied, instead CMPP (mecoprop) a postemergence herbicide was applied on March 28th at the rate of 4.2l/ha. The sites were ploughed with a 15cm ploughing-depth on February 1st and January 31st and then disced on April 4th and February 5th in the 1988 and 1989 growing seasons. Seeds were dressed with Baytan for protection against fungal diseases. On June 22th 1988, plots were sprayed with a mixture of CMPP (mecoprop) and ALLY (metsulfuron methyl) both postemergence herbicides against broadleaved weeds at the rates 4.0l/ha and 30g/ha respectively and Corbel (fenpropimorph) at the rate of 0.79l/ha against fungal diseases such as Mildew (Erysiphe graminis). Liquid manganese (Vytel) was added as a 'tank mix' against micronutrient deficiency on the heavy clay site at the rate of 1.50l/ha in 1988. In 1989 the following fungicides were applied against Mildew (E. graminis); Patrol (fenpropidin) at the rate of 1.0l/ha on June 1st, and Corbel (fenpropimorph) at the rate of 1.2l/ha on June the 26th. Aphox (pirimicarb) was also applied against insects attack on May 24th and June 14 at the rates 233.3 and 261.6g/ha respectively.

2.2.2.Crop germination and establishment studies.

Crop germination and establishment were monitored to assess the effect of drilling pattern on the time of emergence in 1988. Areas of 0.5m x 0.5m were marked out with white plastic labels from each of the main-plots on April 16th, 3 days after drilling. Plants were later counted within these areas. Germination was not noted until about 10 days after drilling (Table 2.6), probably because of low soil temperature (Figure 2.6). Plant counts were taken every other day until germination was completed. Plants were considered to have germinated when the coleoptile lengths were about 2-4cm above the ground surface. On each of the counting days the total number of plants emerged was

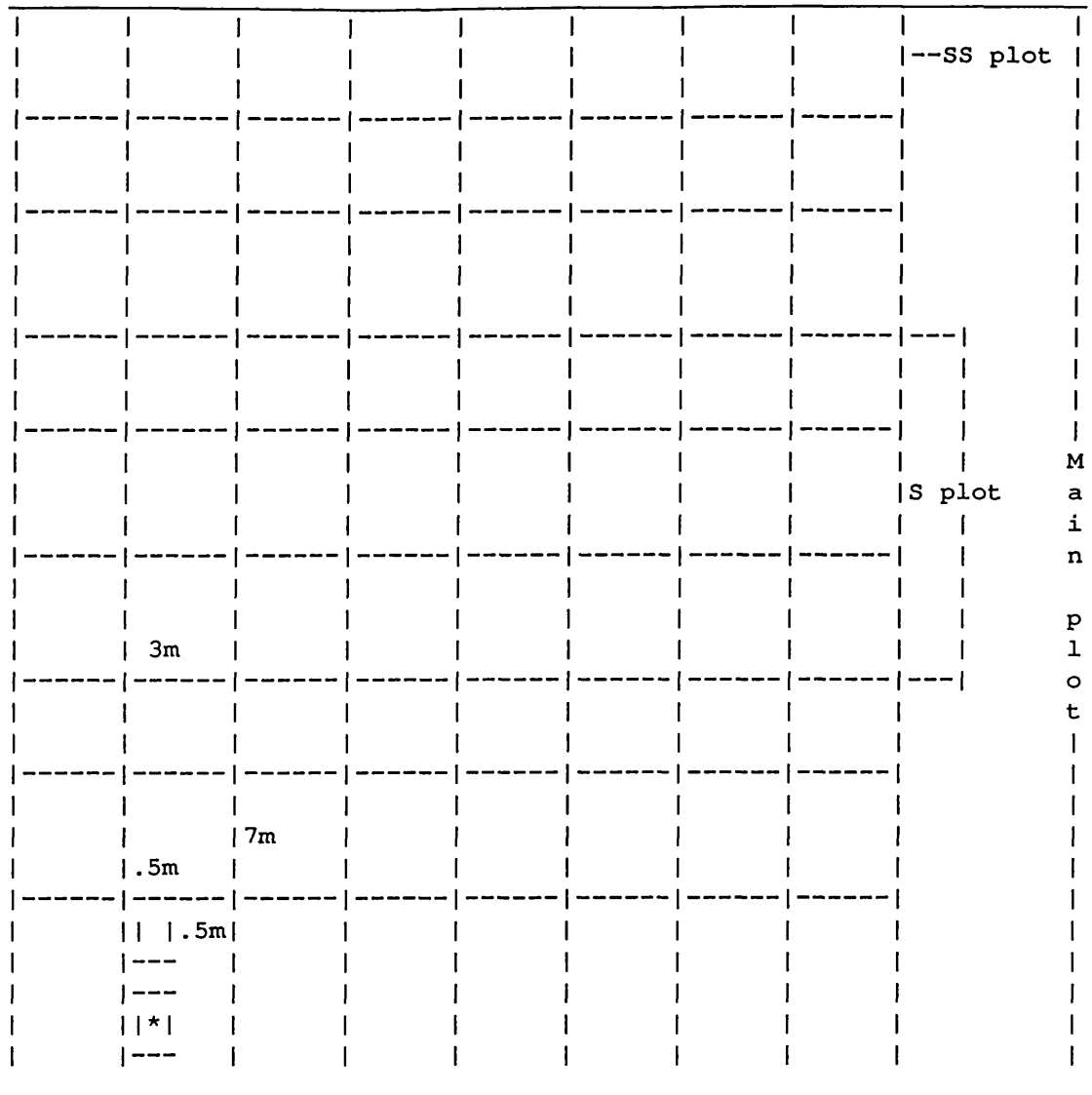
recorded. Results are shown in Tables 2.6 & 2.7. This investigation was not repeated in 1989, due to the very wet soil conditions on the experimental site at the time of seedling emergence which made it impossible to walk across the plots without creating surface damage.

2.2.3.Plant sampling.

Sampling was carried out every 5-7 days for plant growth analysis although more comprehensive record were made during the first season. The first samples were taken 30 and 80 days after drilling in 1988 and 1989 respectively. These were taken before the application of nitrogen fertilizer in 1988, and after the T1 treatment in 1989, in order to assess final plant establishment and to form a base point for the subsequent growth curves. After the first nitrogen application (T1), samples were taken from the T1 and T2 plots which were regarded as treated and control plots respectively. Following the application of the second nitrogen fertilizer treatment (T2), T3 plots were sampled as the control. Sampling from T1, T2 and T3 plots was carried out after the application of the third nitrogen fertilizer treatment.

Samples (0.5m x 0.5m) were taken from areas of full plant establishment on a stepwise basis about 0.3m from the edge of the plots to avoid edge effect. Sampling proceeded systematically from one end of the plots. The sampling method is briefly described in Figure 2.1. Remaining areas (5m x 1.8m) were left undisturbed for machine combining at harvest. A total of nine samples were taken in 1988. In 1989, the number of samples taken for the growth analysis was reduced to six. Growth analysis was continued until anthesis. A final sample was taken from all plots in both seasons at plant maturity to determine the yield components on August 31st 1988, and July 31st 1989. Undisturbed plot areas of 5m x 1.8m were harvested with the Hege Combine on September 7th, 1988 and August 7th, 1989.

Figure 2.1. Diagram describing the method of plant sampling.



*sampling area. Sampling started from one edge of the plot and continued inwards. S plot= subplot. SS plot= sub-subplot.

In 1988, because of the overall size of the experiment (which consisted of 144 plots), samples for plant growth analysis were taken only from the low density plots. The high density plots were later sampled to study grain development. Therefore, results for growth analysis and grain development studies do not include the effect of plant population density. Consequently the results section for these studies only presents the effects of drilling patterns, nitrogen levels and timings. In 1989 plant population density was not included in the treatment combinations.

2.2.4.Growth analysis.

After sampling, plants were packed into polythene bags with their various plot labels, and taken to the crop laboratory for growth analysis. Plants were separated, and each sample was counted to assess numbers of plants and tillers per unit area. These values were then converted to m-2. The average number of tillers per plant was calculated by dividing the numbers of tillers per unit area with the numbers of plants recorded from the same area . At anthesis, the numbers of ears per unit area, ears per plant and the total numbers of spikelets per ear (fertile and infertile) were recorded. Roots were removed and the vegetative parts packed into a paper bag and then dried in an oven at a temperature of 80^{o}C for a period of 48 hours and then weighed.

2.2.5.Measurement of flag leaf area.

In 1988 flag leaf areas were assessed to study the possible effect of the treatments on grain filling. These were carried out at three growth stages (GS45,55 & 65) from 'booting' (June 21st, 1988) to anthesis (July 5th, 1988). A sub-sample of 10 plants was taken from each sample, flag leaves were then removed from the leaf-sheaths and measured by a simple arithemetic method of length x breath. They were then packed into paper bags and dried at 70^{o}C for 24 hours and then weighed. The values obtained for leaf area and the dry weight were then used to calculate the specific leaf area (SLA) of the flag leaves defined "as the ratio of the area of the leaf to the dry weight" expressed in cm2/g.

2.2.6.Grain development studies.

Monitoring of grain development started at the beginning of grain filling on July 19th, 1988 and June 21st, 1989 and was continued until grain maturity. Samples were taken every other day for this purpose. The sampling method used for this study was identical to the one employed

for growth analysis. In the crop laboratory, five mainshoot ears were choosen at random in 1988. This was increased to 10 in 1989. Grains were removed carefully using a dissecting needle during the early stages of development. The exercise was time consuming. For example, in order to remove the grains from one ear required about 5 to 6 minutes, and to complete one treatment sample required about 1hour. As the grains increased in size they were removed by hand threshing. Grains were collected in a petri-dish and then counted. Their fresh weight was determined, and they were transferred into small paper bags measuring 9cm x 5cm, and dried at a temperature of 70^{o}C for 24 hours and then weighed.

Weights per grain (86%DM) were calculated by dividing the total weight of the grain with the total numbers of grains. Grain weight was expressed in mg/grain. A total of 12 and 8 samples were taken for this detailed study in 1988 and 1989 experimental seasons. The grain samples were retained for protein development analysis.

2.2.7.Protein analyses.

Grain samples from the grain development studies were ground to pass a 1mm mesh sieve. The proportion of protein in the developing grains was measured by the determination of total nitrogen using the Kjeldahl microdigestion technique (MAFF, 1986). All grain nitrogen contents, expressed as a percentage of dry grain, were converted to crude protein in grain at 14% moisture content by multiplying with the factor 5.7 (Baker, 1984).

Grain protein in the combined samples was determined using the InfraAlyser - "Technicon 400 Autoanalyser". Approximately 200g of grain dried at 50^{o}C for 72 hours were ground using the Laboratory Mill 3100. The infraalyser was calibrated using the method described by the EEC for hard wheat product codes. The infraalyser cup was carefully filled with

the ground grain sample and scraped flat, to prevent air-pockets which would interfere with the results. The lid was put on and the cup placed glass side up on the infraalyser tray. All equipments were thoroughly cleaned out between samples and the glass of the cup wiped with lens tissue to remove left powdered samples that would lead to cross-contamination. The same cup was used for all samples to prevent possible cup-bias (e.g variation in glass thickness and size) affecting the results.

For each field plot two samples were taken and two replicates carried out on each subsample by turning the cup through 180° between readings. Readings from the infraalyser were obtained at sample moisture contents but these values were then adjusted to the UK standard of 14% moisture contents using the formula:

$$aP = \frac{P \times \%DM}{(100 - m.c)}$$

Where:

aP = Adjusted percentage protein.

P = Percentage protein of the grain sample.

%DM = Percentage grain dry matter, normally given at 86%.

m.c = Moisture contents of the sample at the time of analysis obtained from the infraalyser reading.

2.2.8.Hagberg falling number (HFN).

This techinque assesses the content of the enzyme α-amylase by measuring the rate at which α-amylase liquefies a starch gel. The Hagberg falling number (HFN) was measured using the Falling Number AB Machine, Type 1400 of the Stockholm Sweden System Perten. Part of the samples used for the protein analysis were also used for this measurement. The ground flour was weighed on a highly sensitive

balance. The weight of each sample taken depended upon the percentage moisture contents of the sample as described in the manual for falling number determination. For example, 6.70g of the ground sample was taken when sample moisture contents were 12%. This allows for the moisture contents to be corrected to 15%. Percentage moisture contents of the samples and their corresponding weights taken for analyses are given in Table 2.5.

After weighing, samples were transferred to the Falling number boiling tube. 25ml of distilled water was added on to the flour and mixed until a suspension was produced. The stirrer was quickly inserted to prevent the suspension from oxidising. The tube was then transferred into a boiling water bath (Plate 3). The stirrer started to move after 5 seconds at about two strokes per second and then stop after 60 seconds. The stirrer is supported by the starch gel and the time it takes to fall is taken as the α-amylase content of the wheat. The longer the stirrer takes to fall, the lower the α-amylase activity.

Plate 3. An instrument for measuring Hagberg falling number.



Table 2.2. Skeleton analysis of variance (ANOVA) in 1988.

SOURCE OF VARIATION	df
REPS STRATUM	3
REPS, MAINPLOT STRATUM	
Drill	1
Density	1
Drill x Density	1
Residual (a)	9
Mainplots total	12
REPS, MAINPLOT, SUBPLOT STRATUM	
Nitrogen	2
Drill x Nitrogen	2
Density x Nitrogen	2
Drill x Density x Nitrogen	2
Residual (b)	24
Subplots total	32
REPS, MAINPLOT, SUBPLOT, SUB-SUBPLOT STRATUM	
Time	2
Drill x Time	2
Density x Time	2
Nitrogen x Time	4
Drill x Density x Nitrogen	2
Drill x Nitrogen x Time	4
Density x Nitrogen x Time	4
Drill x Density x Nitrogen x Time	4
Residual (c)	72
Sub-Subplots total	96
GRAND TOTAL	143

Table 2.3. Skeleton analysis of variance (ANOVA) in 1989.

SOURCE OF VARIATION	df
REPS STRATUM	3
REPS, MAINPLOT STRATUM	
Drill	1
Residual (a)	3
Mainplots total	4
REPS, MAINPLOT, SUBPLOT STRATUM	
Nitrogen	2
Drill x Nitrogen	2
Residual (b)	12
Subplots total	16
REPS, MAINPLOT, SUBPLOT, SUB-SUBPLOT STRATUM	
Time	2
Drill x Time	2
Nitrogen x Time	4
Drill x Nitrogen x Time	4
Residual (c)	36
Sub-Subplots total	48
GRAND TOTAL	71

Table 2.4. Description of experimental treatments in 1988 and 1989.

	1988	1989
Drilling Date.	April 13th.	February 8th.
Seed Rate.	145kg/ha - 400seeds m-2.	Not applicable.
	200kg/ha - 550seeds m-2.	259kg/ha - 550seeds m-2.
Fertilizer nitrogen.		
(source: Nitram - 34.5%N)		
Level 1 (N1)	80kg/ha	--do--
Level 2 (N2)*	125kg/ha	--do--
Level 3 (N3)	170kg/ha	--do--
Timings.		
Timing 1 (T1)	GS12-13, 26 days after drilling (May 9th).	GS14, 59 days after drilling (April 4th).
Timing 2 (T2)	GS30, 49 days after drilling (June 1st).	GS30, 81 days after drilling (April 30th).
Timing 3 (T3)	GS32, 56 days after drilling (June 8th).	GS32, 91 days after drilling (May 10th).

*This is the same rate used for the College Farm crop surrounding the experimental site in 1988 growing season.

Table 2.5. Correction of sample weight to 15% moisture basis.

%	.0	.2	.4	.6	.8	
9	6.40	6.45	6.45	6.45	6.50	
10	6.50	6.55	6.55	6.55	6.60	g
11	6.60	6.60	6.65	6.65	6.70	r
12	6.70	6.70	6.75	6.75	6.80	a
13	6.80	6.80	6.85	6.85	6.90	m
14	6.90	6.90	6.95	6.95	7.00	m
15	7.00	7.00	7.05	7.05	7.10	e
16	7.10	7.15	7.15	7.15	7.20	s
17	7.20	7.25	7.25	7.30	7.30	
18	7.30	7.35	7.35	7.40	7.40	

2.3.Results.

2.3.1.Crop establishment.

To assess the effect of the drilling patterns on crop germination and seedling establishment during 1988, the time and day of emergence were monitored on the field. Seedling emergence was recorded at intervals of two days, from the appearance of the first seedling (day 8) until the 18th day after drilling. Extra seedling counts were again carried out on the 23rd day to estimate the total number of seedlings that had emerged, and similarly on day 29th to determine the possible loss of seedlings. Germination was completed between days 18 and 23. Results showing the time and day intervals of seedlings emergence averaged over 4 replicates are presented in Tables 2.6 & 2.7.

Table 2.6. Seed germination and seedling establishment m-2 (means of 4 replicates).

Drilling patterns.	Loss.								Final estimate.
Days after Drilling.	8	10	12	14	16	18	23	29	
Suffolk Coulter (Low).	0	8	100	244	300	316	330	46	284
Suffolk Coulter (High).	0	20	124	312	460	468	488	92	396
Band Coulter (Low).	0	0	82	218	294	354	368	60	308
Band Coulter (High).	0	10	60	228	340	394	500	72	428

Table 2.7. Day of seedling emergence (means of 4 replicates m-2).

Drilling patterns.	Day intervals.					
	8-10	10-12	12-14	14-16	16-18	18-23
Suffolk Coulter (Low).	8	92	144	56	16	14
Suffolk Coulter (High).	20	104	188	148	8	20
Band Coulter (Low).	0	82	136	76	60	14
Band Coulter (High).	10	50	168	112	54	106

Final crop establishments based on the plant counts taken 29 days after drilling were 71%, 72% and 77%, 78% of the target populations (400 and 550 seeds m-2) for the low and high plant population densities (Table 2.6). Seedling emergence was 2 days later in the band coulter drilled plots (Table 2.6). For example on day 10, no emergence was noted on the band coulter drilled plots from the low plant population density, whilst on the same day, 8 seedlings had emerged m-2 in the suffolk coulter drilled plots. At high density, similar results were obtained. While the suffolk coulter drilled plots recorded 20 seedlings m-2 on day 8, only 10 seedlings m-2 had emerged from plots drilled with the band coulter (Table 2.6).

The same pattern of seedlings emergence continued until the 18th day in the low density plots, and until day 23 at high density. From day 18, the number of seedlings that emerged m-2 increased with the band

coulter on the low density plots. Similar trend was also observed on the high density plots on day 23 (Table 2.6).

Table 2.7 shows the day of seedling emergence within a given intervals of time. The percentages of seedlings which emerged between day 12 and 14 were about 44%, 39% and 37, 34% with the low and high densities, corresponding to suffolk and band coulter treatments (Table 2.7). On the 14th day, 74% and 64% of the seedlings had emerged from the suffolk coulter plots for the low and high densities. The corresponding values for the band coulter drilling on the same day were 59% and 46% respectively. In the high density population about 21% of the seedlings had not emerged on day 18 from the band coulter plots, as compared to 4% for the suffolk coulter (Table 2.6).

The above results suggest that, drilling using the band coulter possibly placed the seeds deeper into the soil as compared to those drilled with suffolk coulter. However, this is only speculatory, since no measurements were carried out on coleoptile length to determine the depth of seed placement. It was hoped to investigate sowing depth in the 1989 growing season, however, because of the wet field conditions mentioned in the material and methods (page 64) it was not feasible to repeat the establishment observations. Therefore, this aspect may require more detailed study to explore the relationship between seeding depth in band coulter drilling and the coleoptiles length. Seedling establishment was more synchronised in suffolk coulter drilled plots during 1988 growing season (Table 2.7).

Plant mortality was also assessed on day 29. Results showed greater plant mortality from the suffolk coulter drilled plots (Tables 2.6 and 2.7). The averaged numbers of plants (averaged over densities) that died between days 23 and 29 were 138 and 132 for the suffolk and band coulters respectively (Table 2.7).

2.3.2.Dry matter production and crop growth rate.

Table 2.8 shows the effects of N levels and timings on the total dry matter production by the crop for both drilling methods. In 1988, nitrogen fertilization at T1 (GS12-13) gave the highest total dry matter. On the second sampling date, (May 19th), 10 days after the first N treatments (T1), total dry matters m-2 obtained from the T1 treatments by the suffolk coulter drilled plots were 21.3g, 23.8g and 19.7g as compared to 20.4g, 17.8g and 18.5g for the T2 treatments, which had not received any Nitrogen. The corresponding values for the T1 and T2 treatments for the band coulter drilled plots, were 25.5g, 21.4g and 23.7g for the former and 21.3g, 19.2g and 22.5g for the latter. At this time, although there was a trend of an increase in total dry matter m-2 due to T1 treatment T1, no significant difference (P>0.05) was detected between the T1 and T2 treatments (SED = 2.4), Table 2.8.

This trend of dry matter production as influenced by the N levels and timings continued until anthesis when growth analysis was stopped. On each of the sampling dates, the T1 treatment produced higher dry matter than T2 and T3; except with the application of 170kg/ha of N, at which the T2 treatment slightly produced higher (NS) total dry matter on day 58. Even then, this effect was only noticed with the band coulter drilled plots (Table 2.8). The early (T1) Nitrogen effects mainly resulted from higher numbers of tillers m-2 and to some extent from a rise in individual plant weight (Tables 2.14 & 2.10). The latter ranged from 2797mg to 2935mg in the suffolk coulter drilled plots and from 2474mg to 3038mg for the band coulter at anthesis (H9) Table 2.10. From the trend of plant dry weights, it appeared that, with N treatment at T1 crop growth rate was influenced earlier and hence a higher leaf area index was probably obtained from this treatment. Evidence for this is given by the results of flag leaf area (Table 2.17).

Table 2.8. Effect of N levels and timing on total biomass (g m-2) of a spring wheat (variety-Axona) in 1988.

		Suffolk Coulter.				Band Coulter.				
		Nitrogen levels (kg/ha).								
		80	125	170	Mean	80	125	170	Mean	SED.
Hts.	N Timing									
H1	-		9.9				11.1			1.2
	T1	21.3	23.8	19.7	21.6	25.5	21.4	23.7	23.5	
H2	T2	20.4	17.8	18.5	18.9	21.3	19.2	22.5	21.0	
	Mean	20.9	20.8	19.1		23.4	20.3	23.1		3.2
	T1	40.5	47.0	38.2	41.9	40.7	36.6	36.1	37.8	
H3	T2	40.9	36.9	38.3	38.7	40.3	34.6	40.3	38.4	
	Mean	40.7	42.0	38.3		40.5	35.6	38.2		21.8
	T1	108.5	133.5	102.1	114.7	121.7	110.7	118.6	117.0	
H4	T2	86.0	74.7	89.7	83.5	97.2	80.0	94.6	90.6	
	T3	98.4	86.1	79.9	88.1	109.5	100.2	102.5	104.1	
	Mean	97.5	98.1	90.6		109.5	97.0	105.2		18.5
	T1	210.1	213.0	178.5	200.6	239.8	192.3	182.9	205.0	
H5	T2	181.8	141.4	160.3	161.2	184.7	164.9	200.7	183.4	
	T3	162.1	159.4	131.3	150.9	178.9	169.6	164.0	170.8	
	Mean	184.7	171.3	156.7		201.1	175.6	182.5		27.0
	T1	256.3	285.5	254.9	265.6	282.6	245.4	266.6	264.9	
H6	T2	223.4	212.7	194.1	210.1	249.0	214.9	224.3	229.4	
	T3	221.3	206.0	207.7	211.7	237.6	224.4	212.3	224.8	
	Mean	233.7	234.7	218.9		256.4	228.2	234.4		32.2
	T1	352.6	396.8	339.7	363.0	428.4	391.0	397.8	405.7	
H7	T2	333.3	280.5	295.2	303.0	375.1	377.8	322.6	358.5	
	T3	337.3	298.0	264.8	300.0	334.3	350.9	364.5	349.9	
	Mean	341.1	325.1	299.9		379.3	373.2	361.6		38.6
	T1	530.7	608.6	528.6	556.0	569.2	542.7	557.7	556.5	
H8	T2	444.9	465.8	478.4	463.0	553.9	476.2	533.6	521.2	
	T3	476.6	450.7	416.7	448.0	481.3	439.7	499.0	473.3	
	Mean	484.1	508.4	474.6		534.8	486.2	530.1		55.0
	T1	577.2	582.1	657.4	605.6	721.6	676.3	741.7	713.2	
H9	T2	563.8	528.0	473.8	521.9	618.6	636.5	561.9	605.7	
	T3	498.4	502.2	521.5	507.4	565.1	622.9	600.7	596.2	
	Mean	546.5	537.4	550.9		635.1	645.2	634.8		55.6

At anthesis (H9) the total dry matter produced by applying 170kgN/ha at T1 (GS12-13) was higher than those obtained by the

applications of 125kg and 80kg/ha. This was true for both suffolk and band coulter drilled plots (Table 2.8). For example, 657.4g of dry matter m-2 was produced at anthesis by applying 170kgN/ha at T1 as compared to 582.1g and 577.2g corresponding to 125kg and 80kgN/ha with the suffolk coulter drilled plots. Dry matter production during this period by the application of the same levels of N at T1 from the band coulter drilled plots, were 741.7g, 676.3g and 721.6g corresponding to N levels 170kg, 125kg and 80kg/ha respectively (Table 2.8). For each of the drilling methods and the N levels, the early fertilizer treatment (T1) produced the highest total dry matter. On the other hand, the dry matters obtained by N application at T2 and T3 were not significantly different ($P>0.05$) from each other (Table 2.8). However, the total dry matter produced at anthesis was usually higher (NS) when N was applied at T2 than at T3. This was true for plots which received 80kg and 125kgN/ha. Plots treated with 170kgN/ha produced more dry matter with the latter timing (Table 2.8).

At H9, the total dry matter averaged over N levels and timings was higher from plots that were drilled using the band coulter (Table 2.8). However, this trend was not consistent at earlier harvests. Total dry matters m-2 at anthesis for the band coulter were 635.1g, 645.2g and 634.8g versus 546.5g, 537.4g and 550.9g for the suffolk coulter. The dry matter production at anthesis decreased with the time of N applications (Table 2.8). Final dry matter production averaged over N levels by the suffolk coulter drilled plots were 605.6g, 521.9g and 507.4g for the T1, T2 and T3 treatments, whilst corresponding values for the band coulter plots were 713.2g, 605.7g and 596.2g respectively.

In 1989, fewer samples were taken for dry matter measurement, the main reasons for this have been given in materials and methods. Results for total dry matter m-2 and the dry matter production per plant are presented on Tables 2.9 and 2.11.

Table 2.9. Total biomass (g m-2) in 1989 experimental season of a spring wheat (variety-Axona).

		Suffolk Coulter.				Band Coulter.				
		Nitrogen levels (kg/ha).								
		80	125	170	Mean	80	125	170	Mean	SED.
Hts.	N Timing									
	T1	105.8	115.1	112.5	111.1	116.0	139.4	141.4	132.3	
H1	T2	88.9	86.7	89.4	88.3	92.7	124.2	132.3	116.4	
	Mean	97.4	100.9	101.0		94.4	106.8	106.9		16.5
	T1	571.9	577.5	514.7	554.7	590.9	630.8	623.5	615.1	
H2	T2	446.3	606.3	484.1	512.2	559.7	614.7	561.1	578.5	
	T3	447.7	490.6	494.6	477.6	458.5	545.1	510.9	504.8	
	Mean	488.6	558.1	497.8		536.4	596.9	565.2		46.1
	T1	722.0	694.5	760.0	725.5	665.7	709.2	789.8	721.6	
H3	T2	557.5	713.2	661.5	644.1	669.1	678.5	639.5	662.4	
	T3	557.6	595.4	615.5	589.5	618.8	658.4	614.9	630.0	
	Mean	612.4	667.7	679.0		651.2	682.0	681.4		48.1
	T1	796.5	804.6	814.4	805.2	786.1	843.0	785.2	804.8	
H4	T2	557.4	823.3	771.4	717.4	699.5	697.2	766.4	721.0	
	T3	617.5	704.9	721.0	681.1	680.8	715.9	673.3	690.0	
	Mean	657.1	777.6	768.9		722.1	752.0	741.6		68.6
	T1	856.0	960.2	990.1	935.3	937.1	936.0	970.0	947.7	
H5	T2	755.1	919.1	899.0	857.7	899.0	952.0	844.2	898.3	
	T3	743.0	844.0	764.1	783.7	774.1	875.9	934.0	861.3	
	Mean	784.7	907.7	884.3		870.0	921.3	916.0		91.8
	T1	878.0	945.8	997.2	940.3	1044.0	985.9	1033.2	1021.0	
H6	T2	778.9	774.2	936.0	829.7	815.0	871.8	945.3	877.3	
	T3	786.9	852.0	930.1	856.3	849.8	881.8	870.4	867.3	
	Mean	814.7	857.3	954.3		903.0	913.3	949.3		81.6

Total dry matter m-2 was increased by the first N application (T1). The increase in total dry matter with T1 treatment was not significantly different from the T2 and T3 treatments in the suffolk coulter plots. Similarly, in the band coulter plots the effect of T1 treatment on total dry matter was not significantly different from the T2 treatment. However, there was a significant increase ($P<0.05$) in total dry matter by the T1 treatment compared to T3 on May 30th (H2). The mean total dry matters m-2 produced by the T1 and T3 treatments were 615.1g and 504.8g

respectively (Table 2.9).

The trends in dry matter production m-2 in relation to time of application of N were consistent until the fifth sampling (H5). When the mean dry matters produced m-2 were 935.3g, 857.7g, 783.7g and 947.7g, 898.3g, 861.3g for the T1, T2 and T3, suffolk and band coulter plots respectively. It is important to note that, at some of the sampling dates the differences between treatments were not significant due to high standard error of difference (SED) Table 2.9. At the last sample for growth analysis, the lowest total dry matter m-2 was recorded from the T2 treatment in the suffolk coulter plots. The mean total dry matter recorded from the T2 treatment was 829.7g compared to 940.3g and 856.3g for the T1 and T3 treatments. On the other hand, the band coulter plots showed a systematic decrease in total dry matter with the delay in N application. The mean total dry matter produced by the T1 treatment was 1021.0g, whilst T2 and T3 treatments recorded mean dry matter m-2 of 877.3g and 867.3g respectively (Table 2.9).

Dry matter production m-2 was not consistent with increase in the level of N at the start of growth analysis (April 29th). However, on May 30th application of 125kg/haN influenced the total dry matter m-2 slightly. By June 23rd, the total dry matter was increased with the level of N application. This suggests that the increase in the levels of N from 80 to 170kg/ha decreased the rate of leave senescence which resulted in high dry matter at anthesis. The dry matters produced m-2 at anthesis were 814.7g, 857.3g, 954.3g and 903.0g, 913.3g, 949.3g for the N1, N2 and N3 corresponding to suffolk and band coulter treatments (Table 2.9).

The method of sampling described in materials and methods (pages 64-65) did not give a precise assessment of the numbers of plants per unit area. The number of plants within a sample at a given sampling date varied even within the same treatment. This created some

inconsistency in the results obtained from the total dry matter. For example, at H5 in 1988 a trend in increase in total dry weight was detected with delaying N application. This trend was not notice in the following harvest (H6), Table 2.8. Therefore treatment effects based on total dry matter results were not detected on some smpling dates. This was probably due to the variability in the numbers of plants per unit area. This 'background variation' from plot to plot and from one sampling date to another, resulted in high cofficients of variation, hence high SED (Tables 2.8 & 2.9). For this reason, a detailed study of the change in dry matter per plant was carried out in order to minimise this difficulty. The results are presented in Tables 2.10 and 2.11. Table 2.35 also shows the rate of change in dry matter per plant in mg/plant/day during the active growth stages of the crop.

In 1988, the dry matter production from day 51 to 76, when all treatments had been applied was significantly higher ($P<0.05$) with the T1 treatment. However, application of 80kgN/ha in suffolk coulter drilled plots at T1 did not give a significant increase in dry matter per plant from the T3 treatment on day 76; H8 (Table 2.10). At anthesis also, application of 125kg/ha of N at T1 had a lower dry matter per plant compared to the T2 treatment in the suffolk coulter drilled plots. Similar results were obtained when 80 and 125kg/ha of N were applied at T1 as compared to T2 with the band coulter drilled plots (Table 2.10).

The application of 170kgN/ha at T1 gave the highest dry matter per plant in each of the drilling patterns. For example at H9, 2935.0mg and 3038.0mg of dry matter per plant were obtained when 170kg/ha was applied at T1 as compared to 2797.0mg,2700.0mg and 2474.0mg, 2555.0mg corresponding to 80 and 125kg/ha of N for the suffolk and band treatments respectively (Table 2.10). Treatments with 80 and 125kg/ha of N at T2 in the suffolk coulter drilled plots produced a higher dry matter per plant than when 170kg/ha of N was applied.

Table 2.10. Effects of N levels and timing on the dry matter per plant (mg) in 1988.

		Suffolk Coulter.				Band Coulter.				
		Nitrogen levels (kg/ha).								
		80	125	170	Mean	80	125	170	Mean	SED.
Hts.	N Timing									
H1	-		34.9				36.3			2.0
	T1	75.9	72.8	71.1	73.3	81.9	71.8	73.3	75.7	
H2	T2	72.9	65.4	65.8	68.0	67.6	64.6	68.5	66.9	
	Mean	74.4	69.1	68.5		74.8	68.2	70.9		6.4
	T1	147.0	154.5	135.5	145.7	146.8	132.0	140.0	139.6	
H3	T2	147.3	133.9	139.3	140.2	136.5	126.7	137.1	133.4	
	Mean	147.2	144.2	137.4		141.7	129.4	138.6		24.1
	T1	451.1	468.2	413.3	444.2	464.5	420.3	438.7	441.2	
H4	T2	336.7	314.3	329.1	326.7	376.9	300.4	385.5	354.3	
	T3	337.8	321.1	319.7	326.2	382.3	363.6	346.5	364.1	
	Mean	375.2	367.9	354.0		407.9	361.4	390.2		45.7
	T1	836.1	906.1	834.1	858.7	871.3	676.1	692.2	746.3	
H5	T2	652.2	643.3	578.2	624.3	643.2	561.2	647.3	617.0	
	T3	574.9	643.2	597.0	605.0	692.9	538.3	604.1	611.7	
	Mean	687.7	730.7	669.7		735.7	591.7	647.7		57.7
	T1	1058.2	1206.8	1102.3	1122.3	1096.2	919.8	901.2	972.3	
H6	T2	785.3	853.9	837.0	825.3	928.3	873.2	808.8	870.0	
	T3	886.1	861.1	729.1	825.3	848.9	781.3	829.0	819.7	
	Mean	909.7	974.0	889.3		957.7	858.0	846.3		92.4
	T1	1762.8	1636.2	1634.1	1677.7	1591.7	1662.1	1556.2	1603.3	
H7	T2	1322.0	1427.1	1280.3	1343.0	1330.0	1321.3	1397.1	1349.3	
	T3	1441.3	1395.3	1114.2	1316.7	1368.3	1193.2	1265.1	1275.0	
	Mean	1508.7	1486.2	1342.7		1430.1	1392.1	1406.2		145.9
	T1	2183.1	2825.7	2426.1	2478.3	2273.3	2150.3	2369.2	2264.0	
H8	T2	1911.7	2428.9	2093.8	2145.0	2016.2	1888.3	1843.3	1915.7	
	T3	2179.0	1904.0	1646.0	1876.3	1879.1	1622.2	1978.0	1826.3	
	Mean	2091.3	2386.3	2055.3		2055.8	1886.7	2063.3		181.8
	T1	2796.9	2700.1	2934.9	2810.7	2474.0	2555.0	3038.0	2689.0	
H9	T2	2286.7	2780.2	2653.1	2573.3	2614.3	2679.6	2395.9	2563.3	
	T3	2147.1	2261.4	2330.8	2246.3	2175.0	2247.1	2092.1	2171.3	
	Mean	2410.3	2580.3	2639.7		2421.0	2494.0	2508.7		287.9

By comparison, the band coulter drilled plots gave the highest dry matter per plant using 125kg/ha of N. When results were averaged over

drilling methods and N levels, plant dry matter production at anthesis was significantly lower with the T3 treatment as compared to the T1 and T2 treatments (Table 2.10).

Table 2.11. Dry matter per plant (mg) during 1989 experimental season.

		Suffolk Coulter.				Band Coulter.				
		Nitrogen levels (kg/ha).								
		80	125	170	Mean	80	125	170	Mean	SED.
Hts.	N Timing									
	T1	315.0	342.5	335.0	330.8	297.5	357.5	362.5	339.1	
H1	T2	289.2	287.0	282.7	286.3	278.6	269.7	279.2	275.8	
	Mean	302.1	314.8	308.9		288.1	313.6	320.9		38.5
	T1	1862.1	1866.8	2070.0	1933.0	1975.2	1934.8	2072.1	1994.0	
H2	T2	1545.0	1989.9	1629.8	1721.7	1655.0	2049.8	1801.9	1835.7	
	T3	1690.2	1580.0	1689.8	1653.3	1360.2	1957.0	1626.8	1648.0	
	Mean	1699.0	1812.3	1796.7		1663.3	1980.7	1833.7		68.4
	T1	2305.2	2342.0	2430.1	2359.0	1957.2	2470.1	2506.7	2311.3	
H3	T2	1677.0	2326.8	2330.0	2111.3	1994.8	1927.2	2100.0	2007.3	
	T3	1787.3	1876.7	2220.0	1961.3	1692.0	2152.1	2221.9	2022.0	
	Mean	1923.0	2182.0	2326.7		1881.3	2183.0	2276.3		90.2
	T1	2654.9	2970.0	2784.8	2803.3	2477.0	2615.0	2582.1	2558.0	
H4	T2	2185.0	2732.0	2647.1	2521.3	2122.2	2454.8	2382.0	2319.7	
	T3	2190.2	2422.0	2425.3	2345.7	2239.9	2367.0	2347.1	2318.0	
	Mean	2343.3	2708.0	2619.0		2279.7	2479.0	2437.0		92.1
	T1	3250.1	3417.2	3407.0	3358.0	3035.0	3144.9	3060.1	3080.0	
H5	T2	2620.0	2996.8	3352.1	2989.7	2915.0	2690.1	2567.0	2724.0	
	T3	2702.2	3510.0	2906.9	3039.7	2365.1	2760.0	2411.9	2512.3	
	Mean	2857.3	3308.0	3222.0		2771.7	2865.0	2679.7		128.2
	T1	3500.0	3691.8	3676.9	3623.0	3277.0	3445.1	3455.0	3392.3	
H6	T2	2945.1	3492.0	3400.2	3292.3	2905.1	3299.9	2960.0	2955.0	
	T3	2732.0	3021.9	3672.0	3142.0	2787.0	3037.1	2905.0	2909.7	
	Mean	3059.0	3402.0	3596.3		2989.7	3160.7	3106.7		149.3

Plant dry matter averaged over N levels and timing was slightly higher (NS), when plots were drilled using the suffolk coulter. For example, at anthesis plant dry matters were 2543.4mg with suffolk coulter treatment compared to 2474.6mg (SED = 182.9), for the band coulter plots (Table 2.10). Plant weight was increased by additional N.

With the chosen range of 80kg/ha to 170kg/ha, the dry weights were 2410.3mg, 2580.3mg, 2639.7mg, and 2421.0mg, 2494.0mg, 2508.7mg for the suffolk and band coulters respectively.

Table 2.12. Crop growth rate (g m-2/day) during 1988 and 1989.

Drilling methods.	Timings.	Nitrogen levels (kg/ha). 80	125	170	Means.
		1988			
	T1	16.9	19.0	17.1	17.7
Suffolk Coulter.	T2	14.4	15.6	15.5	15.2
	T3	15.1	15.0	13.5	14.4
	Mean.	15.5	16.4	15.4	
	T1	17.9	17.3	17.6	17.6
Band Coulter.	T2	18.3	15.8	17.6	17.2
	T3	14.8	13.6	15.9	14.8
	Mean.	17.0	15.6	17.0	
		1989			
	T1	12.8	15.4	20.0	16.1
Suffolk Coulter.	T2	13.9	15.2	18.8	16.0
	T3	14.1	15.1	18.1	15.8
	Mean.	13.6	15.2	19.0	
	T1	18.9	14.8	17.1	16.9
Band Coulter.	T2	16.6	14.3	16.0	15.6
	T3	16.3	14.0	15.0	15.1
	Mean.	17.3	14.4	16.0	

In the 1989 experimental season a similar procedure was followed to study the detail dry matter production per plant. The results are presented on Table 2.11. These show a consistent response in increase in dry matter per plant. The influence of the first N treatment (T1) was recorded from the start of growth analysis. This continued until the last sampling for this exercise. On April 29th (H1), the mean plant dry matters produced by the T1 treatment were 330.8g and 339.1g compared to 286.3g and 275.8g for the T2 treatment, corresponding to suffolk band coulters. At each of the sampling dates, plant dry matter production by the T1 treatment was significantly higher ($P<0.05$) than T2 and T3 treatments (Table 2.11). At anthesis (H6), the T1 Treatment recorded

3623.0mg and 3392.3mg mean plant dry weight, while T2 and T3 gave 3292.3mg, 3142.0mg and 2955.0mg, 2909.7mg for the suffolk and band coulters respectively.

The level of N did not give a consistent result in respect to dry matter per plant in 1989 experimental season. However, application of 125kg/haN influenced the dry matter per plant. Plant dry matter was increased with levels of N at anthesis in the suffolk coulter plots. In case of the band coulter highest dry matter per plant was recorded from the application of 125kg/haN (Table 2.11).

The rate of increase in total dry matter (g m-2/day) during the main growth period (days 51 to 76), in 1988 was greater when N was applied at T1. In the suffolk coulter drilled plots, application of 125kg/haN at T1 produced the greatest rate of increase (19.0g m-2/day). By comparison the same level applied at T1 produced a lower rate of increase when plots were drilled using the band coulter compared to plots which received 80kg and 170kgN/ha (Table 2.12).

Rates of increase in dry matter in T2 were similar when suffolk coulter plots were treated with 125kg and 170kgN/ha (15.6 and 15.5g m-2/day). Similar results were also given by the T3 treatment using 80kg and 125kgN/ha (Table 2.12). The lowest rates of increase in dry matter were obtained from the suffolk coulter drilled plots using 80kgN/ha at T2 and 170kgN/ha at T3. On the other hand, the lowest rate of increase in dry matter from the band coulter plots was obtained when they received 125kg/haN at T3 (Table 2.12).

The results of rate of total dry matter increase m-2 for the 1989 are also presented in Table 2.12. In this experimental season, the mean rate of increase in total dry matter was also decreased with the delay in application of N. The delay in N application decreased the rate of total dry matter m-2 from 16.1g m-2/day to 15.8g m-2/day with the

suffolk coulter plots. Similarly, this was decreased from 16.9g m-2/day to 15.1g m-2/day with the band coulter treatment. Rate of dry matter decreased with the time of N application in the suffolk coulter plots when they were treated with 125 and 170kg/haN. But delay in application of 80kg/haN increased the rate of total dry matter m-2. In the case of band coulter plots, the decrease in the rate of total dry matter were recorded at all the three levels of N (Table 2.12).

The mean rate of dry matter (g m-2/day) increased with the level of N in the suffolk coulter plots. While in the band coulter treatment, the highest mean rate of dry m-2 was recorded from the application of 80kg/haN (Table 2.12). Results of the rate of dry matter change with time (Table 2.12) were calculated using the formula:

$$C = \frac{W2 - W1}{T2 - T1}$$

Where:

C = Crop growth rate in g/m2/day.

W1 = Initial dry weight of the plant in mg.

T1 = Time T at which plant dry weight = W1.

W2 = Final dry weight of the plant in mg.

T2 = Time T at which the dry weight of the plant = W2.

These results were not statistically analysed and tested hence, could be misleading.

2.3.3.Tillering.

Tables 2.13 and 2.15 show total number of tillers m-2 while Tables 2.14 and 2.16 present the number of tillers per plant during the two experimental seasons. Tillering started from mid May and continued until mid June in 1988. In 1989, tillering commenced in mid March due to the earlier drilling. (February 8th). From these dates, the numbers of

living shoots (mainstems and tillers) were counted at intervals of about one week, starting from H2. This enabled the course of tiller formation during the main vegetative growing period to be ascertained.

Table 2.13. Effect of N levels and timing on total numbers of tillers m-2 in 1988.

		Suffolk Coulter.				Band Coulter.				
		Nitrogen levels (kg/ka).								
		80	125	170	Mean	80	125	170	Mean	SED.
Hts.	N Timing									
H1		Not determined				Not determined				
	T1	479	536	460	491.7	517	451	515	494.3	
H2	T2	439	419	450	436.0	503	456	544	501.0	
	Mean	459.0	477.5	455.0		510.0	453.5	529.5		58.1
	T1	612	669	568	616.3	664	636	600	633.3	
H3	T2	593	571	583	582.3	657	630	659	648.7	
	Mean	602.5	620.0	575.5		660.5	633.0	629.5		79.4
	T1	683	835	761	759.7	847	822	774	814.3	
H4	T2	660	641	681	660.7	760	665	753	726.0	
	T3	712	670	671	684.3	777	759	802	779.3	
	Mean	685.0	715.3	704.3		794.7	748.7	776.3		83.6
	T1	738	763	712	737.7	890	789	770	816.3	
H5	T2	728	636	738	700.7	722	744	829	765.0	
	T3	652	667	553	624.0	708	753	659	706.7	
	Mean	706.0	688.7	667.7		773.3	762.0	752.7		65.6
	T1	696	729	771	732.0	789	780	839	802.7	
H6	T2	670	642	618	643.3	739	699	675	704.3	
	T3	627	648	648	641.0	709	672	652	677.7	
	Mean	664.3	673.0	679.0		745.7	717.0	722.0		65.6
	T1	604	688	571	621.1	698	708	685	696.8	
H7	T2	577	504	514	531.5	651	680	612	647.6	
	T3	577	552	478	535.3	604	644	656	634.4	
	Mean	585.7	581.2	520.9		650.8	677.2	650.8		56.4
	T1	574	668	576	605.7	540	656	611	602.5	
H8	T2	478	507	537	507.2	605	551	654	603.2	
	T3	518	542	506	521.8	554	537	586	559.0	
	Mean	523.1	571.9	606.4		566.4	581.2	617.1		54.7
	T1	372	415	442	409.6	481	456	527	487.9	
H9	T2	383	366	342	363.8	426	441	395	420.6	
	T3	344	367	366	359.0	405	410	418	410.9	
	Mean	366.3	382.8	383.4		437.2	435.6	446.6		36.8

In 1988 the numbers of tillers increased rapidly to a maximum (58 days after drilling) and then gradually declined (Table 2.13). By 62 days after sowing tillers had started to die (Table 2.13). Only about 50% of the tillers produced ears and reached anthesis (Table 2.13). At all harvests, plots drilled using the band coulter produced a higher number of tillers m-2 than those drilled with the suffolk coulter (Table 2.13). This was as a result of the higher numbers of plants per unit area obtained from the former treatment. Although seedling emergence and establishment were later in these plots (Tables 2.6 & 2.7) more plants survived.

Results on tillering (Table 2.13) showed that N application at T1 (GS12-13) enhanced tiller formation slightly (NS). For example, by 51 days after sowing (H4), the mean numbers of tillers m-2, averaged over N levels, were 759.7 and 814.3 for the suffolk and band coulter treatments. Treatments with N at T2 and T3 (GS30&32) on the other hand gave a mean numbers of tillers m-2 of 660.7, 684.3 and, 726.0, 779.3 respectively (Table 2.13). Similarly, the numbers of tillers which survived and reached anthesis were influenced by the same treatment (T1). The numbers of reproductive tillers obtained at anthesis were 409.6, 487.9 for the former and 363.8, 359.0 ; 420.6, 410.9 for the latter, corresponding to the suffolk and band treatments (Table 2.13).

There was no significant interaction between the levels of N and the time of application on tillering (Table 2.13). However, the effect of N treatment at T1 was much more consistent using 125kgN/ha (Table 2.13). No significant effect of N level on tillering was detected in 1988 although increasing the levels of N within the range tested (80 to 170kg/ha) did influence the survival of the ear bearing tillers. For example, the numbers of tillers survived and produced ears at anthesis averaged over timings were 366.3, 382.8, 383.4 and, 437.2, 435.6, 446.6 for the suffolk and band treatments respectively (Table 2.13).

Table 2.14. Effect of N levels and timing on numbers of tillers per plant in 1988.

		Suffolk Coulter.				Band Coulter.				
		Nitrogen levels (kg/ha).								
		80	125	170	Mean	80	125	170	Mean	SED.
Hts.	N Timing									
H1		Not determined				Not determined				
	T1	1.6	1.6	1.6	1.6	1.7	1.5	1.6	1.6	
H2	T2	1.6	1.4	1.6	1.5	1.6	1.5	1.6	1.6	
	Mean	1.6	1.5	1.6		1.6	1.5	1.6		0.2
	T1	2.2	2.2	2.1	2.2	2.4	2.3	2.3	2.3	
H3	T2	2.1	2.1	2.1	2.1	2.2	2.3	2.3	2.3	
	Mean	2.2	2.2	2.1		2.3	2.3	2.3		0.3
	T1	2.9	2.9	3.2	3.0	3.3	3.2	3.0	3.1	
H4	T2	2.6	2.7	2.6	2.6	3.0	2.5	3.1	2.9	
	T3	2.5	2.6	2.7	2.6	2.7	2.9	2.7	2.7	
	Mean	2.6	2.7	2.8		3.0	2.8	2.9		0.2
	T1	3.0	3.3	3.4	3.2	3.3	2.8	2.9	3.0	
H5	T2	2.6	2.9	2.7	2.7	2.6	2.6	2.7	2.6	
	T3	2.4	2.7	2.6	2.5	2.8	2.4	2.5	2.5	
	Mean	2.6	2.9	2.9		2.9	2.6	2.7		0.3
	T1	2.9	3.1	3.3	3.1	3.1	3.0	2.8	3.0	
H6	T2	2.4	2.6	2.7	2.5	2.8	2.8	2.5	2.7	
	T3	2.5	2.7	2.3	2.5	2.6	2.4	2.5	2.5	
	Mean	2.6	2.8	2.8		2.8	2.7	2.6		0.2
	T1	3.1	2.8	2.8	2.9	2.6	3.0	2.7	2.8	
H7	T2	2.3	2.6	2.2	2.4	2.3	2.4	2.7	2.5	
	T3	2.5	2.6	2.0	2.4	2.5	2.2	2.3	2.3	
	Mean	2.6	2.7	2.3		2.5	2.5	2.6		0.3
	T1	2.4	3.1	2.7	2.7	2.2	2.5	2.6	2.4	
H8	T2	2.1	2.7	2.4	2.4	2.2	2.2	2.3	2.2	
	T3	2.4	2.3	2.0	2.2	2.2	2.0	2.3	2.2	
	Mean	2.3	2.7	2.3		2.2	2.2	2.4		0.2
	T1	1.8	1.9	2.0	1.9	1.7	1.7	2.2	1.8	
H9	T2	1.6	1.9	1.9	1.8	1.8	1.9	1.7	1.8	
	T3	1.5	1.7	1.6	1.6	1.6	1.5	1.5	1.5	
	Mean	1.6	1.8	1.9		1.7	1.7	1.8		0.2

The pattern of tiller formation and survival per plant followed a similar trend with the total numbers of tillers m-2 (Table 2.14). No significant differences were detected between the treatments from H2 to

H5. However, from H6 to anthesis (H9), some treatment differences were observed. During these periods, the numbers of tillers per plant given by the T1 treatments increased significantly ($P<0.05$) when compared with the T3 treatments (Table 2.14). But, there was no significant difference between either the T1 and T2 or T2 and T3 treatments with respect to both the suffolk and band coulter treaments. The possible reasons for these responses are reviewed in the discussion section.

Tiller formation and survival m-2 and the subsequent ear production during the 1989 experimental season were similar to 1988 (Tables 2.13 & 2.15). The differences in reproductive tillers recorded at anthesis for the two growing seasons mainly resuLted from plant population differences. Densities were higher in 1989, 550 seeds m-2 as compared to 400 seeds m-2.

Dry soil surface conditions made sampling difficult during 1989. For this reason the first sample for the tiller counts was taken at a later growth stage (GS25), 80 days after drilling. Results for the number of tillers m-2 and the number of tillers per plant for the 1989 experimental season are presented in Tables 2.15 and 2.16. These results show that, the highest number of tillers m-2 was recorded on the first harvest date (H1). This was also true for the number of tillers per plant (Tables 2.15 & 2.16). After the first sampling, number of tillers m-2 and the number of tillers per plant decreased at the subsequent sampling dates (H2 to H6). In this growing season it was not possible to determine the period at which tiller production was maximum since no early sampling was carried out. However, when plants were sampled on April 29th, the T1 treatment gave higher (NS) number of tillers m-2 and number of tillers per plant (Tables 2.15 & 2.16). The mean numbers of tillers obtained from the T1 treatments were 1632.7 and 1946.7 as compared to 1407.0 and 1192.7 for T2, corresponding to suffolk and band treatments. The number of tillers per plant for the same treatments

were 4.8, 5.0 and 3.5, 3.5 respectively.

Table 2.15. Tiller formation and survival during 1989 experimental season.

		Suffolk Coulter.				Band Coulter.				
		Nitrogen levels (kg/ha).								
		80	125	170	Mean	80	125	170	Mean	SED.
Hts.	N Timing									
	T1	1453	1756	1689	1632.7	1648	2135	2057	1946.7	
H1	T2	1399	1412	1410	1407.0	1194	1206	1178	1192.7	
	Mean	1426.0	1584.0	1549.5		1421.0	1670.5	1617.5		133.5
	T1	657	673	571	633.7	658	727	708	697.7	
H2	T2	581	749	634	654.7	701	766	731	732.7	
	T3	569	676	634	626.3	631	707	659	665.7	
	Mean	602.3	699.3	613.0		663.3	733.3	699.3		61.3
	T1	614	562	619	598.3	601	583	624	602.7	
H3	T2	594	646	645	628.3	657	726	627	670.0	
	T3	598	696	664	652.5	676	723	651	683.3	
	Mean	602.0	634.5	642.7		644.7	677.3	634.0		45.0
	T1	542	560	556	552.7	508	618	553	559.7	
H4	T2	469	609	587	555.0	588	537	599	574.7	
	T3	559	585	588	573.3	576	628	525	576.3	
	Mean	523.3	584.7	577.0		557.3	594.3	559.0		51.5
	T1	451	506	546	501.0	475	517	582	524.7	
H5	T2	436	511	495	480.7	502	552	485	513.0	
	T3	428	456	407	430.3	453	525	516	498.0	
	Mean	438.3	491.0	482.7		476.7	531.3	527.7		51.9
	T1	426	476	500	467.3	485	483	540	502.7	
H6	T2	403	373	492	422.7	373	449	478	433.3	
	T3	435	422	446	434.3	443	469	466	459.3	
	Mean	421.3	423.7	479.3		433.7	467.0	494.7		41.0

The effect of early N application (T1) on tiller formation in this season was transient. On May 30th when the second sample was taken for the purpose of growth analysis, a higher number of tillers m-2 (NS) was recorded from the T2 treatment compared to the T1 and T3 treatments. The number of tillers m-2 corresponding to these treatments were 654.7, 732.7 and, 633.7, 697.7 and 626.3, 665.7 respectively (Table 2.15). However, the number of tillers per plant for the respective treatments

were similar (Table 2.16). From June 11th to June 17th (H3 & H4), the pattern of tiller formation showed a shift in favour of the T3 treatment (Table 2.15). At anthesis the number of reproductive tillers was slightly influenced by the T1 Treatment (Tables 2.15 & 2.16). This suggests that many of the secondary tillers produced as a result of late N fertilizer applications did not survive to produce ears.

It is important to note that, throughout the growing season of 1989 experimental year there was no significant effect of the treatments on the number of tillers m-2 or the number of tillers per plant. This might have resulted from the exceptional nature of the season, which is described in Figure 2.6. This possibly affected the developmental physiology of the crop, a point of view examined further in the discussion (section 2.4).

The rate of N fertilizer also did not produce any significant effect vis a vis total number of tillers m-2 and the number of tillers per plant. However, there was a trend of increased tiller formation and survival with the application of 125kg/haN (N2). This effect was noted from the first harvest (H1) and lasted until anthesis (H5) Table 2.15. On April 29th, the mean numbers of tillers m-2 recorded from N2 treatment were 1584.0 and 1670.5. For the N1 and N3 the corresponding values were 1426.0, 1549.5 and 1421.0, 1617.5 for the suffolk and band coulter plots (Table 2.15). But, at the final harvest taken for this growth analysis, more reproductive tillers (NS) were obtained from the N3 treatment. During this period, the mean numbers of reproductive tillers m-2 recorded from N3 were 479.3 and 494.7 as compared to N1 and N2 of 421.3, 423.7 and, 433.7, 467.0 (Table 2.15). There was no consistent effect of the rate of N on the number of tillers per plant. However, N2 and N3 seemed to have influenced it slightly at the final harvest (H6) Table 2.16.

Table 2.16. Numbers of tillers per plant for the 1989 experimental season.

		Suffolk Coulter.				Band Coulter.				
		Nitrogen levels (kg/ha).								
		80	125	170	Mean	80	125	170	Mean	SED.
Hts.	N Timing									
	T1	4.3	5.2	5.0	4.8	4.2	5.5	5.3	5.0	
H1	T2	3.6	3.4	3.5	3.5	3.5	3.3	3.6	3.5	
	Mean	4.0	4.3	4.3		3.9	4.4	4.5		0.4
	T1	2.2	2.2	2.3	2.2	2.2	2.2	2.4	2.3	
H2	T2	2.0	2.5	2.2	2.2	2.1	2.5	2.4	2.3	
	T3	2.2	2.2	2.2	2.2	1.9	2.5	2.1	2.2	
	Mean	2.1	2.3	2.2		2.1	2.4	2.3		0.2
	T1	2.0	1.9	2.0	2.0	1.8	2.0	2.0	1.9	
H3	T2	1.8	2.1	2.3	2.1	2.0	2.1	1.9	2.0	
	T3	1.9	2.1	2.4	2.1	1.9	2.4	2.4	2.2	
	Mean	1.9	2.0	2.2		1.9	2.2	2.1		0.2
	T1	1.8	2.1	1.9	1.9	1.6	1.9	1.8	1.8	
H4	T2	1.9	2.0	2.0	2.0	1.8	1.6	1.9	1.8	
	T3	2.0	2.0	2.0	2.0	1.9	2.1	1.9	1.9	
	Mean	1.9	2.0	2.0		1.8	1.9	1.9		0.2
	T1	1.7	1.8	1.9	1.8	1.5	1.7	1.8	1.7	
H5	T2	1.5	1.7	1.8	1.7	1.6	1.6	1.5	1.6	
	T3	1.6	1.9	1.6	1.7	1.4	1.7	1.3	1.5	
	Mean	1.6	1.8	1.8		1.5	1.7	1.5		0.2
	T1	1.7	1.9	1.8	1.8	1.5	1.7	1.8	1.7	
H6	T2	1.5	1.7	1.8	1.7	1.4	1.6	1.5	1.5	
	T3	1.5	1.6	1.8	1.6	1.4	1.7	1.6	1.6	
	Mean	1.6	1.7	1.8		1.4	1.7	1.6		0.2

2.3.4.Flag leaf.

In the 1988 growing season, flag leaf measurements were carried out at three different crop growth stages. The measurements were taken at booting (GS45), ear emergence (GS55) and anthesis (GS65). The objectives were to study the effects of the treatments on flag leaf area, dry weight and specific leaf area (SLA). Results are presented in Tables 2.17, 2.18 and 2.19.

2.3.4.1.Area cm2.

At booting a significantly higher ($P<0.05$) flag leaf area was recorded with the first N treatment (T1). This was true for both drilling patterns and rates of fertilizer N. The mean flag leaf areas at GS45 with the T1 treatment were 37.4cm2 and 37.6cm2. Corresponding values for the T2 and T3 treatments were 28.4, 24.7cm2 and 29.6, 26.5cm2 for the suffolk and band coulters (Table 2.17). This effect of time of application of N on flag leaf area continued until anthesis. Increasing the levels of N from 80kg/ha had no effect on flag leaf area, also there was no effect of drilling patterns on this variable.

Table 2.17. Effect of N levels and timing on flag leaf area (cm2) of the spring wheat (variety-Axona) in 1988.

		Suffolk Coulter.				Band Coulter.				
		Rate of nitrogen (kg/ha).								
		80	125	170	Mean	80	125	170	Mean	SED.
N Timings.										
	T1	36.7	35.5	39.9	37.4	35.7	38.2	38.8	37.6	
Booting	T2	27.4	29.6	28.1	28.4	29.5	29.1	30.2	29.6	
	T3	25.0	24.5	24.7	24.7	26.0	27.9	25.7	26.5	
	Mean	29.7	29.9	30.9		30.4	31.7	31.6		2.0
	T1	35.3	37.4	38.2	37.0	34.9	37.6	41.7	38.1	
Ear emergence	T2	27.4	35.2	30.1	30.9	28.5	29.6	30.1	29.4	
	T3	26.9	26.1	28.1	27.0	29.3	26.5	28.3	28.0	
	Mean	29.9	32.9	32.1		30.9	31.2	33.4		1.7
	T1	34.0	34.0	38.1	35.4	32.8	36.2	39.9	36.3	
Anthesis	T2	27.1	33.0	30.9	30.3	31.6	32.5	32.6	32.2	
	T3	24.6	27.8	25.8	26.1	28.2	25.3	28.0	27.2	
	Mean	28.6	31.6	31.6		30.9	31.3	33.5		1.6

2.3.4.2.Dry weight.

Results for flag leaf dry weight showed a similar trend to that of the flag leaf area (Table 2.18). There was a significant increase

(P<.05) of flag leaf dry weight with the T1 treatment during booting. The mean values given by the T1 treatment were 135.3mg and 135.4mg, compared to 103.2, 88.8mg and 106.8, 90.2mg for the T2 and T3 treatments (Table 2.18). At ear emergence the T2 and T3 treatments were not significantly different from each other. However, at anthesis the T2 treatment gave a higher (P<.05) flag leaf weight compared to T3. There was no significant effect of drilling patterns and N levels on the flag leaf dry weight, although during anthesis an increasing trend was recorded (Table 2.18).

Table 2.18. Effect of N levels and timing on flag leaf dry weight (mg) of the spring wheat (variety-Axona) in 1988.

		Suffolk Coulter.				Band Coulter.				
		Rate of nitrogen (kg/ha).								
		80	125	170	Mean	80	125	170	Mean	SED.
N Timings.										
	T1	134.6	129.1	142.1	135.3	129.1	139.3	137.8	135.4	
Booting	T2	99.5	107.6	102.4	103.2	106.8	104.6	109.1	106.8	
	T3	89.5	86.4	90.4	88.8	91.8	86.8	92.1	90.2	
	Mean	107.8	107.7	111.6		109.2	110.2	113.0		6.6
Ear	T1	128.6	139.4	137.9	135.3	128.9	140.3	153.4	140.9	
emergence	T2	98.0	132.3	113.1	114.5	106.2	107.8	110.3	108.1	
	T3	101.4	96.5	106.0	101.3	105.8	95.2	105.5	102.2	
	Mean	109.3	122.7	119.0		113.6	119.4	123.1		7.4
	T1	125.1	127.1	145.3	132.5	122.6	134.4	150.3	135.8	
Anthesis	T2	105.9	130.8	120.9	119.2	120.5	126.8	128.7	125.3	
	T3	90.9	107.4	101.8	100.0	109.2	97.7	109.5	105.5	
	Mean	107.3	121.8	122.7		117.4	119.6	129.5		7.8

2.3.4.3.Specific leaf area.

Neither N levels nor time of application had any effect on flag leaf specific leaf area (SLA). Similarly, there was no effect of the drilling patterns. However, during booting the mean specific leaf area was slightly higher (NS) with the band coulter treatment (Table 2.19).

The value given by treatment with the band coulter averaged over N levels and timing during anthesis was 283.2cm2/g compared to 275.9cm2/g recorded from the suffolk coulter plots.

Table 2.19. Effect of N levels and timing on SLA (cm2/g) of the spring wheat (variety-Axona) in 1988.

		Suffolk Coulter.				Band Coulter.				
		Rate of nitrogen (kg/ha).								
		80	125	170	Mean	80	125	170	Mean	SED.
N Timing										
	T1	273.1	275.8	281.6	276.8	276.5	275.2	281.4	277.7	
Booting	T2	275.1	274.7	274.7	274.8	276.8	277.9	277.1	277.3	
	T3	278.5	275.9	273.7	276.0	284.5	319.7	279.6	294.6	
	Mean	275.6	275.5	276.7		279.3	290.9	279.4		15.0
	T1	274.3	269.4	277.3	273.7	270.6	268.3	272.5	270.5	
Ear emergence	T2	279.1	266.2	265.9	270.4	268.5	274.7	273.6	272.3	
	T3	265.3	271.4	266.0	267.6	277.2	278.2	268.5	274.6	
	Mean	272.9	269.0	269.7		272.1	273.7	271.5		5.6
	T1	271.6	268.2	262.4	267.4	268.2	269.6	265.5	267.8	
Anthesis	T2	256.1	252.8	255.6	254.8	262.2	256.3	254.4	257.6	
	T3	271.2	258.8	253.6	261.2	258.6	259.0	256.8	258.1	
	Mean	266.3	259.9	257.2		263.0	261.6	258.9		5.4

2.3.5.Yield components.

Cereal grain yield depends upon the following yield components: number of ears per unit area, number of spikelets per ear, number of grains per ear and the thousand grain weight. In this experiment final hand samples were taken in both experimental seasons to determine the yield components, and to study relationships between them and total combine grain yield.

2.3.5.1.Number of ears m-2.

The patterns of tiller survival and ear production were similar in both seasons (1988 & 1989), hence they are not reported in isolation. These results are presented in Table 2.20. The application of N fertilizer at T1 increased the number of ears m-2 significantly ($P<.05$) at low plant population when seeds were drilled using the suffolk coulter in 1988. In the case of the band coulter, the numbers of ears m-2 were not significantly different from each other when N was applied either at T1 or delayed until T3 (Table 2.20). At high plant population during 1988 the first N application (T1) increased number of ears significantly ($P<.05$) in the band coulter treatment compared to the suffolk coulter. The numbers of ears m-2 given by the former treatment at high plant population in 1988 were 519, 466 and 416, whilst the latter recorded 465, 462 and 391 ears corresponding to T1, T2 and T3 treatments respectively (Table 2.20).

The time of N application did not have any significant effect on the number of ears in the 1989 growing season. However, the delay in N application decreased (NS) the number of ears (Table 2.20). This could have been due to the unusual dry and hot conditions recorded during the growing season of 1989, which might have affected tiller production and survival (Appendix 2.4).

Drilling with the band coulter gave a higher (NS) number of ears m-2. This was due to the higher number of plants recorded compared to the suffolk coulter plots, and not as a result of tiller production per plant per se. Even then, the effect of drilling systems on the number of ears was only recorded at high population in 1988 and that of 1989 which had the same plant density. There was no effect of drilling pattern on the number of ears in the low population during the first growing season. Similarly, the level of N had no effect on the number of ears m-2. However, application of 125kg/haN favoured ear production compared

to treatments with 80 and 170kg/haN. This was true for both drilling patterns (Table 2.20).

Table 2.20. Effect of drilling pattern, rate and time of application of N on number of ears m-2 of spring wheat (variety-Axona).

		Suffolk Coulter.				Band Coulter.				
		Rate of nitrogen (kg/ha).								
		80	125	170	Mean	80	125	170	Mean	SED.
Density.	N Timing.				1988					
	T1	441	546	493	493	476	456	467	466	
Low	T2	361	390	419	377	404	383	467	418	
	T3	381	389	404	391	339	422	376	379	
	Mean	394	442	439		406	420	437		38.4
	T1	472	467	457	465	508	534	514	519	
High	T2	453	477	457	462	517	471	409	466	
	T3	370	411	391	391	375	447	426	416	
	Mean	432	452	435		467	484	450		40.2
					1989					
	T1	415	503	513	477	459	530	580	523	
	T2	407	438	439	428	458	458	476	464	
	T3	442	440	405	429	419	466	454	446	
	Mean	421	460	452		445	485	503		43.0

2.3.5.2.Length of ear (cm).

Measurements were taken on a random sample of 10 ears from the final hand harvested samples in each of the experimental seasons. The results are shown in Table 2.21. Application of N at T1 increased (NS) the length of the ear. This effect expressed to a greater extent in the low compared to the high population during 1988. The time of application effect on the length of ear which was detected in 1988 was not recorded in 1989. Similarly, in each of the growing seasons, neither drilling patterns nor N levels had any effect on this variable (Table 2.21).

Table 2.21. Effect of drilling pattern, rate and time of application of N on ear lenth (cm) of spring wheat (variety-Axona).

		Suffolk Coulter.				Band Coulter.				
		Rate of nitrogen (kg/ha).								
		80	125	170	Mean	80	125	170	Mean	SED.
Density.	N Timing.									
					1988					
	T1	9.2	9.0	9.3	9.2	9.0	9.0	9.4	9.1	
Low	T2	8.6	8.7	9.1	8.8	8.9	9.1	9.3	9.1	
	T3	8.4	8.9	8.8	8.7	8.8	8.6	8.8	8.7	
	Mean	8.7	8.9	9.1		8.9	8.9	9.2		0.4
	T1	8.6	8.8	8.7	8.7	8.4	8.6	9.2	8.7	
High	T2	8.4	8.4	8.5	8.4	8.5	8.5	8.9	8.6	
	T3	8.1	8.4	8.3	8.3	8.1	8.5	8.3	8.3	
	Mean	8.4	8.5	8.5		8.3	8.5	8.8		0.3
					1989					
	T1	8.4	8.5	8.8	8.6	8.5	8.5	8.5	8.5	
	T2	8.3	8.7	8.4	8.5	8.5	8.9	8.5	8.6	
	T3	8.4	8.6	8.6	8.5	8.3	8.5	8.5	8.4	
	Mean	8.4	8.6	8.6		8.4	8.6	8.5		0.2

2.3.5.3.Number of spikelets per ear.

Total spikelets before anthesis and the fertile spikelets at plant maturity were recorded in both growing seasons. Results are presented in Table 2.22. There was no significant effect of the time of application on both the total and fertile spikelets per ear. This was true for both drilling patterns. However, there was a trend of increased spikelets and spikelets survival per ear with the early application of N (Table 2.22). The response of this variety to the time of application of N vis a vis number of spikelets per ear was similar in both years, although the total number per ear was slightly higher during the 1989 drier season presumably due to prolonged developmental period resulting from the earlier drilling. The level of N as well as drilling methods did not affect the number of spikelets per ear in each of the

experimental seasons (Table 2.22).

Table 2.22. Effect of N levels and timing on number of spikelets per ear of spring wheat (variety-Axona).

		Suffolk Coulter.				Band Coulter.				
		Rate of nitrogen (kg/ha).								
		80	125	170	Mean	80	125	170	Mean	SED.
N Timings.					1988					
Total Spikelets	T1	19.7	19.4	19.8	19.6	19.6	19.4	19.8	19.6	
	T2	19.2	19.6	19.4	19.4	19.7	19.6	19.5	19.6	
	T3	19.2	19.4	18.9	19.2	19.4	19.2	19.4	19.3	
	Mean	19.4	19.5	19.4		19.6	19.4	19.6		0.4
Fertile Spikelets	T1	17.3	16.9	16.6	16.9	17.3	17.0	17.6	17.3	
	T2	16.9	16.7	16.7	16.8	16.8	16.8	16.8	16.8	
	T3	16.7	17.2	16.8	16.9	16.8	16.9	17.1	16.9	
	Mean	17.0	16.9	16.7		17.0	16.9	17.2		0.5
					1989					
Total Spikelets	T1	20.2	20.7	20.6	20.5	20.3	20.5	20.7	20.5	
	T2	19.9	20.6	20.6	20.4	20.5	20.4	19.1	20.0	
	T3	19.6	20.4	20.0	20.0	20.0	20.5	19.7	20.1	
	Mean	19.9	20.6	20.4		20.3	20.5	19.8		0.4
Fertile Spikelets	T1	16.6	17.1	17.0	16.9	16.8	16.6	16.9	16.8	
	T2	16.8	17.4	16.7	17.0	17.5	17.3	17.3	17.4	
	T3	17.2	17.4	17.4	17.3	16.7	16.9	16.9	16.8	
	Mean	16.9	17.3	17.0		17.0	16.9	17.0		0.3

2.3.5.4.Number of grains per ear.

The number of grains per ear was higher (NS) with the first N application in 1988. This applied to both low and high plant populations. In case of the high population, the effect of the time of application of N was more clearly expressed in the suffolk coulter plots (Table 2.23). The mean number of grains per ear averaged over N levels and timing was greater in suffolk coulter plots in 1988 growing season. In the low population, plots drilled using the suffolk coulter recorded 38.0 grains per ear compared to 37.0 given by the band coulter

treatment. From the high plant population the corresponding values were 35.2 and 33.4 respectively (Table 2.23).

In 1989, the number of grains per ear increased with the delay in application of N. When application of N was delayed until T3 in the suffolk coulter plots, the numbers of grains per ear were 31.4 compared to 30.7 and 28.3 for the T2 and T1 treatments. Similarly, when plots were drilled using the band coulter the corresponding numbers of grains per ear were 31.5, 31.2 and 28.6 for the T3, T2 and T1 respectively (Table 2.23). During this growing season the number of grains per ear averaged over N levels and timing was slightly increased (NS) with the band coulter treatment. The mean number of grains per ear was 30.4, compared to 30.1 recorded from the suffolk coulter (Table 2.23).

Increase in the level of N did not give a consistent result in both years. In 1988 the high population recorded a slightly higher number of grains from 'all' plots which received 125kg/haN. In the low population also, the mean number of grains was slightly increased by the application of 125kg/haN when seeds were drilled using the suffolk coulter. On the other hand, an increase was found using the band coulter from the application of 170kg/haN (Table 2.23).

In the 1989 growing season more grains per ear were recorded with the application of 125kg/haN in the suffolk coulter plots. The mean number of grains from this treatment was 31.4 compared to 29.5 given by both 80 and 170kg/haN (Table 2.23). There was no effect of N levels on the number of grains when plots were drilled using the band coulter.

Table 2.23. Effect of drilling pattern, rate and time of application of N on numbers of grains per ear of spring wheat (variety-Axona).

		Suffolk Coulter.				Band Coulter.				
		Rate of nitrogen (kg/ha).								
		80	125	170	Mean	80	125	170	Mean	SED.
Density.	N Timing.				1988					
Low	T1	40.3	38.8	39.3	39.5	36.9	35.9	38.5	37.1	
	T2	37.3	37.8	37.6	37.6	36.9	37.3	38.0	37.4	
	T3	35.4	38.2	36.9	36.8	35.6	35.4	34.7	35.2	
	Mean	37.7	38.3	37.9		36.5	36.2	37.1		2.1
High	T1	36.6	36.4	36.4	36.5	33.0	34.1	33.8	33.6	
	T2	33.6	35.6	33.8	34.3	31.8	34.4	33.3	33.2	
	T3	33.0	36.1	35.4	34.8	34.6	33.8	31.6	33.3	
	Mean	34.4	36.0	35.2		33.1	34.1	32.9		1.9
					1989					
	T1	29.2	28.8	26.9	28.3	30.7	27.5	27.6	28.6	
	T2	29.6	32.6	29.9	30.7	31.5	31.3	30.9	31.2	
	T3	29.7	32.7	31.8	31.4	30.0	32.5	32.0	31.5	
	Mean	29.5	31.4	29.5		30.7	30.4	30.2		1.8

2.3.5.5.Grain development.

Measurements of grain filling were carried out on 10 mainstem ears, beginning from 9 and 10 days after anthesis in 1988 and 1989 respectively. The objectives were to monitor grain development until a constant grain dry weight had approximately been achieved (physiological maturity). Tables 2.24 and 2.25 describe the rate of grain growth and the slopes of the lines during the two experimental seasons. The time of grain set and the rate of grain fill were not significantly affected by the time of N application. However, there was a trend in increase in the rates of grain filling with delaying N applications (Table 2.25). For example in 1989, when plots were treated with 80kg/haN, the rate of grain growth increased from 1.09 to about 1.20mg/grain/day by delaying N application until T3. Similarly, treatments 125 and 170kg/haN increased the rate of grain growth from 1.15 to 1.23mg/grain/day and from 1.10 to

1.18mg/grain/day with the delay in N application (Table 2.25). When the linear regression equations were compared the slopes of these lines were not significantly different.

The effect of application time on grain growth in 1988 was visible about 30 days after anthesis (August 9th), Table 2.24. On August 25th (46 days after anthesis), treatments effect on grain fill was detected. For example, when application of 80kg/haN was delayed until T3 grain size increased from 42.4mg to 46.9mg. Treatments with 125 and 170kg/haN also increased grain dry weight from 42.8mg to 47.0mg and, from 41.4mg to 47.7mg respectively (Table 2.24).

The grain filling period was shorter by about 10 days in 1989. Hence, the initial grain weight recorded on June 21st were smaller, even though grain fill measurements was started a day later in 1989. The effect of the treatments on grain growth was however similar. In this experimental season, the rate of grain fill also showed a slight increase with delay in N application. For example treatment with 80kg/haN increased the rate of grain growth from 1.29 to 1.40mg/grain/day by delaying N application until T3. When plots received 125 and 170kg/haN, the increases in the rate of grain growth were from 1.33 to 1.37mg/grain/day and, from 1.28 to 1.40mg/grain/day (Table 2.25). In 1989, the treatment effect started to be visible on July 13th (Table 2.24). During this period grain size began to increase with the late timing of N. The grain dry weight recorded on July 17th was highest when plots were treated with N at T3. Grain size increased from 37.8mg to 40.6mg with the 80kg/haN while treatments with 125 and 170kg/haN gave an increase in grain size from 36.4mg to 38.7mg and 37.8 to 43.5mg respectively.

On July 21st, when the last sample for grain development was taken the T3 treatment recorded grain dry weight of 42.6mg, 43.0mg and 45.5mg for the N1, N2 and N3 respectively. The T1 and T2 treatments gave 39.8mg

and 42.0mg with the application of 80kg/haN (N1). Grain dry weight obtained with the same times of application (T1 and T2) of N levels 250kg/ha and 170kg/ha were 40.4mg, 42.3mg and 40.8mg, 42.8mg respectively (Table 2.24).

Table 2.24. Grain development (dry weight 'mg') in 1988 and 1989.

	Treatments								
Dates.	N1T1	N1T2	N1T3	N2T1	N2T2	N2T3	N3T1	N3T2	N3T3
				1988					
19/7	6.3	6.2	6.7	4.3	5.6	4.8	5.4	5.1	7.1
21/7	7.5	7.7	7.6	6.9	7.4	7.5	6.8	6.7	7.6
25/7	11.4	11.2	12.2	9.8	11.3	11.4	9.9	11.4	12.7
27/7	14.5	14.3	15.6	12.0	14.5	15.5	12.8	13.3	15.5
1/8	20.8	21.7	21.4	18.0	20.9	20.8	18.5	19.1	21.9
3/8	22.6	24.2	23.8	21.3	22.8	25.1	23.5	21.9	23.0
5/8	25.3	26.1	27.0	24.7	25.9	27.2	26.6	26.4	27.6
9/8	33.0	33.2	32.9	31.5	34.1	34.1	30.8	32.3	33.2
13/8	38.9	37.8	41.7	34.7	36.6	40.7	35.8	37.6	39.2
17/8	39.1	41.8	42.5	40.8	42.0	43.0	39.0	39.8	39.9
21/8	40.7	43.5	44.2	41.7	44.2	44.6	40.7	42.3	45.2
25/8	42.4	44.3	46.9	42.8	45.8	47.0	41.4	44.8	47.7
				1989					
21/6	5.0	4.7	4.4	3.5	4.3	4.3	3.8	4.3	5.6
23/6	6.4	6.8	6.0	6.0	6.6	6.8	5.1	5.5	6.2
27/6	9.2	9.2	9.7	9.3	11.1	10.3	8.9	10.0	9.9
1/7	14.5	15.3	15.2	13.4	13.9	14.0	13.9	12.7	16.7
5/7	21.6	21.2	20.1	18.0	18.8	18.0	17.1	18.5	20.8
9/7	27.9	30.8	29.4	27.9	29.2	30.0	24.4	27.2	26.0
13/7	30.5	31.6	32.1	33.1	34.8	33.6	29.9	31.6	32.4
17/7	37.8	40.0	40.6	36.4	36.8	38.7	37.8	38.9	43.5
21/7	39.8	42.0	42.6	40.4	42.3	43.0	40.8	42.8	45.5

Increasing the levels of N from 80 to 170kg/ha had no significant effect on grain development. However, in the 1988 growing season grain growth was slightly influenced by the application of 125kg/haN. In 1989 on the other hand, it was influenced more by the treatment with 170kg/haN. Mean grain sizes on August 25th during the 1988 growing season were 44.5mg, 45.2mg and 44.6mg corresponding to treatments with 80, 125 and 170kg/haN. In the second experimental season the grain

weights on July 21st were 41.5mg, 41.9mg and 43.0mg respectively (Table 2.24).

In each of the growing seasons, there was an interaction between the levels of N and the time of its application on grain filling. For example, delaying application of 170kg/haN until T3 resulted in higher (NS) grain filling. Grain size with the combinations of these treatments on August 25th during the 1988 experimental period was 47.7mg. In 1989 the grain dry weight recorded on July 17th from the same treatments was 43.5mg (Table 2.24).

Table 2.25. Regression equations for slopes describing grain dry weight of spring wheat (variety-Axona).

	Rate of nitrogen (kg/ha).			
N Timing.	80	125	170	SED.
		1988		
T1	Y = -3.25 + 1.09x	Y = -6.10 + 1.15x	Y = -4.39 + 1.10x	
T2	Y = -4.10 + 1.15x	Y = -5.08 + 1.18x	Y = -5.35 + 1.16x	0.9
T3	Y = -4.40 + 1.20x	Y = -5.35 + 1.23x	Y = -4.08 + 1.18x	
N	Y = -3.92 + 1.14x	Y = -5.50 + 1.19x	Y = -4.60 + 1.14x	0.8
		1989		
T1	Y = 3.33 + 1.29x	Y = 2.19 + 1.33x	Y = 1.88 + 1.28x	
T2	Y = 3.08 + 1.38x	Y = 2.83 + 1.34x	Y = 2.14 + 1.34x	1.0
T3	Y = 2.58 + 1.40x	Y = 3.04 + 1.37x	Y = 2.97 + 1.40x	
N	Y = 3.00 + 1.35x	Y = 2.68 + 1.34x	Y = 2.33 + 1.34x	0.9

2.3.5.6.Thousand grain weight.

Thousand grain weight increased significantly ($P<0.05$) with delay in N application. In 1988, the increase was from 39.9g to 43.7g in low population when N was delayed until T3 in the suffolk coulter plots. With the band coulter treatment it increased from 39.3g to 43.2g (Table 2.26). In the high population, thousand grain weight increased from

39.0g to 43.4g using the suffolk coulter, while in the band treatment it increased from 38.7g to 43.4g (Table 2.26). The 1989 results showed a similar trend with respect to grain size. In this season, thousand grain weight increased from 38.7g to 42.3g when N treatment was delayed until T3 from the drilling using the suffolk coulter. With the same treatment the band drilling recorded an increase in grain weight from 38.8g to 41.4g (Table 2.26).

Increase in the levels of N decreased grain size (NS). In 1988 thousand grain weight was decreased from 42.0g to 41.9g when N was increased from 80 to 170kg/ha in suffolk coulter plots at the low population. A similar decrease in grain size was also recorded from the band treatment. The decrease in grain size was from 41.9g to 41.6 with the same increase in N levels. At the high plant population no consistent decrease in grain size was recorded with increasing N levels in both the drilling patterns (Table 2.26).

In the 1989 growing season, a consistent decrease in grain size was only recorded in the band coulter plots. Thousand grain weight decreased (NS) from 30.7g to 30.2g when N levels were increased from 80 to 170kg/haN. The suffolk coulter treatment on the other hand gave a higher (NS) thousand grain weight with the application of 125kg/haN.

On average, plots drilled using the suffolk coulter produced slightly larger grains compared to band drilling at low population. The mean thousand grain weight when averaged over N levels and timing was 42.0g with the former compared to 41.7g for the latter. At high population in 1988 the results showed a slight increase in grain size using the band coulter. The mean thousand grain weight (averaged over N levels and timing) given by band coulter treatment was 41.4g compared to 38.3g recorded from the suffolk coulter plots (Table 2.26). The 1989 results showed a similar trend with that of the low population of 1988. Thousand grain weight was increased slightly with the suffolk drill.

For which the mean average weight was 41.0g while the band recorded a thousand grain weight of 40.5g (Table 2.26).

Table 2.26. Effect of drilling pattern, rate and time of application of N on thousand grain weight (g) of spring wheat (variety-Axona).

		Suffolk Coulter.				Band Coulter.				
		Rate of nitrogen (kg/ha).								
		80	125	170	Mean	80	125	170	Mean	SED.
Density.	N Timing.				1988					
Low	T1	40.1	40.1	39.4	39.9	39.9	39.2	38.7	39.3	
	T2	42.3	42.4	42.1	42.3	42.7	42.0	42.9	42.5	
	T3	43.6	43.3	44.2	43.7	43.2	43.3	43.1	43.2	
	Mean	42.0	41.9	41.9		41.9	41.5	41.6		0.4
High	T1	39.2	39.2	38.5	39.0	39.1	38.7	38.2	38.7	
	T2	41.3	41.5	41.6	41.5	41.1	42.0	41.8	42.0	
	T3	43.2	44.3	42.8	43.4	43.5	43.1	43.5	43.4	
	Mean	41.2	41.7	41.0		41.6	41.3	41.2		0.6
					1989					
	T1	40.0	38.2	37.9	38.7	40.1	38.7	37.6	38.8	
	T2	42.4	42.2	41.2	41.9	41.9	41.1	41.2	41.4	
	T3	42.7	43.2	41.0	42.3	41.7	41.0	41.5	41.4	
	Mean	41.7	41.2	40.0		41.2	40.3	40.1		0.7

2.3.6.Grain yield (t/ha 86%DM).

The total combine grain yields obtained from this experiment ranged from 4.4t/ha to 5.8t/ha and, 5.0t/ha to 6.5t/ha for the low and high populations of 1988 respectively. In 1989, grain yields ranged from 5.2t/ha to 6.1t/ha. Grain yield was consistently less in the low compared to the high population. Table 2.27 presents the total grain yield at 86%DM for the two experimental seasons. The grain yield was not greatly influenced by the treatments in each of the growing seasons. However, some yield differences (NS) were still detected.

In the first experimental year grain yield was decreased with the delay in N application. In the low plant population, it decreased (NS) from 5.4t/ha to 5.1t/ha when N was applied at GS32 (T3) in the suffolk coulter plots. This decrease was greater when the band coulter was used. With this treatment the yield decreased from 5.4t/ha to 4.7t/ha by delaying application of N until T3. A similar decrease was also associated with the high population. Yield decreased from 6.2t/ha to 5.3t/ha in the former and, from 5.2t/ha to 5.0t/ha in the latter (Table 2.27). The reduction in grain yield with the delay in N application were however not significant.

When the two different plant populations were compared during the 1988 growing season grain yields were higher (NS) from the high plant population with the suffolk coulter. With the band coulter treatment the same grain yield was obtained. Grain yields from the suffolk coulter plots averaged over N levels and timing were 5.2 and 5.7t/ha from the low and high populations respectively. With the band coulter treatment, the grain yield was 5.1t/ha from both populations (Table 2.27).

Grain yield results in 1989 were a reverse of those obtained in 1988. Yield was increased (NS) with the delay in N application. Late N treatment increased yield from 5.4t/ha to 5.7t/ha when plots were drilled using the suffolk coulter. Similarly drilling with the band coulter resulted in a yield increase of the same magnitude (Table 2.27). As in 1988 growing season, the results were not significantly different from one another.

The effect of N levels on total grain yield was more clearly expressed in the suffolk coulter treatment. In the 1988 experimental season, grain yield increased in the low population from 5.0t/ha to 5.4t/ha when N level was increased from 80 to 170kg/ha with this drilling method. A very small increase from 5.1t/ha to only 5.2t/ha was recorded from the band coulter plots with the same range of increase in

N levels. In the high suffolk population, the additional grain yield resulting from the increase in the rate of N was similar to that of the low population. Grain yield increased from 5.4t/ha to 5.8t/ha. The band coulter treatment on the other hand recorded a slight increase in grain yield with the application of 125kg/haN. The total grain yield obtained from plots which received 125kg/haN was 5.2t/ha compared to 5.0t/ha and 5.1t/ha given by treatments with 80 and 170kg/haN.

Table 2.27. Effect of drilling pattern, rate and time of application of N on total grain yield (t/ha 85%DM) of spring wheat (variety-Axona).

		Suffolk Coulter.				Band Coulter.				
		Rate of nitrogen (kg/ha).								
		80	125	170	Mean	80	125	170	Mean	SED.
Density.	N Timing.				1988					
Low	T1	5.2	5.2	5.8	5.4	5.6	5.3	5.3	5.4	
	T2	4.9	5.2	5.2	5.1	5.3	5.1	5.3	5.2	
	T3	5.0	5.1	5.2	5.1	4.4	4.6	5.0	4.7	
	Mean	5.0	5.2	5.4		5.1	5.0	5.2		0.2
High	T1	5.8	6.3	6.5	6.2	5.1	5.4	5.2	5.2	
	T2	5.4	5.8	5.5	5.6	5.0	5.2	5.1	5.1	
	T3	5.1	5.4	5.3	5.3	5.0	5.0	5.0	5.0	
	Mean	5.4	5.8	5.8		5.0	5.2	5.1		0.3
					1989					
	T1	5.4	5.3	5.4	5.4	5.3	5.4	5.5	5.4	
	T2	5.5	5.9	5.4	5.6	5.2	5.9	5.6	5.6	
	T3	5.4	5.5	6.1	5.7	5.5	5.9	5.9	5.7	
	Mean	5.4	5.6	5.6		5.3	5.7	5.7		0.5

In 1989 grain yields from treatments 125 or 170kg/haN were the same. However, the increase in the levels of N from 80 to 125 resulted in a yield increase of 0.2t/ha and 0.4t/ha with the suffolk and band coulter treatments respectively (Table 2.27).

The average grain yields given by both drilling systems were similar in the 1989 growing season. Grain yield averaged over N levels

were 5.5t/ha and 5.6t/ha corresponding to suffolk and band coulter. Simiarly, yield averaged over the timing treatments was 5.6t/ha for each of the drilling methods. The possible benefit in changing from drilling with the suffolk coulter to the band coulter with a view to increase yield is succinctly summarised in the discussion page 136.

2.3.7.Grain quality.

Wheat grains are usually assessed for quality attributes before they are marketed. Quality requirements depend on the purpose for which grains are traded. To assess grain quality during the two seasons of experiment 1, measurements were carried out on the following: grain moisture content, grain protein contents and Hagberg falling number. Specific weight, which is one of the important quality characteristics was not determined. Instead thousand grain weight (a more useful scientific measure of grain filling) was recorded to evaluate the effect of the treatments on grain size (Table 2.26). It is important to note that thousand grain weight is not identical to specific weight, which is the measure of the packing density (volume), the function of the surface roughness and the size of the grains. This is mentioned later in discussion (page 167).

2.3.7.1.Grain moisture content (%).

Nowadays grain buyers request lower grain moisture content (14%) to suit the storage constraints in warmer and more humid importing countries. In the course of these trials, the grain moisture content was assessed using oven drying. Which is considered to be more accurate than the use of electrical capacitance or resistance methods employed for use in the field for quick checking of grain moisture before combining. Percentage grain moisture contents were calculated using the following formula:

$$\%gmc = \frac{W1 - W2}{W1} \times 100$$

Where:

gmc = calculated grain moisture content.

W1 = Initial weight of the grain sample taken soon after harvest.

W2 = Final weight of the grain sample after drying to a constant moisture content.

The percentage moisture calculated from the above formula for wheat grains during the two experimental seasons are presented in Table 2.28. In the first experimental year (1988) the time of application of N affected grain moisture. Delaying the N treatment until T3 increased grain moisture from 17.3% to 18.2% and 17.5% to 18.3% corresponding to the suffolk and band coulter treatments in low plant population. This increase is significant at the 5% level. In the high plant population density the increase in grain moisture was not significant. But even then, grain moisture was increased from 17.4% to 17.8% and from 17.2% to 17.9% for the respective drilling methods (Table 2.28).

In the following much drier growing season, the N timing had no effect on grain moisture. The corresponding values of grain moisture with respect to time of application of N were therefore similar with all the treatments (Table 2.28). This was probably due to the very dry weather during grain filling (Appendix 2.4) which continued until all plots were combined on August 7th. The air temperature during this grain filling period was also high compared to the ten year means and the previous growing season (Appendix 2.4).

In each of the two experimental seasons there were no effects of drilling methods and N levels on grain moiture content. This was not surprising, since none of these treatments was found to delay grain set or grain maturity significantly.

Table 2.28. Effect of drilling pattern, rate and time of application of N on grain moisture content (%) of spring wheat (variety-Axona).

		Suffolk Coulter.			Band Coulter.			
		Rate of nitrogen (kg/ha).						
		80	125	170	80	125	170	SED.
Density.	N Timing.			1988				
	T1	17.7	17.3	17.1	17.6	17.6	17.4	
Low	T2	17.5	17.7	17.5	17.7	17.8	17.8	0.4
	T3	17.9	18.3	18.4	18.3	18.4	18.3	
	T1	17.6	17.4	17.2	17.4	17.2	17.1	
High	T2	17.7	17.6	17.4	17.4	17.4	17.4	0.3
	T3	17.8	17.9	17.7	17.8	17.9	17.9	
				1989				
	T1	10.6	10.8	10.8	10.6	10.7	10.6	
	T2	10.6	10.4	10.7	10.4	10.5	10.3	0.2
	T3	10.6	10.8	10.7	10.6	10.6	10.5	

The use of SED with percentage data given in Table 2.28 should be questioned. Although the small spread of values eliminates the need to transform these data, it is probably best to simply compare the means without using statistics.

2.3.7.2.Grain protein at 14% m.c.

The main factor enhancing grain protein content is uptake of nitrogen by the wheat plant. Correct nitrogen application at the appropriate stage of growth is therefore important. Grain protein is the most important quality attributes of wheat. During these trials, grain protein were assessed during grain development until maturity. Final grain protein content was also determined. While the former was meant to study protein deposition during grain fill and to assess the stage of grain development at which protein is fixed, the latter was employed to evaluate the final protein content of the grains. The procedures involved in carrying out these measurements are described in

the materials and methods (section 2.2.7, pages 67-68).

The results on protein accumulation studies are presented in Figures 2.2 & 2.3. These indicate that almost all the total grain protein harvested was fixed soon after anthesis. In both seasons when protein measurements started; 15 and 10 days after anthesis in 1988 and in the following season respectively, the amounts of protein present in the grain were above 10% (Figures 2.2 & 2.3).

In the 1988 growing season, grain protein measured in the developing grains increased with the delay in N application. The percentage grain proteins recorded 15 days after anthesis with 80kg/haN were 10.2, 11.0 and 12.0% corresponding to T1, T2 and T3. By applying 125kg/haN, the protein contents were 10.7, 12.1 and 12.2%. The grain protein recorded during this season was even greater with 170kg/haN treatment. This treatment gave grain proteins of 11.4, 12.0 and 13.2% (Figure 2.2).

The rates at which protein was deposited into the grains with respect to the time of application of N are described by the equations in Table 2.29. At each level the percentage protein recorded soon after anthesis (day 15th) was consistently lower with the T1 treatment compared to the T2 and T3 treatments (Figure 2.2). When these regression lines were compared they were found to differ significantly ($P<0.05$) from each other. These differences in protein during grain development continued until grain maturity. Grain protein increased with the increase in size of the grains, and then stabilised or decreased slightly towards maturity. The magnitude at which percentage protein decreased towards maturity was found to be higher at the T1 treatment when 80kg/haN was applied (Figure 2.2).

Protein development in the grains was also increased with the levels of N. However, this increase in protein during grain filling was

not as dramatic when compared with the effect of timing. For example increasing N levels from 125 to 170kg/ha did not result in any increase in grain protein during the early part of the grain fill when the treatments were applied at T2 (Figure 2.2).

Table 2.29. Regression equation for slopes describing %protein (%N x 5.7) development in grains of spring wheat (variety-Axona).

Timing	Rate of nitrogen (kg/ha). 80	125	170	SED.
		1988		
T1	Y = 9.95 + 0.04x	Y = 10.13 + 0.05x	Y = 11.31 + 0.04x	
T2	Y = 10.73 + 0.05x	Y = 11.90 + 0.05x	Y = 10.94 + 0.09x	0.2
T3	Y = 11.31 + 0.06x	Y = 11.69 + 0.07x	Y = 11.94 + 0.10x	
N	Y = 10.67 + 0.05x	Y = 11.28 + 0.05x	Y = 11.34 + 0.08x	0.1
		1989		
T1	Y = 12.48 - 0.11x	Y = 13.70 - 0.13x	Y = 12.75 - 0.07x	
T2	Y = 13.32 - 0.09x	Y = 13.73 - 0.09x	Y = 13.58 - 0.06x	0.8
T3	Y = 13.75 - 0.11x	Y = 14.16 - 0.07x	Y = 13.14 - 0.04x	
N	Y = 13.20 - 0.10x	Y = 13.88 - 0.10x	Y = 13.15 - 0.06x	0.7

The pattern of grain protein deposition in 1989 was in contrast to that of the previous season. Hence, the effect of time of application of N on the grain protein accumulation was not consistent (Figure 2.3). The amount of protein measured from the developing grains soon after anthesis (10 days) showed a slight increase (NS) with delay in N timing only when 80kg/haN was applied. The treatments with 125 and 170kg/haN had no effect with respect to time of application (Figure 2.3). Timing effect on protein development became even more complicated as the grains advanced in size. Only towards grain maturity was the effect of timing on grain protein was detected (Figure 2.3). In this season, grain protein increased soon after anthesis and then decreased as the grains advanced in size. It increased again towards grain maturity stage. Table 2.29 presents the equations describing these lines. At no time of grain

filling period were the lines differ significantly from one another. Also there was no significant effect of N levels on protein development during this growing season.

Final grain protein was assessed at harvest using the combined harvest sample to determine the effect of the treatments on the total protein content of the grain sample. Percentage proteins were determined at the moisture content of the ground sample. These were then adjusted to 14% moisture using the formula described in the materials and methods (page 68). Results are presented in Table 2.30. Grain protein increased significantly ($P<0.05$) with the late applications of N (Table 2.30). Mean grain protein increased from 11.8% to 13.8% and from 12.0% to 13.6% in the low population in 1988 growing season. This increase in protein resulted from the delay in N treatments until T3 corresponding to suffolk and band coulters. With the high population, the increase in protein content of the grain was similar. It increased from 11.6% to 13.4% and 11.9% to 13.7% with the respective drilling methods (Table 2.30).

N levels increased grain protein significantly ($P<0.05$). However, similar to the results described in grain protein development above, this increase in protein content was less compared to the timing effect (Table 2.30). Increasing N levels from 80 to 170kg/ha resulted in an increase of grain protein from 12.1% to 13.4% and from 11.9% to 13.6% in the low plant population. The corresponding increases in the high population were 11.8% to 13.2% and 12.0% to 13.4%. Grain protein was not affected by the drilling methods in the low plant population density. In the high population on the other hand, it increased (NS) when plots were drilled using the band coulter. The mean grain protein averaged over N levels and timing was 12.8% as compared to 12.5% for the suffolk coulter. There was an interaction between N levels and the time of application. For example treatment with 170kg/haN at T3 produce the

highest grain protein. Percentage grain protein obtained from the combination of these treatments were 14.4% for both the low and high plant populations (Table 2.30).

In 1989, results from the experiment at lower Orchard produced a slightly different positive response. Protein content of the grain increased significantly by delaying N application. It increased from 11.6% to 12.9% and, from 11.7% to 12.9% corresponding to the suffolk and band coulters, when N application was delayed until T3 (Table 2.30). In suffolk coulter plots, grain protein for the T2 and T3 treatments were identical during this season. Also the mean grain protein obtained with the treatment at T1 and T2 in the band coulter plots were the same (Table 2.30).

Grain protein content averaged over the drilling methods were similar for the T2 and T3 treatments in 1989 experimental season. This was due to lack of rainfall between the time when plots were treated with N at T2 and the subsequent treatment at T3. Hence, T2 and T3 treatments behaved as if they were applied at one timing.

Grain protein was also increased significantly ($P<0.05$) with N levels during this growing season. Protein increased from 11.5% to 13.4% and from 11.6% to 13.2% with increase in N levels from 80 to 170kg/ha corresponding to the drilling methods (Table 2.30). The magnitude by which grain protein increased with the N levels was greater when compared to the effect of timing. The interaction effect between N levels and the time of application in this season was relatively less. However, an interaction effect was still detected. For example, combination of 170kg/haN with T2 or T3 treatments in suffolk coulter plots gave the highest grain protein. Similarly, with band coulter drilling the highest protein content was abtained when the same level of N was applied at T3 (Table 2.30).

Fig. 2.2 GRAIN PROTEIN ACCUMULATION — 1988

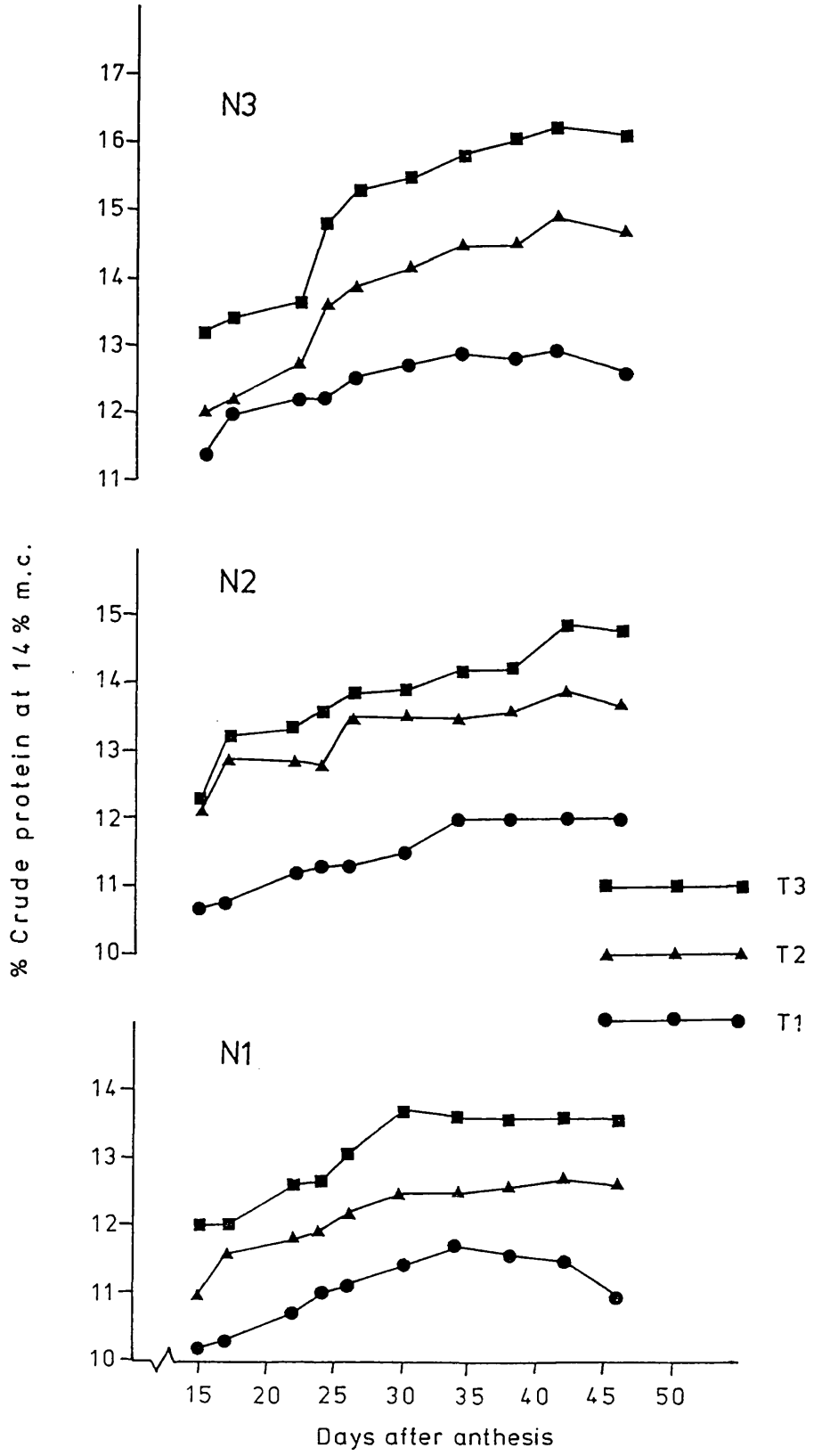


Fig. 2.3 GRAIN PROTEIN ACCUMULATION — 1989

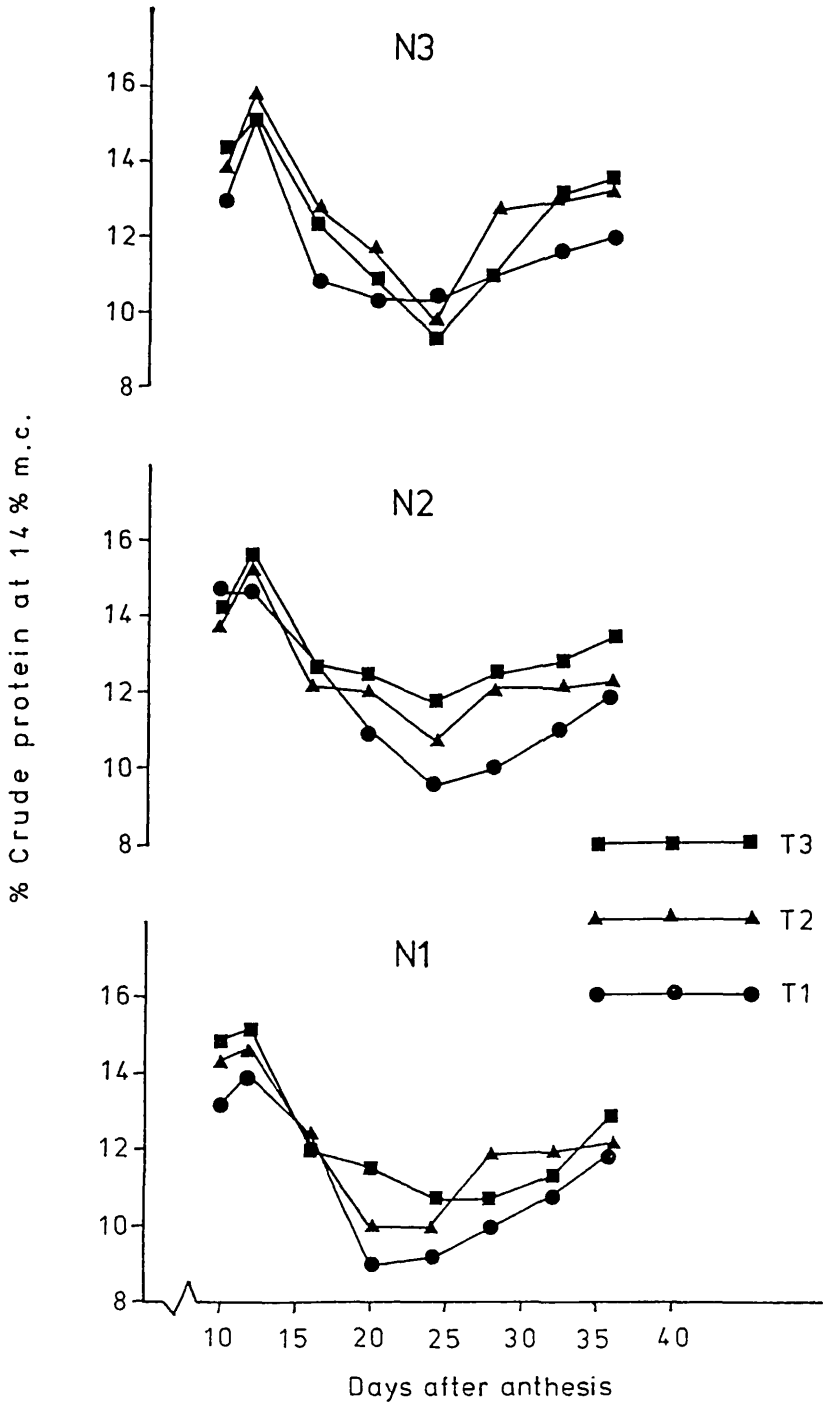


Table 2.30. Effect of drilling pattern, rate and time of N application on percentage protein (%N x 5.7, 14%m.c) of spring wheat (variety-Axona).

		Suffolk Coulter.				Band Coulter.				
		Rate of nitrogen (kg/ha).								
		80	125	170	Mean	80	125	170	Mean	SED.
Density.	N Timing.				1988					
Low	T1	11.2	11.8	12.5	11.8	11.2	12.1	12.7	12.0	
	T2	11.9	12.5	13.4	12.6	12.1	12.8	13.6	12.8	
	T3	13.1	14.0	14.2	13.8	12.5	14.0	14.4	13.6	
	Mean	12.1	12.8	13.4		11.9	13.0	13.6		0.3
High	T1	10.9	11.6	12.3	11.6	11.2	12.0	12.5	11.9	
	T2	11.9	12.5	13.2	12.5	12.0	12.7	13.3	12.7	
	T3	12.6	13.6	14.1	13.4	12.9	13.7	14.4	13.7	
	Mean	11.8	12.6	13.2		12.0	12.8	13.4		0.2
					1989					
	T1	10.5	11.8	12.5	11.6	10.6	11.8	12.7	11.7	
	T2	12.0	12.9	13.8	12.9	11.9	12.8	13.4	11.7	
	T3	11.9	13.1	13.8	12.9	12.2	12.9	13.6	12.9	
	Mean	11.5	12.6	13.4		11.6	12.5	13.2		0.3

2.3.7.3.Hagberg falling number.

This method assesses the content of the enzyme α-amylase. α-amylase which is needed in breadmaking to produce sugars from the breakdown of starch, since these sugars are required for the yeast to feed on and produce the necessary gassing during fermentation. However, an excess of α-amylase can lead to over production of sugars when this enzyme reacts with starch, which results in a loaf of large irregular shape, with a dark crust colour.

The enzyme α-amylase increased its activity dramatically just before sprouting begins and is encouraged by wet harvest conditions. The miller uses the Hagberg falling number test to measure the activity of the α-amylase present in wheat. In this experiment, falling number was measured to study the activity of the enzyme α-amylase in a spring wheat

variety (Axona). Results of falling number measurement are averaged over the drilling methods. These are presented in Table 2.31 below. There was no significant effect of N level or timing on falling number in 1988. Similar results was also obtained in the following growing season. However, in the 1989 experimental season, there was a trend in increase (NS) in falling number with the rate of N.

Table 2.31. Effect of rate and timing of N on Hagberg falling number of spring wheat (variety-Axona).

	Rate of nitrogen (kg/ha).				
	80	125	170	Mean.	SED.
N Timing.		1988			
T1	345	354	346	348	
T2	351	347	347	348	
T3	353	370	376	366	
Mean	350	357	356		20.0
		1989			
T1	403	414	457	425	
T2	459	450	471	460	
T3	433	433	509	458	
Mean	432	432	479		30.0

Averaged over drilling patterns and plant populations.

2.4.Discussion.

2.4.1.Biological Yield.

Data presented here were obtained primarily to study the effects of (i) crop establishment, different levels of N and the time of application on the dry matter production of the spring wheat variety, Axona and (ii) dry matter on the yield components and final grain yield. The experiments were conducted during 1988 and 1989, at different sites using two different drilling dates. Both experimental sites were second cereal crop situations, chosen to provide the opportunity for differential N response to develop. Growth analyses were carried out on different plant populations. In 1988 when two plant densities were drilled, plant analyses were performed on the low population (400 seeds m-2). In 1989, only the high population (550 seeds m-2) was sown and growth analyses were performed on this population. Therefore, it is important to emphasise at this introductory stage of discussion that variations in total biomass in the two seasons might have been caused by differences in husbandry practices as well as seasonal traits. For example, drilling dates varied from April 13th in the first year to February 8th in 1989 and the trials were conducted on 'light and heavy' soil types (Table 2.4). The disadvantage of using two distinct drilling dates was offset to some extent by the presence of an adjacent postgraduate trial in 1989 which used Axona. As this was designed to examine the effect of sowing dates, an April 1989 drilling comparison was fortunately made available. As a result drilling made in April for both seasons can be included within the overall discussion. A summary of the experimental treatment of this work is given in Appendix 2.2.

In order to make meaningful treatment comparisons, the time of N application was defined by growth scale, designed by Zadoks, Chang and Konzak (1974); Nerson, Sibony and Pinthus (1980) and Tottman (1987) for

cereals, which is based on the growth stage of the mainshoot. Crop development in spring wheat varieties is usually faster due to the shorter growing season than in winter wheat varieties. Growth changes quickly from one stage to another. For example, the time lapse between double ridge and spikelet initiation is very short. However, in conducting this experiment, efforts were made to ensure that treatments were applied at the growth stage of the crop described in the materials and methods (Table 2.4). Thus, although many differences existed between the seasons treatment comparisons are made easier because Nitrogen fertilizer was applied at approximately the same stage of crop development.

2.4.1.1.Crop establishment.

Establishment is the first of many stages which subsequently determine the growth and yield of a cereal crop. It provides the initial plant population from which the final number of reproductive tillers is derived. Good crop establishment usually defined by the number of plants m-2 is an important basic pre-requisite of high yield. In practice, the seed or seedling prior to emergence is subjected to a variety of interacting environmental stresses. In order to discuss the effects of factors such as soil temperature and rainfall on establishment and subsequent crop development, the details of the weather conditions during the two growing seasons are presented in Appendix 2.4. Figure 2.6 describes the rainfall and soil temperature regime for both the seasons.

In 1988 a field assessment of seed germination and seedling establishment was carried out in order to compare the effect of drilling methods on the date of crop emergence. Results showed a delay of 2 days in seedling emergence when the band coulter was used especially with the low plant population (Table 2.6). This suggests that the change from

using the suffolk coulter which is normally used by most UK farmers probably resulted in an increased sowing depth due to the downward pressure imposed by the additional weight of the band coulters. These results are in agreement with the findings of Knight (1983), who revealed that, change of drilling depth from 2.5cm to 4.5cm resulted in a delay of emergence of 7 days, and as a consequence reduced grain yield per ear from 2.49g to 0.69g using the wheat cultivar Warimba. In another report, Heege (1987) demonstrated that a deviation of 2cm from the target depth (2.5cm) reduced germination of wheat by 40%.

Although initial plant establishment was delayed (Table 2.6), using the band coulter, the final number of plants established m-2 was consistently higher. As a result total biomass was significantly higher ($P<0.05$) using the band technique. However, despite the higher dry matter, grain yields eventually obtained from this treatment over the seasons were lower (Table 2.27).

Crop establishments in 1988 were 71%, 72% and 77%, 78% of the target populations of 400 and 550 seeds m-2. In 1989, on the lighter soil the mean establishment was greater (82%). Differences in the number of plants recorded in 1988 resulted from variation in plant survival after establishment (Table 2.7). The number of plants lost during a given interval of time was higher in the high populations. Similar results have been reported by Ellis, Elliot, Pollard, Cannell and Barnes (1979) who attributed plant loss to inadequate soil moisture content which resulted into the death of small weak plants during establishment. Darwinkel, tenHag and Kuizenga (1977), reported from the Netherlands that up to about 330 seeds sown m-2 had no effect on plant survival although their data referred only to initial establishment without consideration of events during the subsequent seedling development period. In a field trial such as the one presently described, it is extremely difficult to study in detail the many factors affecting

seedling mortality. Detailed investigations really require much smaller plots in which seeds can be hand sown at varying depths and spacings. Thus the precise reasons for the establishment results given in Tables 2.6 and 2.7 cannot be explained with a high degree of precision. Many studies use the descriptive terms 'competetive effects' or variation in drilling depth to explain establishment data, but in most cases little quantitative evidence is provided which links 'cause and effect'. More over, statistical analyses do not allow differentiation between cause and effect and do not even necessarily show cause to effect relationships. Hence, it was not possible to reach a definite conclusion about the mechanisms underlying the differences in establishment.

The criterion guiding the correct seed or drilling rate used in practice is the target number of established plants the farmer expects to achieve m-2. A systematic calculation rather than a blind guess at seed weight should be employed by using the following:

$$\text{Seed rate (kg/ha)} = \frac{\text{Target population (plants m-2)} \times \text{TGW (g)}}{\text{Expected \% establishment.}}$$

Despite the plant losses indicated above, the final plant populations achieved were typical of those normally obtained in UK Agriculture. These data do confirm that as much as 30% of spring sown seed is lost during the establishment period. This represents approximately 75pounds with the present seed price at 250pounds/tonne.

2.4.1.2.Dry matter production and crop growth rates.

Results presented in Tables 2.8 and 2.9 show that total plant dry matter production was significantly increased ($P<0.05$) by the first N application (T1), applied at GS12-13 in 1988 and GS14 in 1989. However, the initial differences in dry weight obtained from the early harvest samples (e.g H2) were relatively small. For example, in 1988, the mean

total dry matter yields m-2 were 18.9g, 21.6g and 21.0g, 23.5g for treatments T1 and T2 in the suffolk and band coulters respectively. Corresponding values for the following year were 111.1g, 88.3g and 132.3g, 116.4g. However, these differences increased by anthesis. Tillers produced as a result of the early N treatments (T1) were observed to be taller than those in treatments T2 and T3 and survived until anthesis. When the mean total biomass m-2 was divided by the corresponding mean number of tillers m-2 at anthesis, the results did not demonstrate a significant change in tiller dry weight due to timing (Table 2.32). Therefore, the consistent increase in total biomass by the T1 treatment in each of the seasons must have resulted from an increase in the number of tillers m-2. Delayed application of N until T2 and T3 resulted in less numbers tillers m-2 (Table 2.13 & 2.15). For example, the mean number of tillers m-2 averaged over drilling methods and N levels during 1988 and 1989 at anthesis, were 448.8, 392.2, 385.0 and 485.0, 428.0 446.8 for treatments T1, T2 and T3 respectively. It is note worthy that both numbers of tillers m-2 and mean tiller weight (Table 2.32) were higher during 1989 which was drier than 1988. Darwinkel (1983) reported that, postponing N application until GS32 or later resulted in suboptimal soil N levels during tiller initiation and growth. Tiller development was stagnated and as a consequence they were unable to produce ears. Similar results were obtained in experiment 1 in each of the seasons. However, the increase in the number of ears in 1989 did not result in a higher grain yield as in the previous year.

There was a relationship between dry matter yield at anthesis and the number of grains per ear as well as total grain yield in 1988 (Figure 2.4). Positive relationships were also found between flag leaf weight and the number of grains and the final grain yield. However, similar links were not manifested in the 1989 growing season (Figure 2.5) probably due to the lower number of grains per ear and grain weight resulting from a shorter grain filling period. In 1988, the period of

Fig. 2.4 RELATIONSHIPS BETWEEN TOTAL BIOMASS, NUMBERS OF GRAINS PER EAR AND GRAIN YIELD — 1988.

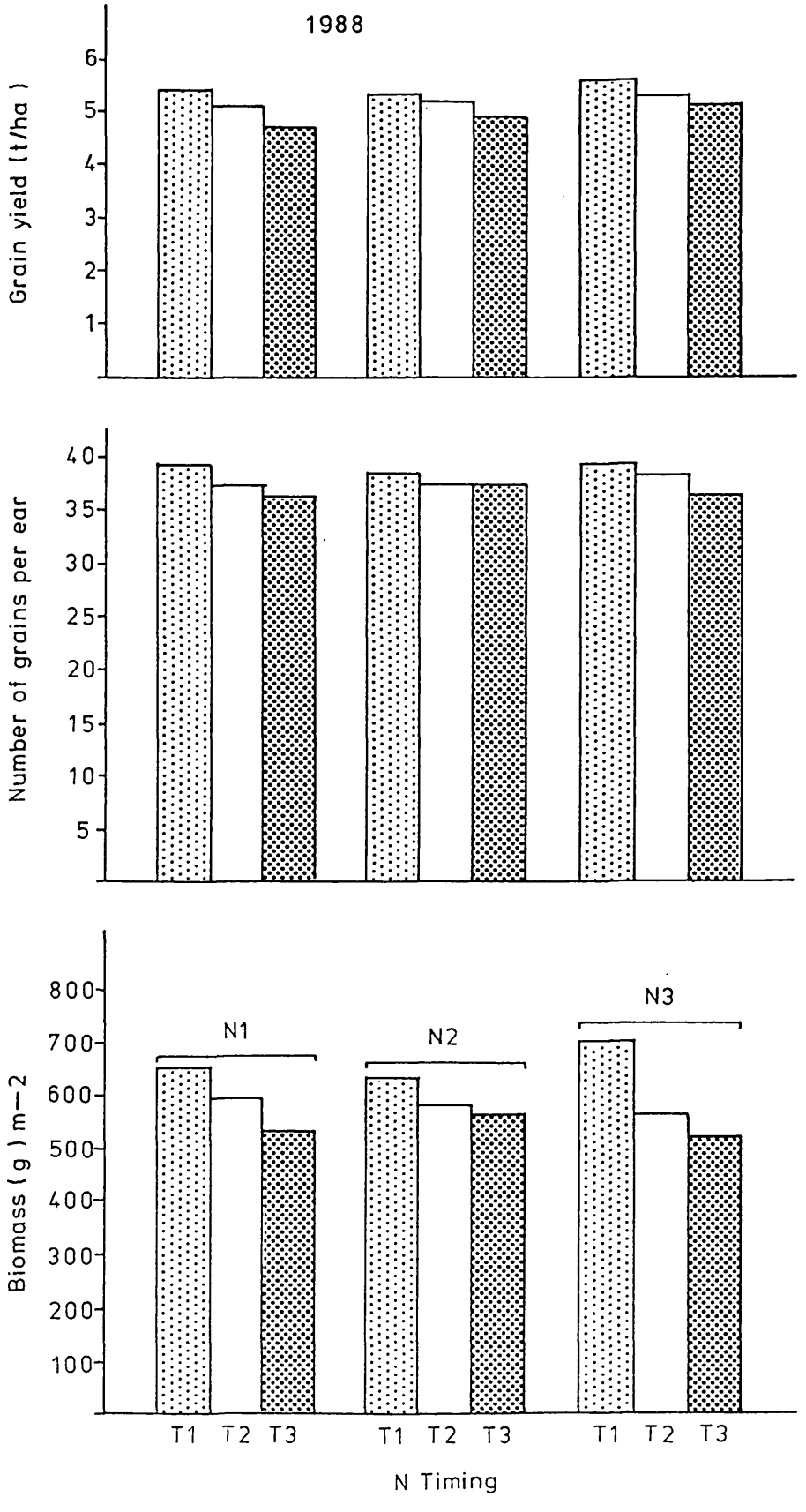
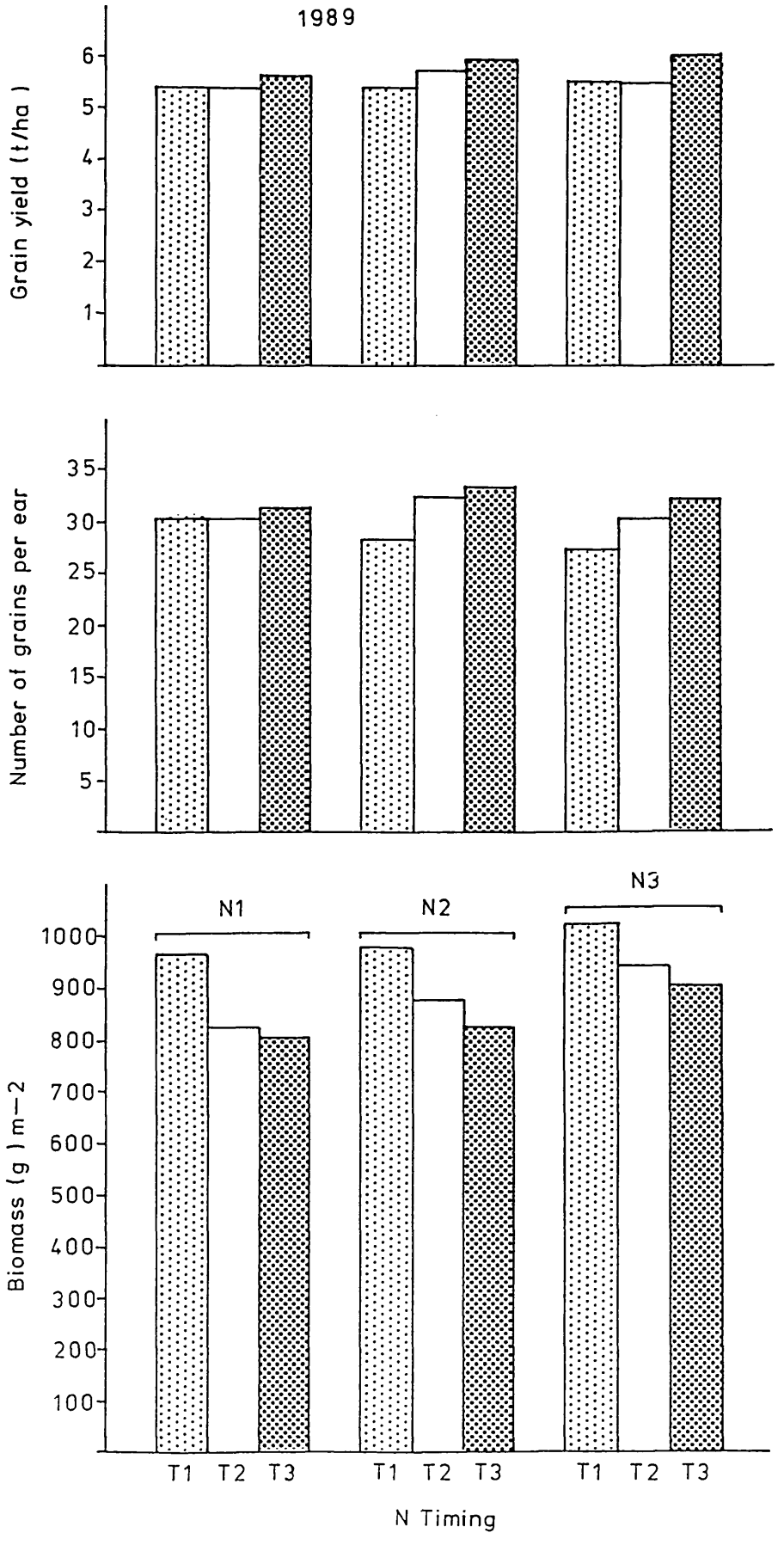


Fig. 2.5 RELATIONSHIPS BETWEEN TOTAL BIOMASS, NUMBERS OF GRAINS PER EAR AND GRAIN YIELD — 1989.



grain filling was 46 days whilst in 1989 it was 40 days due to drought and high temperatures (Appendix 2.4).

Table 2.32. Contribution of tiller dry weight to total biomass at anthesis (averaged over N levels).

	Suffolk Coulter.			Band Coulter.		
N timing.	Mean no. of tillers m-2.	Mean biomass m-2 (g).	Biomass /tiller (g).	Mean no. of tillers m-2	Mean Biomass m-2 (g).	Biomass /tiller (g).
			1988			
T1	409.6	605.6	1.48	487.9	713.2	1.46
T2	363.8	521.9	1.43	420.6	605.7	1.44
T3	359.0	507.4	1.41	410.9	596.2	1.45
			1989			
T1	467.3	940.3	2.01	502.7	1021.0	2.03
T2	422.7	829.7	1.96	433.3	877.3	2.02
T3	434.3	856.3	1.97	459.3	867.3	1.89

Total dry matter production was affected more by the timing rather than the levels of N application; although some interactions were detected (Tables 2.8 & 2.9). For example, prior to anthesis in 1988 (H8), the T1 treatments produced the highest total dry matter yield, irrespective of the drilling patterns (Table 2.8). However, the greatest yield was obtained by an application of 125kgN/ha in the suffolk coulter treatment, whilst with the band treatment, the highest total dry matter was produced by the application of 80kgN/ha (Table 2.8). This was only true during the first experimental season. In the following year, total dry weight was greater (NS) with the first application of 125kg/haN in both suffolk and band coulters prior to anthesis (H5), Table 2.9. The reason why 80kg/haN resulted in higher total biomass m-2 with the band coulter treatment in 1988 was not understood. Although some significant interactions ($P<0.05$) were found between the levels of N and the time of application they were not consistent at all harvests. The importance of timing on total biomass at anthesis is succinctly summarised in Table

2.33 below.

Table 2.33. Summary of total biomass m-2 at anthesis (GS60) during 1988 and 1989, averaged over drilling methods and N levels.

Years.	Treatments.		
	T1	T2	T3
1988	659.4	563.8	551.8
1989	980.7	861.8	853.5

Several authors have measured and described the rapid increase in crop growth rate that occurs during the spring (GS20-39) and subsequent decline in the rate of dry matter accumulation towards anthesis (Biscoe and Gallagher, 1977; Biscoe and Willington, 1984; Lidgate, 1984). However, the precise pattern does vary from one season to another. For example, crop growth rate (CGR gm-2/day) in 1988 during the early growth period (GS30-49) was lower (12.3g m-2/day) than the values (17.5g m-2/day) recorded later (GS51-60) Table 2.34. By comparison in 1989, the rate of dry matter increase was higher (20.3gm-2/day) between the period of stem extension to booting (GS30-49) compared to the values achieved during ear emergence to anthesis (GS51-60). The average rate of increase in crop growth during the period GS30-GS60 was higher (16.9g m-2/day) in 1989 when summer conditions were hot and very dry than in the previous year year (14.9g m-2/day). This was presumably due to earlier drilling (February 8th 1989 versus April 13th 1988) which provided an additional period for the establishment of an earlier canopy cover which must have improved the solar radiation interception by the crop. Higher air temperatures ranging from 9.4 to 19.8^{o}C during February to June might also have hastened the rate of leaf initiation, growth and expansion. The expansion of crop leaf area in the field is related to the rate of leaf extension, which is strongly dependent on temperature (Gallagher and Biscoe, 1979; Gallagher et al. 1979 and Watts, 1972). The number of

day degrees during the period from February to August in 1989 was relatively higher, 1433.32 as compared to 1365.55 accumulated during the period from April to September in the first experimental year. This must have contributed to the higher crop growth rates achieved during GS30-49 in the second growing season (Table 2.34).

Table 2.34. Crop growth rate (CGR in g m-2/day) during the early and late period of growth (GS30-49 & GS51-60). Spring wheat cv. Axona.

Levels of N (kg/ha).	CGR (g m-2/day) GS30-49	GS51-60.	N timing.	CGR (g m-2/day) GS30-49	GS51-60.
		1988			
80	12.9	16.5	T1	13.6	19.6
125	12.2	17.3	T2	12.1	16.6
170	11.7	18.7	T3	11.2	16.2
Mean	12.3	17.5	Mean	12.3	17.5
		1989			
80	19.9	14.1	T1	23.1	14.6
125	16.2	10.0	T2	18.0	11.2
170	24.8	16.4	T3	19.8	14.7
Mean	20.3	13.5	Mean	20.3	13.5

Work in Northern France by Beaux and Martin (1985) and in England Dowdell, Crees and Chritian (1984) using N-15 labelled fertilizer on winter wheat, showed that during tillering (GS20-27) only 43% of N applied to the crop was recovered from the soil. However, during stem extension (GS30-39) about 70% of the applied N was recovered. Table 2.35 mainly demonstrates higher crop growth rates with early N treatment (T1). This suggests that more N may be taken up from the soil as a result of N treatment at early growth stages (GS12-13 & GS14) if soil temperatures of 4-5^{o}C at 10cm depth have mainly been achieved. These results are in agreement with those reported by many authors including Darwinkel (1983), who described the relationship between growth stages of the winter wheat cultivars Arminda, Caribo and Okapi and the uptake

of nitrate ions from the soil. He concluded that N uptake was highest during early tillering (GS21-25).

Table 2.35. The rate of dry matter accumulation per plant (mg/plant/day) from stem extension (GS30) to anthesis (GS60).

Drilling Methods.	Timings.	Nitrogen Levels (kg/ha). 80	125	170	Means.
			1988		
	T1	69.3	94.3	80.5	81.4
Suffolk Coulter.	T2	63.0	84.6	70.6	72.7
	T3	73.6	63.3	53.1	63.3
	Mean.	68.6	80.7	68.1	
	T1	72.3	69.2	77.2	72.9
Band Coulter.	T2	65.6	63.5	58.3	62.5
	T3	59.9	50.3	65.3	58.5
	Mean.	65.9	61.0	66.9	
			1989		
	T1	68.3	76.0	67.0	70.4
Suffolk Coulter.	T2	58.3	62.6	75.4	65.4
	T3	43.4	60.1	82.6	62.0
	Mean.	56.7	66.2	75.0	
	T1	54.3	62.9	57.6	58.3
Band Coulter.	T2	52.1	39.6	48.3	46.7
	T3	59.5	45.0	53.3	52.6
	Mean.	55.3	49.2	53.1	

In experiment 1, the N concentrations in the shoot dry matter determined 21 days after the first N treatment (T1) in 1989, were 4.9%, 5.7% and 6.0% with 80, 125 and 170kg/haN respectively. On the other hand plots which received no N treatment gave 3.9%N. It may be inferred from these data that early N treatments resulted in higher available nitrate levels in the soil, and that soil temperatures (7.3^{o}C), Appendix 2.4 were adequate for ion uptake by the root hairs. Thus, the increase in dry matter recorded 21 days after the T1 treatments had been applied in 1989 (Tables 2.9) resulted from nitrate uptake which encouraged tillering (Table 2.15) and leaf growth. For example, treatment with N at

the early growth stage (GS12-13) in 1988 increased flag leaf area at anthesis from 26.1cm2 to 35.4cm2 and 27.2cm2 to 36.3cm2 for the suffolk and band coulter treatments respectively. This contributed to the increase in crop growth rate toward anthesis as well as the final grain yield (Tables 2.17 & 2.27). Results described by Ellen and Spiertz (1980) in the Netherlands working with winter wheat cv. Donata support these observations.

During 1988 crop growth rate was decreased by additional N during the early growth stages (GS30-49). However, between growth stages GS51-60, the converse result was recorded. The rate of increase in dry matter declined when N application was postponed until T2 or T3 (Table 2.34). Trends in crop growth rate in 1989 with respect to N levels were less consistent. During the early and later stages of growth (GS30-49 & GS51-60), the lowest growth rate was recorded from an application of 125kg/haN. The lowest rate of increase in dry matter was also recorded when N fertilizer was applied at T2 (GS30), probably due to the long dry period recorded after this treatment. The first rainfall occurred about a month after the second treatment had been applied (Figure 2.6), which meant that N was mainly unavailable. The decrease in crop growth when plots received 125kg/haN is difficult to explain precisely using these data. However, despite the low crop growth rate recorded at this level of N, the total biomass and final grain yields were not seriously affected (Tables 2.9 & 2.27).

Time of fertilizer application affected the rate of increase in individual plant dry matter (Table 2.35). The mean rates of increase by the T1 treatments during the period 51 to 76 days (a period of linear biomass increase) after drilling in 1988 were 81.4mg and 72.9mg/plant/day for the suffolk and band treatments. Corresponding values for the T2 and T3 treatments were 72.7mg, 63.3mg/plant/day and, 62.5mg, 58.5mg/plant/day (Table 2.35). The mean values for the 1989

experimental season were lower although values for the suffolk coulter were again higher than for the band drill. These data confirm that, early N application provided the established seedlings with additional nitrates. In experiment 1 it was observed soon after the T1 treatments had been applied that leaves were greener and provided larger canopy cover than in adjoining plots. This probably influenced the interception of solar radiation and consequently the increased plant growth rate (Table 2.35) and the total biomass of treatment T1 (Tables 2.8 & 2.9). Photosynthetic rates were not assessed in this trial, however, the higher leaf area of the flag leaf with early N and subsequent additional grain yield in 1988 (Tables 2.17 & 2.27) suggest that total assimilation of the canopy from the T1 treatment was probably greater compared with those achieved by the T2 and T3 canopies.

Although individual plant growth rate was higher in 1988, its duration from stem extension (GS30) to anthesis (GS60) was less (25 days) than the following growing season. In 1989, the duration of this period was longer (54 days) due to late February drilling. The entire growing season in the first year was about 6 months compared to 7 months in 1989 even though the second season was shortened by the unusually dry and hot summer. Cereal harvest dates in 1989 were the earliest recorded in the UK since 1976. A faster growth rate was required during 1988 to complete the life cycle required for seed production. Another contributory factor for the higher plant growth rate recorded during 1988 (Table 2.35) may have been the lower plant population chosen for growth analysis (400 seeds m-2). At low population providing there is complete canopy cover (LAI of at least 3), the ability exists to intercept about 80% of the photosynthetic active radiation (Hipps, Asrar and Kanemasu, 1983). Interception of solar energy is maximised using both upper and lower leaves. However, at higher populations such as those achieved in 1989, the interception may have been greatly reduced by overshading. Increased shading in high density crop canopies occurs

as a result of excessive leaf area indices (>5). This may decrease the potential photosynthetic activity of single leaves because of reduced light at their surfaces (Pearman et al., 1977). Which may reduce the growth rate of individual plants. However, despite the higher growth rates of the individual plants in 1988, plant dry matter recorded at anthesis was lower than in 1989. The longer growth period in 1989 contributed to higher plant dry weight (Table 2.11). This also influenced the final grain yield because when plots were combined there was no significant yield decrease, even though the summer period was hot and dry (Appendix 2.4). Ellen (1987) reported similar results for the winter wheat variety Arminda in the Netherlands.

Rates of plant growth, corresponding plant dry weights and grain yield (t/ha) in each of the seasons were consistently higher using the suffolk coulter (Tables 2.35, 2.10, 2.11 & 2.27), although crop growth rates (g m-2/day) were greater in the band treatment where plant population was higher (Table 2.12). Thus, the above discussion in relation to plant population, canopy density and its effect on the rate of plant growth may have contributed to the differences recorded in plant growth rates with the drilling systems.

Although the yield differences between the suffolk and band coulter treatments were not significant, the grain yields were consistently slightly higher with the former drill. Variation in the soil area available to each plant accounted for about 14% reduction in grain yield of a wheat cv. Warimba (Knight, 1983). However, it is not knowm from the present experimental results if the variation in spacing achieved by using different drilling systems was really responsible for the higher (NS) yields obtained. Detailed studies of randomly selected plants from the population may have helped to acertain this. However, such an exercise is not feasible when carrying out growth analysis. Even a mini plot experiment may not be feasible in practice because using farm

drilling equipments is not easy. The study has therefore indicated some of the effects that confound detailed interpretation of the results given by two drilling systems. They do not provide clear guide to a farmer wishing to improve the productivity of his crop by using different spatial arrangement techniques.

As both grain yield and plant dry weight declined, the yield reduction with the band coulter treatment can possibly be linked to the delay in seedling emergence recorded from this drilling method (Table 2.6). Differences in plant weight may have been due to the time of seedling establishment. The speed of germination and emergence, is a potentially powerful factor which determines the performance of plants because it occurs early in the growth period of the crop. Early emerged plants could attain greater absolute and relative growth in two ways: first, their more extensive shoots and roots could more readily exploit any untapped resources, aerial or in the soil; secondly, they could invade the environment earlier by intercepting more radiant energy or nutrients from the soil.

In an experiment with barley cv. Clipper, Soetono and Donald (1980) reported an 11% decrease in the number of grains per plant for each day of retardation in seedling emergence. This may have been the case in this study, where seedling emergence indicated by the results on plant establishment count in 1988 in Table 2.6 showed a delay of 2 days with the band coulter drilling. The numbers of grains per ear as well as thousand grain weight were slightly lower with this drilling system. (Tables 2.24, 2.26, 3.14 & 3.16). However, dates of emergence did not affect the total biomass per unit area, since there was a full compensation by the increase in the number of plants m-2 with the band coulter drilling (Appendix 2.1).

The initial hypothesis that changing from the suffolk coulter normally used in British Agriculture to the band 'broadcasting' coulter

could result in significantly higher grain yields was not achieved during the course of this study. Thus, from the three years' trial results, little evidence was found to recommend the adoption of band drilling for use in future British Agriculture. The claimed grain yield advantages of this drilling system that were put forward by preliminary studies in West Germany were probably optimistic. The increase in plant establishment, subsequent biomass but reduced grain yield cannot be easily explained in terms of 'cause and effect' from these trials.

However, there may be some areas of research into band coulter drilling that could be useful. Because of the consistent increase in dry matter associated with this drilling throughout the experimental period (Tables 2.8 & 2.9) the technique may be valuable for the establishment of forage and grassland crops. A 'one pass' broadcast technique would offset the need for cross drilling herbage seeds when re-seeding grassland. However, as the area of grassland establishment is declining due to cost, the market place for band coulter purchase would not be large.

The increase in plant dry weight due to additional N fertilizer was greater in the second growing season (Tables 2.10 & 2.11). This suggests under high levels of radiation as experienced in 1989, that the response to N was greater (Table 2.11). In a field experiment with spring barley in the Netherlands, high dry matter production per unit N (35kgDM/kgN) was found in a year with high radiation, and considerably lower dry matter production per unit N (29.5kgDM/kgN) with low radiation per unit ground area (Ellen and Van Oene, 1989). The response of Axona during 1988 and 1989 experimental seasons are summarised in Table 2.36. The dry matter yields per kg of N applied declined with levels of N. Thus, for dry matter production there is no economic benifit in applying high levels of N.

Application of 125 and 170kg/haN instead of the lowest level of 80kg/ha resulted in increase in plant dry weights at anthesis of about 7%, 9% and 3%, 4% in 1988, for the suffolk and band coulters. In 1989 the resultant increases were 10%, 15% and 5%, 4% respectively. It was observed that additional N retarded the senescence of older leaves, and reduced tiller loss. Experimental evidence of a small reduction in tiller loss with the increase in the levels of N is presented in Table 2.39. The increase in leaf area illustrated by the flag leaf data, and delayed senescence that resulted from increased levels of N probably increased photosynthetic capacity due to improved light interception by the canopy.

Table 2.36. Crop response to N (kgDM/KgN) in 1988 and the February and April drilling in 1989.

N levels (kg/ha).	Crop dry matter yield per kg of Nitrogen.		
	1988	1989 (February drilling)	1989 (April drilling).
80	73.9	107.4	73.4
125	47.3	70.8	____
170	34.9	56.0	____

In temperate cereals maximum dry matters (within the range 12-15t/ha)are obtained at anthesis when most of the ear dry matter as rachis, glumes, rachilla, florets and awns has accumulated. At anthesis optimum radiation interception should occur as all leaves are fully expanded. Higher shoot weight at anthesis correletes strongly with high grain yield per ear (Ellen, 1987). In pot experiments Rawson (1971) demonstrated a positive correlation (r=0.94) between shoot weight at anthesis and grain yield. Fischer (1979) described the relationship between number of grains and dry matter at anthesis for the wheat variety Yecora-70 involving several sites, years and sowing dates. He concluded that the dry matter at anthesis was postively correlated (r^2 = 0.83) with the number of grains present. However he questioned the

application of this relationship if the total dry matter at anthesis was less than 600g m-2. In experiment 1, the mean total dry matter yields m-2 given by the T1 treatments at anthesis in each of the seasons were greater than 600g and in 1988, a positive correlation (r=0.81) was obtained between total dry matter at anthesis and the final grain yield. However, this was not true in 1989 (Figure 2.5) due to the lower number of grains per ear and thousand grain weight recorded in the T1 treatments (Tables 2.23 & 2.26). The linear relationship between crop biomass and grain yield may not hold in a drought season when number of grains per ear and individual grain weight are depressed (Midmore, Cartwright and Fischer, 1984).

Evans (1980) suggested that, where several sinks compete for a limited supply of assimilates, the relative magnitude of the sinks might be of overriding importance for partitioning, with a pronounced bias in favour of the largest sinks. Such bias in favour of storage increases yield by increasing the proportion of assimilates stored in the grains. Grain size was related to the duration of filling in experiment 1 (Table 2.24). This was shorter in the second season about 40 days as compared to 1988 which lasted for over 46 days. High temperatures as well as drought (Appendix 2.6) shortened the period of grain filling in 1989. As a result of the shorter grain growth period, plots were combined a month earlier, (August 7th) as against September 7th in 1988. Therefore large grains may be an important attribute when the grain filling period is prolonged as in 1988. In this experiment thousand grain weight was much more influenced by duration of grain fill, rather than the total dry matter m-2. Thus, late N application increased the period of grain filling, hence, the consequent increase in thousand grain weight (Table 2.26). The proportionality between the number of grains and grain yield in experiment 1 implies that the photosynthetic system of the plant had produced adequate amounts of assimilates to satisfy the demands of the grains. It is established that the grain yield of cereals is not only

affected by the supply of assimilates from dry matter accumulation, but also the number of cells formed during the endosperm's meristematic period, which in wheat lasts for 16-20 days after anthesis, but longer in barley (Cochrane and Duffus, 1981). Thus grain yield may be limited by its capacity to store assimilates. The relationships between total biomass at anthesis, number of grains per ear and the thousand grain weight in experiment 1 is summarised in Table 2.38.

Table 2.37. Relationships between total biomass at anthesis (g m-2), number of grains per ear, thousand grain weight (g) and final grain yield (t/ha 86%DM) averaged over drilling systems.

N Timing.	Mean biomass (g m-2).	Grains /ear.	TGW (g).	Grain yield (t/ha).
		1988		
T1	659.4	38.3	39.6	5.4
T2	563.8	37.5	42.4	5.2
T3	551.8	36.0	43.5	4.9
		1989		
T1	980.5	28.5	38.8	5.4
T2	861.8	31.0	41.7	5.6
T3	853.5	31.5	41.9	5.7

Because the time lapse between the first application and plant sampling was only 10 days in 1988, it was possible to obtain some idea about the relationship between timing and effectiveness. The effect of early timing (T1) of N on plant dry matter was not manifest until GS30 . For example, the H2 (May 19th) results during the 1988 growing season were not significantly different from each other although N had been applied on May 9th. During this early growth period absorption of nutrients from the soil was probably limited by soil temperature (4.5 to 8.0^{o}C) Figure 2.6. However, as stem extension started with the concommitant leaf expansion, total dry matter began to increase with the early N treatment (T1). The mean dry matter yields m-2 averaged over the

drilling systems were 115.9g compared to 96.3g and 87.1g for the T2 and T3 treatments. In the following year, when growth analysis was started 21 days after the early N treatments, the effect of N timing on plant biomass was evident (121.7g versus 102.4g) for the T1 and T2 treatments (Table 2.9). It could then be argued that, during the period between the early N application and day 21, plants had not absorbed sufficient nutrient from the soil probably due to low soil temperatures (2.5 to 4.8) Appendix 2.6 which could not produce any significant changes in their physiology and morphology. Treatment with N at the early growth stage (GS14) also promoted flag leaf expansion (Table 2.17). Similar results were reported by Ellen and Spiertz (1980) on winter wheat cv. Donata, due to an increase in the number of tillers m-2 and from a rise in individual tiller dry weight. However, in experiment 1 the dry weights of individual tillers were not affected by the treatments (Table 2.32). Thus, the increase in total dry matter resulted from more number of tillers m-2 given by the T1 treatment (Tables 2.13 & 2.15).

The number of tillers per plant and corresponding dry weights at double ridge stage of development are presented in Table 2.38, illustrating the effects of seasonal drilling dates on these variables. This shows the advantage of earlier drilling on tillering and dry matter production. Even though samples were taken at a similar growth stage of the crop (GS27), the number of tillers per plant and the dry matter yields were higher in 1989 than the previous year.

Site variation may have also contributed to these differences. Soil conditions (lighter clay loam) at lower Orchard in 1989 were more suitable for early establishment compared to the heavy gault clay in 1988 at Burgate. N uptake as nitrate and ammonium ions by the root hairs is influenced by soil temperatures especially during early spring, and may vary from year to year because of differing weather conditions (Dilz et al. 1982). Soil temperature is one of the most important factors

affecting early nutrient uptake. However, as it varies with time, depth and season, it is difficult to report the relationship between soil temperature and crop growth concisely in field trials. An outstanding problem when relating soil temperature to crop growth is the lack of information on temperature fluctuation in the top 1-2cm of soils where the vegetative apex of cereals and grasses is situated. Successful establishment and early growth of Axona proceeded at relatively low temperatures in 1989 when biomass production was not curtailed by low soil temperatures during the seedlings establishment. For example, individual plant dry matter (mg) averaged over the drilling systems recorded at the double ridge stage (May 25th and April 29th) varied from 142.6mg in 1988, to 335.0mg in 1989 when the range of soil temperature was lower (4.6 to 7.3^{o}C) than the previous year (8.4 to 12.9^{o}C) Appendix 2.4.

Table 2.38. Number of tillers per plant and the corresponding dry weight at double ridge stage, recorded on 16 days (May 25th) and 21 days (April 29th) after the early N treatment (T1) in 1988 and 1989 respectively, averaged over drilling methods.

N timing.	Rate Of Nitrogen (kg/ha).		
	80	125	170
		1988	
No of tillers /plant.	2.30	2.30	2.24
Dry weight /plant (mg).	146.90	143.30	137.80
		1989	
No of tillers /plant.	4.30	5.40	5.20
Dry weight /plant (mg).	306.30	350.00	348.80

Low soil temperatures (< 5^{o}C) usually increase the soluble N content of plants (Stewart and Larher, 1980), therefore early spring

growth is probably not initially limited by a deficiency of N supply at low temperature. However, in experiments using water culture solutions with Lolium perene L. (Clarkson, Hopper and Jones, 1986) and Hordeum vulgare L. (Macduff and Hopper, 1986) did demonstrate depressed dry matter production at low root temperatures of less than 5°C. The evidence obtained during the second growing season suggested that crop biomass increase was limited to a lesser extent at Olantigh by soil temperature in 1989. More over, for lighter soils which are able to warm up quickly, nutrient uptake is not as seriously affected even when the mean temperature is less than 5°C (Gales, 1983). The lighter soils at lower Orchard are more sensitive to the daily 'saw tooth' fluctuations of air temperature. It is unlikely that similar increases and decreases would have occurred on heavy gault clay site which was used in 1988.

The total numbers of tillers m-2 (Tables 2.13 & 2.15) produced, surviving and total dry weights varied considerably between seasons the latter being higher during 1989. For example, plots drilled using the suffolk coulter gave total dry weights of 605, 521, 507g m-2 and 940, 829, 856g m-2 at anthesis for treatments T1, T2 and T3 in 1988 and 1989 respectively. The corresponding values for the band coulter treatments were 713, 606, 596g m-2 and 1021, 877, 867g m-2 (Tables 2.8 & 2.9). These differences in total dry weight were mainly due to variation in plant population. However it was surprising that individual plant dry weights (Tables 2.10 & 2.11) were higher in 1989 when the summer period was unusually dry (Plate 4). The main contributory factor was probably earlier drilling (February 8th 1989 versus April 13th 1988) which increased dry matter accumulation and number of tillers.

Total dry matter and final grain yields produced in this experiment were less than 70% of those produced by the winter wheat variety-Slejpner during the 1986/87 growing season (Table 3.3 of experiment 2). As the spring wheat growth period is often restricted, the initiation

and development of the vegetative parts and the yield components (number of ears, spikelets and thousand grain weight) are under greater environmental control. This restriction contributes to the lower biomass (5-10t/ha) and final grain yields (5.5t/ha) normally recorded from spring wheat varieties. However, despite these constraints, the distribution of dry matter expressed as the ratio between grain and total above ground dry weight (harvest index) obtained from Axona was higher than the winter variety (slejpner) grown in 1986/87. Harvest indices (HI) in experiment 1 ranged from 63.1% to 68.0% and 54.9% to 66.4% with the timing of N treatments T1 to T3 in 1988 and 1989 respectively. The winter variety on the other hand, recorded a range of 52.3% to 56.4% within the four N treatment levels applied (Table 3.19 experiment 2).

The longer growth and development period associated with high input winter wheat crops may result in excessive production of dry matter caused by high numbers of tillers (about 20,000 m-2) and increased leaf area index. The increase in above ground dry weight, reduces the ratio between grain yield and total biological yield (HI). Jenkins, Payne and Sharp (1987) noted that on a national average in the UK, spring wheat grain yields were 76% of winter wheats in treated trials and 80% in untreated. However, harvest indices are often lower in winter wheat varieties compared to spring grown. Data presented in experiments 1 and 2 on grain yields and harvest indices support this argument. They also added that yield variations between spring and winter wheat varieties was largely due to the lower plant breeding efforts on the former crop. Wibberly (1984) noted that the crop had neither justified nor received as much breeding effort as devoted to winter varieties. He reported that, spring wheat was considerably more sensitive to climate than either winter wheat or spring barley, attributed in part to the relatively shorter growth period, and restricted plant breeding efforts for the crop.

2.4.1.3.Tillering.

The results of this experiment demonstrated that the response to timing and amounts of N for spring varieties was different in many respects to reported responses obtained for many winter varieties grown in the United Kingdom. Nevertheless, there were some important similarities. For example, the numbers of tillers m-2 and tillers per plant increased (NS) with N application at GS12-13 and GS14 in 1988 and 1989 respectively (Tables 2.13, 2.14, 2.15 & 2.16). It is quite reasonable to assume that observed treatment differences in tiller production were the consequence of greater amounts of N in the soil after the early application of N (T1). Application at these stages (GS12-13 & GS14) in 1988 and 1989 respectively, which increased tillers also influenced the total dry matter of the crop (Tables 2.8 & 2.9). Masle-Meynard (1981) showed that, the production of tillers by wheat which resulted in a higher dry matter production was dependent not simply on plant population, i.e competition, but also on the supply of N to the young plants. Darwinkel (1983) supported this, and described an increase in dry matter yield resulting from an early N application before tillering. The results from this experiment agree with those reported by these authors.

The mean number of tillers per plant increased to a maximum of 3 and 6 with the early N treatments in 1988 and 1989 respectively (Tables 2.14 & 2.16). Tillers declined gradually during the vegetative phase of growth. By anthesis, the number of reproductive tillers surviving was reduced to an average of about 2 tillers per plant (Tables 2.14 & 2.16). Numerous studies have shown that the application of N during the tillering phase almost invariably results in an increased emergence of tillers and vegetative growth. However, this does not always result in an increase in final grain yield. For example, tillers still growing during stem extension compete vigorously for the mineral N in the top

15-20cm soil layer (Needham, 1982). Their root system may rapidly exhaust the soil supply before they extend to deeper layers in the soil profiles. Growth may then be retarded by nutrient deficiency. Tiller senescence will occur due to inadeqaute N uptake into their leaves which can result in the re-mobilisation of the stored carbohydrates (Spiertz and De Vos, 1983). Thus, tiller death occurs if no supplementary N is applied to the crop during this period (GS32).

Table 2.39. Effect of N levels on tiller survival.

N levels (kg/ha)	1988	(% loss)	1989	(% loss)
80	401.8	45.7	427.5	77.1
125	409.2	44.1	445.4	74.0
170	415.0	44.0	487.0	72.4

In experiment 1, the percentage tiller loss was generally lower in 1988 probably due to the low plant population which may have influenced tiller survival. Even then the number of tillers which survived and produced ears were less than 50% and 30% in 1988 and 1989 respectively.

Nitrogen treatments have many effects on crop structure. Probably the most important and consistent are the effects on tiller emergence and survival. For example, at the optimum tillering stage (H4) in 1988, the mean numbers of tillers m-2 recorded from the early N treatments were 759.7 and 814.3 in the suffolk and band coulters treatments. The corresponding number of ears m-2 at anthesis were 409.6 and 487.9 (Table 2.13). Similarly in 1989, the number of tillers m-2 on April 29th (optimum tillering stage) and those that survived and produced ears were 1632.4, 1946.8 and 467.3, 502.7 respectively (Table 2.15). The percentage number of surviving reproductive tillers at anthesis was higher in 1988. When averaged, the survived tillers amounted to about 60% compared to 30% in the following season. The extremely dry month of May 1989 which had a mean total rainfall of only 1.3mm and a

corresponding high soil temperature of 13.30°C (Appendix 2.4) must have contributed to this enormous tiller loss. Low precipitation at this period (GS32) would have affected plant nutrient uptake from the soil. This may have resulted in an accelerated movement of storage carbohydrates and proteins from the vegetative parts in order to maintain root:shoot ratios (Macduff, Hopper and Wild, 1987). This has been shown to cause leaf senescence and tiller death due to the reduction in the photosynthetic activity of the leaves (Plate 4). In a glasshouse experiment using spring barley Power et al. (1970) reported a decrease in the number of tillers from 3.6 to 1.7 per plant as soil temperature was increased within the range 9-22°C.

Due to crop and sampling variability, the measurements recorded in experiment 1 did not always give consistent results. Even with careful growth analysis, co-efficients of variation sometimes exceeded 15%, so that possible treatment differences may not have been reliably detected. Because of the shorter growth and developmental period associated with spring varieties, the rates and time of application of N did not result in a consistent significant effect throughout the period of crop growth analysis. Normally tiller development and survival are increased by N treatments especially with winter varieties, since the latter have a longer duration period of growth and development. In spring varieties, the number of tillers produced is usually less than the potential even under high fertility conditions being contained by the shorter life cycle. Many writers have reported that increased tiller production is associated with early drilling. For example, the numbers of tillers m-2 of Axona drilled in February (Experiment 1) and April (data from the adjacent trial) during the extra ordinary dry season of 1989 taken at a similar growth stage (GS25-29) were 1424 and 777 respectively (Appendix 2.2). This agrees with the suggestion that early drilling influence tiller production. In experiments with winter wheat, Baker and Gallagher (1983); Kirby, Appleyard and Fellows (1985b); Kirby et al. (1987)

reported that drilling in the month of September gave a higher numbers of tillers m-2 compared to drilling in October.

Treatments with N at GS12-13 or GS14 caused earlier tillering (about 4 days), thus, more tillers (NS) were produced than those treated at GS30 and GS32 (Tables 2.13 & 2.15). Ear formation from additional reproductive tillers resulted in higher grain yields for the winter wheat cultivars Arminda, Caribo and Okapi (Darwinkel, 1983). This was also achieved in experiment 1 during the 1988 growing season. The application of N at GS12-13 which influenced tiller production and survival resulted in a higher grain yield at harvest. Grain yield was increased (NS) by 0.3t and 0.7t/ha in the low population corresponding to the suffolk and band coulters. Similarly in the high population, the yield was increased by 0.9t and 0.2t/ha. The increase was significant ($P<0.05$) in the suffolk coulter treatment. However, the same pattern was not detected the following year. During this drier season, grain yield was decreased in each of the drilling methods by 0.3t/ha with the early N treatment when compared with the late application at GS32 (Table 2.27). This decrease was associated with fewer grains per ear as well as lower thousand grain weight (Tables 2.23 & 2.26).

It is generally accepted that tillering enables winter wheat to compensate early in the season for low plant population, crop damage or to recover from late drilling stresses that depress plant or early tiller numbers. When early winter conditions are harsh reproductive tiller bud initiation is very slow. Thus the final number of ears may remain low, even after N has been applied because tillering in the later spring cannot compensate for earlier environmental restrictions on reproductive development (Darwinkel, 1978; Nerson, 1980).

2.4.1.4.Flag leaf area.

Visual observations indicated that, the leaves were smaller in length when application of N was delayed. Evidence to confirm this was obtained from area measurements carried out on the flag leaves (Table 2.17). At anthesis, the leaf areas averaged over the three N levels and drilling systems were 35.9cm2, 31.3cm2 and 26.7cm2 for the treatments T1, T2 and T3 respectively. It is important to note however that the procedure employed to ascertain flag leaf area measurements was not precise (page 66). The error associated with the method adopted is likely to over estimate the area of the leaf. Nevertheless, it is clear from Tables 2.17 and 2.18 that the early treatment of N resulted in a significant increase ($P<0.05$) in flag leaf area as well as dry weight.

Grain yield has been shown in many studies to be positively related to the flag leaf area which is the morphological character showing the closest association with grain yields of cereals (Ellen, 1987; Hay and Walker, 1989). Data on this relationship obtained in 1988 also revealed a positive relationship with the final grain yield. Early N application (T1) resulted in an increase in flag leaf area of 9.2cm2 compared to the T3 treatment. This gave an additional grain yield of 0.5t/ha with the former over the latter. This effect of flag leaf area on grain yield might have been due to its effect on grain survival. Inncrease in flag leaf area from 26.7cm2 to 35.9cm2 increased the number of grains per ear from 35.0 to 36.7 (Table 2.40).

The main factor responsible for the recommencement of leaf growth and expansion is early N absorption from the soil solution (Pearman, Thomas and Thorne, 1977 & 1978). In this experiment, treatment with N fertilizer at an early growth stage (GS12-13) accelerated dry matter increase (Table 2.8) and the expansion of the leaves. Gales (1983) also demonstrated that N applied early (GS20-25) enhanced leaf expansion, the date of canopy cover and increased rate of solar radiation interception.

However, the rate of N had no significant effect on flag leaf area and its dry weight (Tables 2.17 & 2.18). These results do suggest that for spring cereals, that N timing is much more important than level. This may not be true for winter cereals where the time lapse between growth stages is longer. The problem in practice is to achieve application at the correct growth stage. The period between stem initiation and elongation may be very short under field conditions especially when spring cereals are drilled during April.

2.4.1.5.Yield components.

Cereal grain yield depends upon the following yield components: the numbers of ears m-2, numbers of spikelets per ear, number of grains per ear and the thousand grain weight. The use of yield components in crop production has allowed calculations to be made of a potential crop yield. However, yields estimated from these components are rarely parallel with the final combine yield (McLaren, 1981). The primary objective of agronomic trials such as experiment 1, is to determine the optimum amount and time of application of N fertilizer which would influence the production and survival of such components. Results of this experiment showed that it is possible to obtain an increase in the number of ears in different seasons using similar treatments combinations although final grain yield may vary from one season to another.

Table 2.40. Effect of time of application of N on the yield components of Axona during 1988 and 1989 (averaged over drilling systems).

Yield components.	1988			1989		
	Nitrogen timing.					
	T1	T2	T3	T1	T2	T3
Ears m-2	486	431	394	500	446	438
S./ear (total).	19.6	19.4	19.3	20.5	20.2	20.1
S./ear (fertile).	17.1	16.8	16.9	16.9	17.2	17.1
Grains/ear.	36.7	35.6	35.0	28.5	31.0	31.5
TGW (g).	39.2	42.1	43.4	38.9	41.7	41.9

For example, the positive relationships between the number of ears m-2, number of grains per ear and the final grain yield in 1988 were not found during the following year (Figures 2.4 & 2.5). Also, despite the consistent increase in the number of ears per m-2 with the early N treatment, the converse was the case with final grain yield (Tables 2.40 & 2.27). In 1989 the final grain yield was associated with lower numbers of ears m-2 (Tables 2.27 & 2.40). This variation can be explained on the grounds that yield components are mutually compensating. Thus, a decrease in one is offset at least partly by an increase in another (Gallagher et al., 1975; Gales, 1983). For example, the decrease in the number of ears m-2 with the late N treatments T2 and T3 in 1989 was compensated for by the increase in the number of grains per ear and the thousand grain weight. Relationship between these yield components is briefly summarised in Table 2.40.

A linear relationship between grain yield and the number of ears m-2 has been demonstrated using controlled environment and field studies (Willey and Holliday, 1971; Fischer et al., 1977). Experimental data for 1989 were not in agreement with this simple relationship (Figure 2.5). During this dry season the number of grains per ear and grain weight were the principal determinants of yield and of these components, the former was more variable between seasons.

The number of spikelets per ear was not affected significantly by the treatments (Table 2.22). The small sample size and the sample variability might have precluded the detection of any small differences that might have occurred between treatments. Initiation of spikelets in wheat is established at very early stages of ear development. The rate of plant development during this stage depends upon a range of environmental conditions. Many of these influence spikelet initiation. For example day length (short days) or low temperature enhance the number of spikelets. This also induces vernalization in winter cereals, however, this is not required in spring varieties. Thus, it is important to note that the longer the period available for crop development, for example, due to early sowing or resulting from the early cool season temperatures, the higher will be the potential yield. Kirby and Ellis, (1980); Ellis and Kirby, (1980) reported an increased yield in spring barley due to lower air temperature (differences of 1-3^{o}C) grown at sites 4^{o} latitude apart (Cambridge, England, 52^{o} 11'N and Edinburgh, Scotland, 53^{o} 53'N). Therefore, variations in each of these environmental factors can have a profound influence on ear development. However, it is not possible to present an accurate and detailed interpretation of environmental interactions and their effects on the yield components using the present field data.

Differences in number of spikelets between winter and spring wheat can be associated with their rate of initiation and subsequent development (Darwinkel, tenHag and Kuizenga, 1977). Ellis and Kirby (1980) reported an increase in the number of spikelets in spring barley when they were initiated more slowly and over a longer period, presumably because there was then reduced competition for assimilates between the main-stem apex and the tiller buds. In 1989, the total number of spikelets was higher than 1988 (Table 2.22). This increase could be attributed to the longer period (March to April) of ear development caused by the early drilling. Hence, it may be inferred

that, the corresponding low number of grains per ear (30.3, averaged over timing) in 1989 was probably due to fewer number of grains per fertile spikelet (1.8).

Interest in the timing of N fertilizer has been very much influenced by its effects on crop structure and the final grain quality and yield. Grain yield variations due to differences in timing of N in this experiment were brought about by limitations in the number of grains per ear. A rise in number of grains in both seasons resulted in an increase in grain yield (Tables 2.23 & 2.27). The increase with late N application in 1989 was mainly attributed to the number of grains per ear and grain weight. This agrees with the view that under very sunny high temperature conditions such as those experienced in 1989 (Appendix 2.4) the number of grains per unit ground area is a major component of grain yield (Biscoe and Gallagher, 1977). Hence the lower number of ears was compensated for by the number of grains per ear and the thousand grain weight.

The factors influencing grain set and survival are probably the most important determinants of yield. Under the dry field conditions of 1989 water stress prior to grain set in May (Appendix 2.4) might have occurred. This could help to explain the decrease in grain yield with early N treatment caused by low nutrient uptake. Although N supply may not affect floret initiation (Whingwiri and Stern, 1982), the setting of grains is largely dependent on N supply from the soil. Dilz *et al.* (1982), reported that early applied N as N-15 at GS25 was less mobilisable than when given to plants at successive growth stages in culture solution. In another experiment, he reported that N taken up at an early growth stage (GS21) is less translocated from the vegetative parts to the grains than N taken up later. This means that weather and soil conditions are especially important during the period before, and possibly for several days after anthesis.

Because in 1988, soil conditions before the grain set were quite favourable (Appendix 2.4) the number of grains per ear were higher in the T1 treatment (36.7) compared to treatments T2 and T3 (35.6 and 35.0), even though N fertilizer was applied earlier (GS12-13). This increase in the number of grain per ear boosted the final grain yield (Table 2.27). In the following year however, due to the unfavourable and unusually dry period prior to, and after anthesis the converse was true. This means that in a drought year such as experienced in 1989, early N application may not result in an increase in grain yield.

The relationship between number of grains and grain yield showed that, yield was limited by the number of grains per ear (Tables 2.23 & 2.27). Similar results were reported by Evans (1972). In a review of literature, Gales (1983) reported that, in field crops N timing usually has a much more greater effect on the number of ears per unit area than on the number of grains per ear. This is in agreement with the results of experiment 1 in which the number of ears m-2 were consistently increased with early timing of N, whilst the number of grains varied from one season to another. In an experiment on 25 lines of wheat in New Zealand, Easton and Clement (1972) reported a consistent increase in the number of ears m-2 with the time of application of N, but the effect on the number of grains per ear were unpredictable.

The mean numbers of grains per ear were less (by about 4.0 grains) in 1989. This was most likely due to floret abortion caused by water stress and high temperature during the second growing season (Appendix 2.4). Water stress and high temperature at anthesis are known to affect grain set and survival (Gales, 1983). The same author also reported that, soil temperature differences of 2 or 3^{o}C can significantly affect crop yield by reducing the number of grains per ear. Low water potential during the stages of floral initiation can decrease the number of grains per ear (Fischer, 1973; Day, Legg, French, Johnston, Lawlor and Jeffers,

1978). Another possible reason for the lower number of grains in 1989 might have been due to lack of grain set in the upper florets. Rawson and Evans (1970) reported that, grain set in the upper florets may be inhibited by the rapid growth of grains in the lower florets. This is in agreement with the 1989 growing season, which recorded a relatively higher grain growth rate 1.32mg versus 1.29mg/grain/day in 1988. In addition, the duration of grain fill was also shorter hence a lower (NS) thousand grain weight resulted.

The general response of the crops to temperature after anthesis showed a pattern of grain filling (Table 2.24) similar to those found by various studies which examined the effects of varying temperatures on grain growth in phytotron experiments by Sofield et al., 1974; Spiertz, 1974; Ford and Thorne, 1975; Warrington et al., 1977. The pattern in spring cereals is often characterised by the absence of an initial lag period. The average grain growth rates during the linear phase of grain filling (days 9 to 34) in 1988, were 1.25, 1.27 and 1.37mg/grain/day. The corresponding values for the 1989 growing season (days 10 to 28), were 1.26, 1.37 and 1.32mg/grain/day for the T1, T2 and T3 respectively. These figures are much lower than the 2mg/day quoted by Evans and Wardlaw (1976) for the winter variety Maris Huntsman. In two separate experiments, Meredith and Jenkins (1976) working in New Zealand and Galagher et al. (1976) in England, reported grain growth rates of 2.60 and 2.11mg/day during 11 days and 14 days respectively using the same winter wheat variety.

Grain weight was influenced by the growing conditions after anthesis. Thus, differences in grain size occurred between seasons. Although there were differences in the duration of the grain filling periods, the final thousand grain weights at harvest were not significantly different between seasons (Table 2.26). Probably as a result of the higher levels of radiation under field condition compared

to phytotron conditions (Spiertz and Ellen, 1978). Also, the fewer number of grains per ear in 1989 might have reduced competition for assimilates between grains. Reduction in the number of grains per ear resulted in an increased grain weight (Darwinkel, 1978). However, in the April drilled crop thousand grain weight was lower (36.1g) despite lower number of grains per ear (18.8). This again emphasised the advantage of early drilling in overcoming environmental stresses such as high temperature and low soil moisture under field conditions. Thus, the increase in thousand grain weight obtained in 1989 from the February sown crop may have resulted from earlier drilling.

In order to make meaningful seasonal comparisons in agronomic trials, it is wise to plan identical husbandry practices in both seasons. For example, the 1989 trial should have been drilled on the lighter soil in April for comparative purposes. However, such planning is normally affected by unpredictable UK weather conditions. Hence, field operations especially for postgraduate studies are strictly controlled by the prevailing climate. The second trial was sown in February 1989 because later weather conditions may have eliminated a comparative April sowing date.

During the period of this study in 1989, another postgraduate experiment was designed to study the effects of different sowing dates on the growth, development and yield of spring wheat. The variety was the same Axona and both trials were adjacent and on the same site having similar plant populations. The plots were treated with 80kg/haN in two split application at GS25 and GS45-49. The experimental details have been summarised in Appendix 2.2. The fourth sowing date (S4) is especially helpful because it was similar to the drilling date used in 1988 (April 13th). Therefore, in this section and other subsequent sections references will be made to this treatment for the purpose of comparison with the main trial drilled in February of the same year.

The mean values of total biomass (g m-2) at anthesis, crop growth rate (g m-2/day), thousand grain weight, number of grains per ear and the final grain yield for the April and February drilled crops in 1988 and 1989 are summarised in Table 2.41. Data source for the April 14th, 1989 drilling is given in Appendix 2.2. This has been included in order to emphasise the advantages that may be gained from early sowing, especially when growing seasons are hot and dry.

The total biomass m-2 given by the April drilling in 1989 was 587.0g as compared to 635.1g and 858.9g for the April and February sowings in 1988 and 1989 respectively. However, crop growth rate was not seriously affected by the late drilling in 1989, probably due to the high temperatures. The growth rates from stem extension to booting (GS30-49) and ear emergence to anthesis (GS51-60) were 15.1 and 18.9gm-2/day. These values are greater than those obtained from the April sown crop in 1988 (12.9 and 16.5gm-2/day), but similar to those recorded from the February drilling in 1989 (19.9 and 14.1gm-2/day). However, the extremely dry summer period experienced in 1989 affected the reproductive performance of the April drilled crop.

Table 2.41. Total biomass at anthesis (g m-2), crop growth rates (g m-2/day), thousand grain weight (g) numbers of grains per ear and final grain yield (t/ha) for April and February sown crop in 1988 and 1989.

Parameters.	Sowing dates.		
	13:4:88	14:4:89	8:2:89
TDM (g m-2)	635.1	587.0	858.9
CGR (gm-2/day)			
GS30-49	12.9	15.1	19.9
GS51-60	16.5	18.9	14.1
TGW (g)	41.4	36.1	41.5
Grains/ear	33.8	18.8	30.1
Grain yield (t/ha)	5.2	1.8	5.4

Grain yields varied from 5.2t/ha to only 1.8t/ha for the April drilled crops in 1988 and 1989 respectively (Table 2.41). Low rainfall

during the month of May (1.3mm in 1989 versus 72.8mm in 1988) must have affected early nutrient uptake by the seedlings which in turn influenced the initiation and expansion of the tillers which are the main contributory features to crop biomass and final grain yield. Frank and Bauer (1982) reported a reduction in the number of spikelets from 18.6 to 14.8, and the number of grains from 21.6 to 20.2 when the air temperature was increased from 10^{o}C to 18.0^{o}C in the spring wheat variety 'Sinton'. The results in Table 2.41 suport these findings. The numbers of grains per ear varied from 33.8 in 1988 to 18.8 (April drilling) in 1989.

The lower (36.1g) thousand grain weight recorded for the April sown crop in 1989 clearly indicates the weather stresses, which are summarised in Appendix 2.4. High mean temperatures for the months of July and August (23.8 and 22.2^{o}C) reduced the grain filling period, which varied from 40 to 30 days for the February and April sown crops respectively. Grain filling is more dependent on the supply of assimilates from leaves and stems, especially when nutrient uptake is restricted by drought conditions (Spiertz and Ellen, 1978; Gales, 1983). Spiertz (1977) reported that a decrease in N concentration in the flag leaf from 3.8% to 0.8% in a spring wheat variety 'Orca' due to temperature increase in the range of 10^{o}C to 20^{o}C.

Although the additional postgraduate trial results mentioned above were not an integral part of the main experiment, it is important to point out at this juncture how the earlier February drilling was able to overcome the adverse effect of the harsh growing season experienced in 1989. Thus, if drilling had been delayed in the second year so as to be in line with that of the previous year the results obtained would have been similar to those given by the 1989 April drilled crop. It is noteworthy therefore that by chance, the seeds were drilled earlier in 1989, this helped to escape the unique, hot and dry summer. By drilling

earlier the plants were able to develop a rooting system that could absorb nutrients below the normal zone of root concetration (30cm). More over the entire growing season was 7 months (February-August) compared to the April drilling which was only 5 months (April-August).

2.4.2.Grain Quality.

Wheat grain quality is not a discrete entity, but an expression of a range of grain characteristics dictated by market outlets. Consequently grain for 'off farm' sales has to meet the buyers specifications in relation to certain parameters, such as milling charateristics, protein content, Hagberg falling number, specific weight and the grain moisture content. These have been already mentioned in the literature review (section 1.4). Whilst Hagberg falling number is weather dependent, grain crude protein content and specific weight are characteristics which in addition to yield are influenced by N rate and the timing of its application. In this experiment, protein and Hagberg falling number were studied in detail during 1988 and 1989. Grain size determined by the thousand grain weight (g) was used as an attribute of grain quality ("plumpness"), since specific weight (kg/hl) measured volume weight, frequently used by millers was not measured in this study. Shuey and Gilles (1972) reported a positive correlation (r=0.95) between thousand grain weight and flour yield. Thus, grain size as well as quality is an important attribute of wheat grain quality.

Homegrown wheat from selected varieties, such as Avalon, Mercia, Alexandria, Axona and Tonic with grain protein contents of 11% or greater are suitable for inclusion in the grists of breadmaking flour. In recognition of this, the variety Axona was chosen for these trials. For the purpose of making a UK standard white sliced loaf (weighing 800g), a minimum protein level in the flour of 11.5% at 14% grain moisture content is required. Millers use a quick method to test grain

protein before milling into flour. InfraAlyser - "Technicon 400 Autoanalyser" is used to measure grain protein content. Details of the procedure have been described in materials and methods (pages 67-68). It is believed that protein molecules absorb specific wave length of near-infra red radiation, and by scanning the ground sample, the amount of radiation reflected back to the detector is measured (Allied Mills, personal communication).

2.4.2.1.Protein Content.

The main factor enhancing grain protein content is the uptake of N by the wheat plant. Correct N application at the appropriate stage of growth is therefore important. However, many writers including Dampney (1987); Sylvester-Bradley et al. (1987) have argued that N applied too late, for example, after anthesis especially in the form of urea may not be converted into grain protein.

Results of this experiment indicated a consistent rise in percentage grain protein with delayed application (Table 2.42). For example, when plots were treated with 80kg/haN in 1988 protein was increased from 11.1% (T1) to 12.8% (T3) Table 2.42. Whilst in the second drier season it increased from 10.6% (T1) to 12.1% (T3). The decrease in grain protein content in 1989, was probably linked to the shorter duration of grain filling. Maximum values varied from 14.3% to 13.7% for treatment N3T3 in 1988 and 1989 respectivly (Table 2.42). Lord and Vaughan (1987) working with malting barley variety 'Maris Otter' reported variations in grain protein due to differences in seasonal weather but, failed to identify the environmental factor responsible for this differential in the response of grain protein. A reduction in photosynthesis as a result of early leaf senescence in 1989 due to high temperatures (Plate 4) may have affected the amount of stored protein in leaves, especially the flag leaf and stems. Under normal growth

condition about 75% of the N translocated into the grains as protein is from the leaves and stems (Gregory Marshall and Biscoe, 1981). Thus, any factor that affects the amount of stored protein in the flag leaves and stems during grain filling would definitely affect protein deposition.

The uptake of soil and fertilizer N must have been adversely affected by the severe drought in 1989, although no N measurements were taken from the dry matter samples in order to confirm this. However, some evidence is provided by the fact that dry matter yields and crop growth rates were not affected (Table 2.9 & 2.12) whilst in 1988 a significant increase in dry matter was recorded with the early N treatment. Probably due to available soil moisture which influenced the N uptake by the crop. Reduced N uptake caused by lack of rainfall after the N treatments had been applied contributed to the lower mean grain protein in 1989. N uptake by the crop is affected by rooting depth, and by the duration of root activity (Spiertz and De Vos, 1983). In experiments with two spring wheat varieties 'Ciano' and 'Era', treated with 272kg/haN, Power and Alessi (1979) working in America, reported an increase in grain protein from 13.7% to 16.0% when crops were drilled on May 30th compared to April the 30th. Therefore, the increase in protein content in 1988 may have been associated with the later drilling (April 13th). However, this advantage of increased grain protein was offset by slightly lower grain yields (Table 2.41).

Table 2.42. Percentage protein (%N x 5.7 at 14% m.c), averaged over drilling systems.

N Timing.	Rate Of Nitrogen (kg/ha).		
	80	125	170
		1988	
T1	11.1	11.9	11.8
T2	12.0	12.6	13.4
T3	12.8	13.8	14.3
		1989	
T1	10.6	11.8	12.6
T2	12.0	12.9	13.6
T3	12.1	13.0	13.7

The grain protein response from the N treatments differed during the two seasons. For example, in 1988, the more dominant factor was the time of application, whilst in 1989 similar grain proteins were achieved by the T2 and T3 treatments (Table 2.42). In the first year the highest grain protein was recorded in treatment T3. During 1989, this treatment only resulted in a 0.1% increase compared to T2. Corresponding increases in the first year were 0.8%, 1.2% and 0.9% with N levels 80kg, 125kg and 170kg/haN respectively (Table 2.42).

The unexpected increase in grain yield in 1989 in treatment T3 is likely to have influenced grain protein percentage. Numerous reports have associated decreased protein with dilution from extra starch deposited in the endosperm tissues (Smith, Burn and Bartlett, 1987; Mclean, 1987). Starch is the principal component of yield in cereals and contributes between 60-75% of the final caryopsis weight (Duffus, 1987). However, in this experiment the T3 increase in grain yield (0.3t/ha) was not associated with a decline in protein percentage. As indicated in the previous paragraph, the percent change in this component between the second and third timing was very small (0.1%).

Although protein contents were lower in the second drier year, all but one treatment combination (N1T1) recorded a protein value below the minimum level (11.5%) set by the Intervention Board of Agricultural Produce (IBAP). However, during 1988 this treatment was only 0.4% below the premium standard threshold as compared to 0.9% in 1989 (Table 2.42). This was probably due to inadequate N uptake from the soil under drought conditions. Small amounts of N (60-80kg/ha) applied early in late February or early March have been shown to have little effect on final grain protein concentration (Vaidyanathan, Sylvester-Bradley, Bloom and Murray, 1987). Late applications (around GS32) are generally advised for milling wheat production. However, these data do emphasise that in dry summers this expenditure may not be worthwhile when dry soils prevent nitrate ion uptake.

Maximum grain protein was recorded before physiological maturity had been achieved. For example, in the first year, treatment T3 (170kg/haN at GS32), produced a peak grain crude protein of 16.2% (Figure 2.2). Application at GS12-13 (T1) and GS30 (T2) gave values of 12.9% and 14.9% respectively. However, by harvest time mean grain proteins had declined to 12.5%, 13.3% and 14.4% for the treatments T1, T2 and T3 respectively (Table 2.30). In 1989, just 10 days after anthesis the protein contents were 13.1%, 13.9% and 14.1% when 170kg/haN was applied at T1, T2 and T3. At harvest, the corresponding grain proteins were 12.7%, 13.4% and 13.6% respectively. This decrease in protein during grain filling must have been due to the increasing proportion of starch in the endosperm during grain development. Duffus and Mardoch (1979) reported an increase in starch content from 6% at 14 days to 28% at 56 days in the winter wheat variety Maris Huntsman. Hayward (1987) reported a decline in grain protein from 11.5% to 9.7% when harvesting was delayed by 22 days.

Relatively little is known of the biochemical pathways involved in the synthesis of proteins from nitrogenous fertilizers entering the developing grains. Proteins synthesised during the early stages of cell division and enlargement in wheat grains are mainly enzymes and structural proteins (Duffus, 1987) which are unlikely to become storage proteins at grain maturity, due to their vulnerability to degradation twowards grain maturity (Terce'-Larforgue, Sallantin and Pernollet, 1987).

From these experimental data it remains unclear whether the increase in grain protein caused by delayed application of fertilizer also improved the baking quality of the flour. The inability to carry out baking quality tests has therefore left many economic questions regarding the baking potential of Axona unanswered. It is believed that the value of wheat grains with a high protein content may be offset by insufficient sulphur wich limits the production of methionine and cysteine which are essential for dough elasticity (literature review, page 28). However, this is unlikely to occur in most UK quality wheat, especially those that are produced in the East and the South East England, where sulphur deficiency in soils is rare.

2.4.2.2.Hagberg falling number.

This section discusses the N treatment effects on the falling number. Its method of measurement has been summarised on page 69 (Plate 3). Seasonal effects will also be mentioned because of the environmental differences that were experienced between the two experimental seasons. Millers use the Hagberg falling number test to measure the activities of the enzyme α-amylase present in wheat grains. The higher the number, the lower the α-amylase activity. High α-amylase activity has a deleterious effect on the breadmaking quality. Studies have shown that increasing levels of α-amylase during germination or field sprouting before harvest

may lead to degradation of starch and storage proteins in the endosperm, which in turn may have a profound effect on grain quality (Rule, 1987).

Falling number is a function of varietal characteristics and weather conditions before harvest. However, recent research (Gooding, Kettlwell and Davies, 1986; McDonald and Vaidyanathan, 1987) have reported a linear increase in falling number with increase in the rate of N fertilizer in the cultivars Avalon and Brimstone. In experiment 1, the N treatments did not produce a significant change in the falling number as suggested by the above authors although in 1989 there was a trend of increased (NS) falling number with additional N. Postponing the application of 170kg/haN until T2 or T3 increased (NS) the Hagberg falling number by 14 and 52 units respectively (Table 2.43). However, it is not clear from these data whether this increase occurred as a result of the treatments or due to the background variation in the readings recorded from the falling number apparatus (Plate 3).

It is important to note that Hagberg falling number can vary from one sample to another, or from reading taken on the same sample, even when the procedure for the falling number test are strictly adhered to. This may be caused by a numbers of factors. For example, a change in the sample temperature or the temperature of the distilled water used to mix the flour affects the results. Tests carried out on different days on the same sample may give slightly different results. In this experiment, because of sample numbers (72) it was impossible to perform the test on a single day, hence measurements were taken over two days.

The 1988 growing season produced a mean lower falling number value (354), probably due to the wetter period (19.7mm) 4weeks prior to the harvest in September. However, these Hagberg falling number values were still higher than those reported by McDonald and Vaidyanathan (1987); McDonald (1988) working with the winter wheats Avalon and Brimstone and, spring varieties Alexandria and Tonic. Although the weather before the

1988 harvest was not very wet it is believed that activities of α-amylase can also be influenced by low temperature and high humidity (Hayward, 1987). Thus, the lower night temperatures which ranged from 7.2°C to 11.6°C prior to crop harvest may have adversely influenced the falling number in the first experimental year. Higher (>18%) grain moisture content at harvest (Table 2.28) may also have been a contributory factor since grain moisture contents may influence the activity of the enzyme α-amylase whilst very low (<14%) moisture contents means the embryo in the seed is completely dormant. Hence α-amylase activity is reduced to minimum (Gale, Flintham and Arthur, 1983; Barnes, 1987; Kettlewell, Lawson, Davies and Hocking, 1987).

Scientists suggest that the falling number should be taken from samples completely free from seed admixture. However, this is difficult in field experiments, where harvested grain from different treatments are exposed to contamination by grains from volunteer crops or weeds. Vaiyanathan (1987&1988) reported that, a single grain from the variety Fenman mixed with nineteen grains from another variety Avalon was able to reduce the pure Avalon falling number from 440 to 250.

Due to the above practical problems associated with Hagberg falling number tests, it is not possible to report with a greater degree of scientific accuracy regarding the changes in the falling number given by the data in Table 2.31. The Hagberg falling number test is sufficiently accurate for the milling industry, but is not sufficiently sensitive for detecting small experimental treatment differences in enzyme activity. Nevertheless, there is an indication (NS) when results are averaged over both seasons that the falling number may be increased with additional N (Table 2.43). This confirms the findings of McDonald and Vaidyanthan (1987); McDonald (1988) who reported an increase in the falling number of some winter and spring wheat varieties. The latter author demonstrated that increasing N levels from 80kg/ha to 200kg/ha changed

the falling number from 250 to 380. He then concluded that this increase was due to a delayed in crop development caused by additional N which subsequently resulted in later grain maturity when the summer period was dry.

Table 2.43. Hagberg falling number, averaged over the two seasons.

N Timing.	Rate Of Nitrogen (kg/ha).			
	80	125	170	Mean
T1	374	384	402	387
T2	405	399	409	404 (NS)
T3	393	402	443	413
Mean	391	395	418	

Many writers including Gale, Flintham and Arthur (1983) have reported an increase in α-amylase activity and consequently a decrease in falling number due to a delay in grain drying caused by fungicide treatment using the winter wheat variety Avalon. Gooding, Kettlewell Davies and Hocking (1987) reported that an increase in grain moisture content from 37.0% to 39.6% during harvest reduced the Hagberg falling number of Avalon from 317 to 287. Therefore it is difficult to reconcile the findings of these authors and those reported by McDonald and Vaidyanathan in 1987, since additional N application usually results in an increase grain moisture. However, the lower mean falling number recorded in 1988 (354) may have been associated with the higher (17.6%) grain moisture content at harvest, compared to (448) the second year (10.6%) Table 2.28.

2.4.2.3.Grain Weight.

Specific weight has long been used as an indicator of wheat quality. It is still held in considerable regard by many agencies responsible for grain quality. The International Board for Agricultural

Produce (IBAP) list specific weight as one of several quality characters, and the Home Grown Cereal Authority (HGCA) records specific weight in its annual publications on the quality of wheat and barley.

Specific weight may be influenced by many factors, for example grain shape and density, both of which are determined by the grain filling processes which is affected by environmental and agronomic conditions present after anthesis. In experiment 1, specific weight was not assessed, but a related measurement of grain quality and size was achieved using thousand grain weight. This is a more accurate and scientific method for comparing different treatments. The specific weight is less accurate because all samples cannot be equally and accurately pressed inside the 'volume' container.

The time of application of N influenced grain size significantly ($P<0.05$). Although some differences occurred between the seasons, postponing N treatment until T3 gave the highest thousand grain weight (Table 2.44). Also, thousand grain weight given by the T2 treatment was greater than T1. For example, in 1988 the thousand weight grain recorded from the T1, T2 and T3 treatments were 39.2g, 42.0g and 43.3g respectively. Corresponding values in 1989 were 38.8g, 41.7g and 41.7g. However, the weight given by the T2 and T3 treatments in 1989 were the same compared to the difference of 1.3g in the first year Table 2.44. This was most probably due to a lack of rainfall after N application at T2 (GS30), which resulted in the late treatments (T2 and T3) behaving as if they were applied at the same time. This is true with other variables given by these treatments, for example grain yields and protein content given by the T2 and T3 treatments did not differ significantly from each other (Tables 2.27 & 2.42).

Table 2.44. Thousand grain weight (g) averaged over the drilling systems.

Year.	Treatments.								
	N1T1	N1T2	N1T3	N2T1	N2T2	N2T3	N3T1	N3T2	N3T3
1988	39.6	41.9	43.4	39.4	42.0	43.5	38.8	42.1	43.5
1989	40.1	42.2	42.2	38.5	41.7	42.1	37.8	41.2	41.3

Neither the drilling methods nor the levels of N had any significant effect on the size of the grains. However, a decrease (NS) in grain weight was recorded with additional N (Table 2.44). This decrease was relatively small compared to those obtained in the winter wheat variety-slejpner grown in 1986/87 at Olantigh (Experiment 2) which tested N levels from 0kg/ha to 250kg/ha (Table 3.16). Gallagher, Doyle and Dilworth (1987) reported a decrease in thousand grain weight in the winter wheat variety-Norman. He associated this decrease with an increase in the other yield components, such as the number of ears m-2, number of spikelets per ear and the number of grains per ear. This resulted in competitions amongst the yield components which consequently caused a reduction in grain size. In spring wheat varieties, the components of yield are less likely to be increased significantly by N application therefore the competition between individual components is minimised. Although thousand grain weight was slightly decreased by the levels of N, this was partially offset by the delay in its application until T2 or T3 (Table 2.44). However this occurred only in 1988 probably due to a longer period of grain growth influenced by low temperature (19.0^{o}C) and soil moisture resulting from sufficient rainfall in July (71.2mm).

In spite of the hot and dry summer (Appendix 2.4) during the grain filling period in 1989, the average grain weight was surprisingly not significantly affected. This was due to the longer growth period (7 months) of the crop caused by the early drilling. Drilling earlier

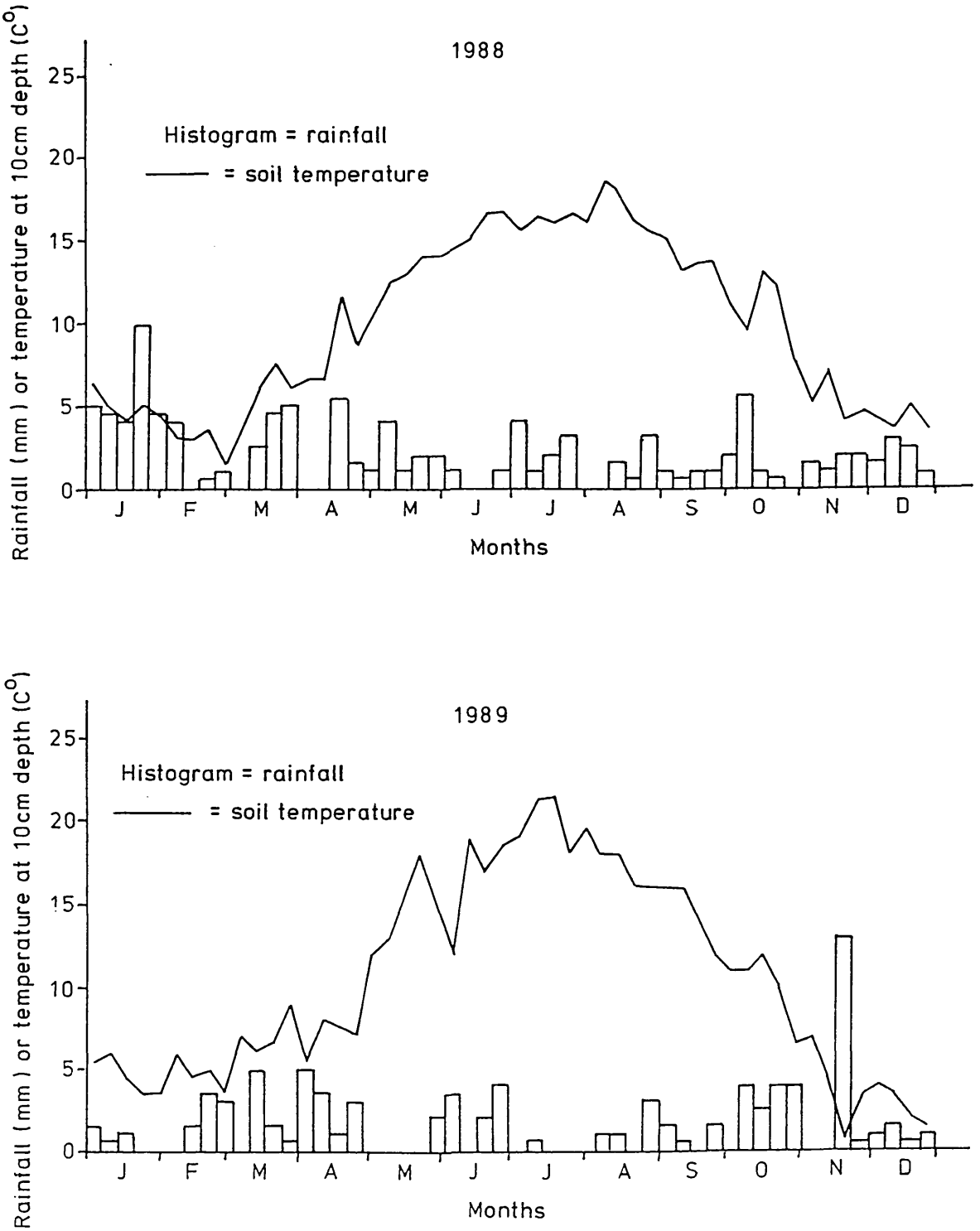
influenced dry matter accummulation which provided the grains with sufficient assimilates during grain fill. This is confirmed by comparing the thousand grain weights of the 1989 April drilled crop with the main experimental results (see Appendix 2.2). The April drilled crop recorded a thousand grain weight of only 36.1g compared to 41.5g for the earlier sown (February 8th) even though both were treated with 80kg/haN.

The time of N application in wheat has become the subject of contentious debate. Whilst this is of an academic interest, little attention seems to have been paid to the practical implications of the changes of the situations on the consequent N recommendations. In view of the inconsistency of the results described in this experiment, it is very pertiment to pose some doubts on the authenticity of N fertilizer recomendations based on field trials. Most experiments have shown the effects of timing on yield to be comparatively small compared with the effects of total amount of N applied. In this experiment, the amount of N did not produced any significant increase in the numbers of tillers or total dry matter, as suggested by many workers in experimente with winter wheat.

Plate 4. Spring wheat under drought stress in 1989 growing season.



Fig. 2.6 SOIL TEMPERATURE AT 10cm DEPTH AND RAINFALL IN 1988 AND 1989.



SECTION 3.

EFFECTS OF SPATIAL ARRANGEMENT AND RATES OF N ON WINTER WHEAT.

CHAPTER III. EXPERIMENT 2. 1986/87.

Effects of spatial arrangement and rates of N on winter wheat.

3.1.Introduction.

It is important to realise that plant population should be defined not only in terms of the number of plants per unit area (plant density), but also in terms of the arrangement of these plants on the ground (spatial arrangement). Surprisingly, there has been no critical investigation of the effect of spatial arrangement on the yield of the winter wheat crop in the UK. Most research on planting patterns has revolved around changes in the distance between rows while retaining random distribution along rows.

Until recently conventional drills mainly operated on a row width of 18cm. However, research at Kiel University in West Germany, from a journalistic report, (Butterworth Annual Report, 1985) suggested that for every centimetre this is reduced, yield increased by an average of 0.7%. The converse was also true. Therefore, this indicated that the ideal situation would be to broadcast the seeds in an even distribution across the field while retaining the correct planting depth. This could be achieved in practice in wheat using the Amazone Drill with band sowing, fitted over the normal suffolk coulters.

An on-farm demonstration during 1983/84, on the Berkshire Downs showed increases in the yields of spring wheat, up to 19% on some parts of the chalk, using band coulters on an Amazone drill. This broadcasted the seeds evenly and gave a complete crop cover, but, this result was not statistically analysed and documented in a scientific report (Butterworth personal communication).

It was decided therefore, to carry out a winter sown trial at Wye College Research Farm, had the following objectives:

i.whether the claimed drilling advantages could be repeated using winter sown variety. (Experiment 1 investgated the response of the spring variety Axona).

ii.to carryout the trial with different plant populations, fertilizer nitrogen levels, and to find possible drill, density and nitrogen yield interactions.

iii.to explore whether the claimed advantages from the band coulter could have resulted from differences in plant establishment.

iv.an assessment of the performance of individual plants, and plant communities, and how this subsequently influenced the final grain yield, yield components and the total biomass of the crop.

3.2.Materials and methods.

Winter wheat (Triticum aestivum), variety-Slejpner was grown at Wye College Research Farm at Olantigh field, on a calcareous rendzina soil overlying chalk gravel, during the 1986/87 growing season. The experimental design was a split-plot factorial combination of 2 x 3 x 4, in randomisation, with drilling pattern, plant population density and nitrogen levels as the main factors, in four replications. The breakdown of the degrees of freedom (df) of the analysis of variance (ANOVA) for the experimental design is shown in Table 3.1.

All plots received 80kg/ha of phosphatic and potassium fertilizers in the seedbed on October 17th, 1986; 9 days before drilling. Seeds were drilled using an **Amazone Drill** with either a suffolk coulter or band coulter. Details of the experimental treatments are described in Table 3.2.

3.2.1.Crop husbandry.

The site was ploughed and disced, and then harrowed on October 23rd, 1986; three days before the seeds were drilled. Seeds were dressed with the fungicides Baytan before drilling. Laural, a pre-emergence herbicide was sprayed onto the plots at the rate of 5l/ha against Blackgrass (Alopecurus myosuroides) and broadleaved weeds on October 26th, 1986. The weedicide did not produce any injurious effects on the crop. Couchgrass (Elymus repens) emerged later when the crop was in 'boot' on plot numbers 9, 84, 88, 92 and 96. This did not cause any significant yield reduction, when grain yields from these plots were compared with those without couchgrass attack, at the final harvest.

The trial was drilled on October 26th in anticipation of my arrival during early spring 1987. When postgraduate management of the trial commenced in February, 1987, sparse plant establishment were noticed on some areas of the plots which might have probably resulted from the chalky nature of the soil, which affected the performance of the drill.

Plots were sprayed with pp450 (Flutriafol) a fungicide against Septoria tritici and Mildew (Erysiphe graminis) at the rate of 0.97l/ha on June 1, 1987. No severe pest attack occurred throughout the growing season. At anthesis, some rodent or possibly pheasant attack was noted on most of the plots, but this did not cause any significant yield reduction.

3.2.2.Plant sampling.

Plants were sampled at intervals of about two weeks for growth analysis. A first sample was taken before the application of fertilizer nitrogen, to determine a base for subsequent growth analysis. A total of six samples were taken for this purpose. Plants were sampled from an area of 0.5m x 0.5m quadrat on a stepwise basis (Figure 2.1). They were

initially removed from the soil using a spade. Later on, plants were handpulled, making sure no aerial parts were destroyed. Soil was washed from the roots which were stored in the cold room for the subsequent growth analysis. A final sample was taken at plant maturity on August 3rd, 1987. Non-sampled plot areas of 21.6m2 were combine-harvested on August 21st, 1987.

3.2.3.Plant analysis.

Plants were separated and then counted. A plant whose roots were destroyed was not scored, but kept separately for inclusion in the number of tillers per unit area. Each sample was counted for number of plants m-2, number of tillers m-2 and number of both live and dead tillers per plant. At ear emergence, the number of ears per plant and potential spikelets were recorded. Roots were removed, and the vegetative parts were dried in an oven at a temperature of 80^{o}C for 48hrs; and then weighed. Leaf area was estimated for the flag leaves at booting and at anthesis, by a simple measurements of length x breadth. Grain development was monitored from the medium density, starting from the begining of grain filling to maturity. Samples were taken at an intervals of less than one week for this purpose. Crop biomass was also studied to relate it with the grain filling.

At maturity plants were analysed for total number of ears m-2, number of spikelets which bore grains per ear, and the final plant height. Shoots were separated into ears and straw, dried in the oven at a temperature of 80^{o}C for a period of 48hrs and then weighed.

3.2.4.Thousand grain weight.

Two separate batches of 500g of seeds were taken and the dry weight converted to 14% moisture contents. A representative sample ranging from 3000 to 4000 seeds were counted using the Decca Radar Limited (Type

120CA) seed counter and then weighed. Thousand grain weight was then calculated.

Table 3.1. Skeleton analysis of variance (ANOVA).

Sources of variation	df	ss	ms	vr.
BLOCK STRATUM.	3			
BLOCKS.PLOTS STRATUM.				
Drill	1			
Density	2			
Drill x Density	2			
Residual (a)	15			
Main plots total	23			
BLOCK.PLOTS.SUBPLOTS STRATUM.				
Nitrogen	3			
Drill x Nitrogen	3			
Density x Nitrogen	6			
Drill x Density x Nitrogen	6			
Residual (b)	54			
Subplots total	72			
GRAND TOTAL	95			

3.2.5.Rainfall and temperature.

Rainfall was satisfactory for the first three months of the growing season (October-December), the total monthly rainfall during these periods ranged from 74mm to 101.10mm. Rainfall decreased from January to March, with the total monthly rainfall ranging from 22.30mm to 55.50mm. There was also low precipitation during the active growth stage (GS31-45) and later at grain filling. Total monthly rainfall at these periods (April-June) ranged from 31.60mm to 67.50mm. A heavy rainfall was recorded towards the end of the grain filling period in July, with a total monthly rainfall of 124.20mm. The winter for the 1986/87 was severe, with a long duration of snow cover. Mean minimum and maximum temperatures for the month of January 1987, were -2 and 2.38^{o}C respectively. This resulted in some plant mortality which was later recorded during the post-winter plant count.

Table 3.2. Experimental details in 1986/87.

Previous crop	Spring Oats.
Soil type	Calcareous loam over chalk. pH = 8.3.
Date drilled	October 26, 1986.
Seed rate	Three seeding rates of low, medium and high.
Low	95.16kg/ha - 200seeds m-2.
Medium	166.53kg/ha - 350seeds m-2.
High	237.90kg/ha - 500seeds m-2.
Plots size	3m x 12m.
Fertilizer nitrogen	Nil,100kg/ha,175kg/ha and 250kg/ha (N0, N1, N2 & N3).
Date of fertilizer split application and the amount applied.	
First application	March 19, 1987. 144days after drilling. ZGS25. 33.3% of the total amount.
Second application.	April 28, 1987. 183days after drilling. ZGS30. 50% of the total amount.
Third application	May 13, 1987. 199days after drilling. ZGS32. 16.7% of the total amount.

3.3.Results.

3.3.1.Total dry matter.

Total dry weight was measured from March the 16th, to plant maturity. Tables 3.3 and 3.4 show total dry weight m-2 and dry weight per plant. Total biomass was higher with the band coulter ($p<0.05$).

Dry matter yield with the suffolk coulter at low density was 18.7g m-2 on the first sampling date (16th March). At plant maturity, the total weights recorded were 988.4, 1492.0, 1391.6 and 1608.8g m-2, when plots were treated with the levels 0, 100, 175 and 250kg/haN. Crop dry matter increased from 26.2g m-2 and 32.5g m-2 from the same time to 948.8, 1280.4, 1338.0, 1224.0g m-2 and 980.0, 1264.8, 1393.2, 1236.4g m-2, in the medium and high densities during the same time interval with increase in the levels of N (Table 3.3). A similar trend was also obtained with the band coulter. The dry weight increased from 17.8g m-2 to 1014.0, 1595.2, 1462.4 and 1744.8g m-2 at the low density; while the medium and high densities gave an increase in dry weight from 25.4g m-2 and 39.6g m-2 to 1043.6, 1372.4, 1544.0, 1608.4g m-2 and 1164.4, 1652.4, 1568.0, 1703.2g m-2 after the nitrogen treatments.

On the first sampling date, before nitrogen application, the crop showed an increase in dry weight with population density. After the nitrogen treatments, the low density eventually produced the highest dry matter on August 3rd in both plant arrangements (Table 3.3). The initial high dry matter with increase in density resulted from more plants at the medium and high densities respectively.

For the two plant arrangements, increase in dry weight was favoured most by the low density, over the medium and high densities, at 250kg/haN (Table 3.3). The high density gave the highest dry weight when treated with 175kg/haN. However, when the slopes of the lines were compared by the use of regression analysis there was no significant difference among all the densities. Application of 100kg/haN to the suffolk coulter plots resulted in the highest dry weight at low density, but the highest dry weight was recorded at the high density in the band coulter plots (Table 3.3), this was also true for the 0kg/haN.

Table 3.3. Total dry weight (g m-2), on different sampling (S) dates.

DAD. (Sample).	Nkg /ha.	Suffolk Coulter. Density (seeds m-2). D1 200	D2 350	D3 500	Mean	Band Coulter. Density(seeds m-2). D1 200	D2 350	D3 500	Mean	SED.
141(S1)	_	18.7	26.2	32.5	25.8	17.8	25.4	39.6	27.6	_
	0	31.6	40.6	42.8	38.3	30.8	43.4	52.0	40.1	
	100	38.5	49.6	41.5	43.2	36.6	50.5	56.5	47.9	
170(S2)	175	38.0	56.2	47.3	47.2	44.7	63.3	88.0	65.3	
	250	39.0	61.2	51.4	50.5	52.1	74.8	116.5	81.1	
	Mean	36.8	51.9	45.8		40.1	58.0	78.3		2.6
	0	121.9	170.6	170.7	154.4	175.3	176.4	230.7	194.1	
	100	172.1	212.7	232.7	205.8	179.0	269.9	301.5	250.1	
192(S3)	175	160.0	227.2	304.4	230.5	234.0	299.6	302.8	278.8	
	250	214.5	264.5	327.4	268.8	277.8	277.0	390.6	315.1	
	Mean	167.1	218.8	258.8		216.5	255.7	306.4		7.0
	0	309.2	310.4	278.0	299.2	312.4	254.8	328.0	298.4	
	100	328.4	426.4	396.8	383.9	398.8	399.6	480.0	426.1	
209(S4)	175	373.2	385.2	478.4	412.3	416.8	500.8	542.4	486.6	
	250	388.4	473.6	401.2	421.1	474.4	434.4	595.2	501.3	
	Mean	349.8	398.9	388.6		400.6	397.4	486.4		12.3
	0	481.2	522.8	595.6	533.2	576.4	541.6	720.0	612.6	
	100	568.0	620.8	750.4	646.4	655.6	899.2	866.0	806.9	
218(S5)	175	687.2	845.6	864.0	798.9	742.8	904.4	987.2	878.1	
	250	751.6	836.4	766.8	784.9	804.4	863.6	1019.2	895.7	
	Mean	622.0	706.4	744.2		694.8	802.2	898.1		18.3
	0	641.6	682.0	625.6	649.7	734.0	703.6	749.2	728.9	
	100	884.8	906.8	878.8	890.1	954.4	1074.0	1063.2	1030.5	
232(S6)	175	867.2	1024.4	1008.4	966.7	1040.0	1079.6	1210.0	1109.9	
	250	862.0	1001.6	1089.2	984.3	963.6	1009.6	1210.0	1061.1	
	Mean	813.9	903.7	900.5		923.0	966.7	1058.1		25.9
	0	988.4	948.8	980.0	972.4	1014.0	1043.6	1166.4	1074.7	
	100	1492.0	1280.4	1264.8	1345.7	1595.2	1372.4	1652.4	1540.0	
281(S7)	175	1391.6	1338.0	1393.2	1374.3	1462.4	1544.0	1568.0	1524.8	
	250	1608.8	1224.0	1236.4	1356.4	1748.8	1608.4	1703.2	1686.8	
	Mean	1370.2	1197.8	1218.6		1455.1	1392.1	1522.5		34.1

DAD = Days after drilling.

For both suffolk and band coulters, the application of 100, 175 and 250kg/haN gave a significant increase ($p<0,05$) of both the rate and total dry matter over the control treatment (0kg/haN). These values are shown in Figures 3.1, 3.2 & 3.3. The regression equation for comparing the lines are given in Table 3.5. The slopes of the lines were 9.17,

13.93, 13.01, 14.71 and 9.43, 14.89, 13.65, 15.79, for the suffolk and band coulters at the low density. For the medium and high densities, the corresponding slopes were 8.69, 11.76, 12.54, 11.21 and 9.62, 12.83, 14.03, 14.59; then 8.89, 11.61, 12.66, 11.43 and 10.50, 15.02, 14.31, 15.14 for the two plant arrangements respectively, with 0, 100, 175 and 250kg/haN . When the differences between these values were divided by their various standard errors of difference between two slopes, it was found that the levels 100, 175 and 250kg/haN were not significantly different from one another, but the slopes of the lines produced by these levels were highly significant ($p<0.01$) over 0kg/ha nitrogen (Figures 3.1, 3.2 & 3.3).

The individual slopes from the low, medium and high densities were compared for both plant arrangements, it was found that the trend of the slopes were similar. With the lowest level of nitrogen (0kg/ha) giving the lowest slope compared to the nitrogen treatments 100, 175 and 250kg/haN.

Results showed that the highest total dry weight was obtained at 250kg/haN with the band coulter (Table 3.3). In the suffolk coulter plots, only the low density produced the highest dry weight at 250kg/haN (Table 3.3); with the same drilling method, the medium and high densities gave the highest dry weights at 175kg/haN (Table 3.3). The band coulter plots produced a higher total dry weight compared to the suffolk coulter (Table 3.3). Whilst the mean dry weights per plant were slightly higher (0.45g) from the suffolk coulter plots.

Fig. 3.1 CROP BIOMASS, g m−2 (A) SUFFOLK COULTER AND (B) BAND COULTER (200 plants m−2).

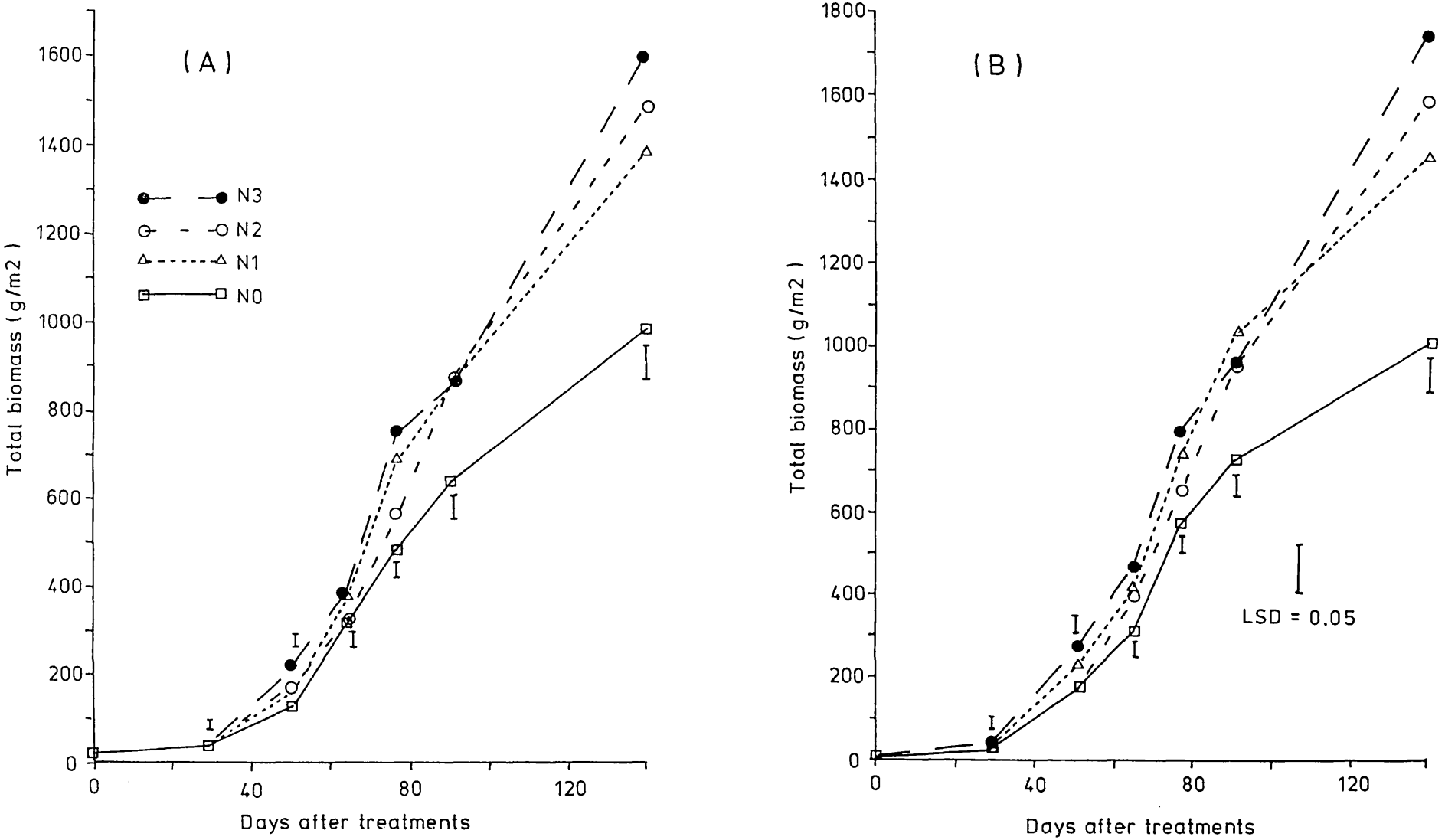
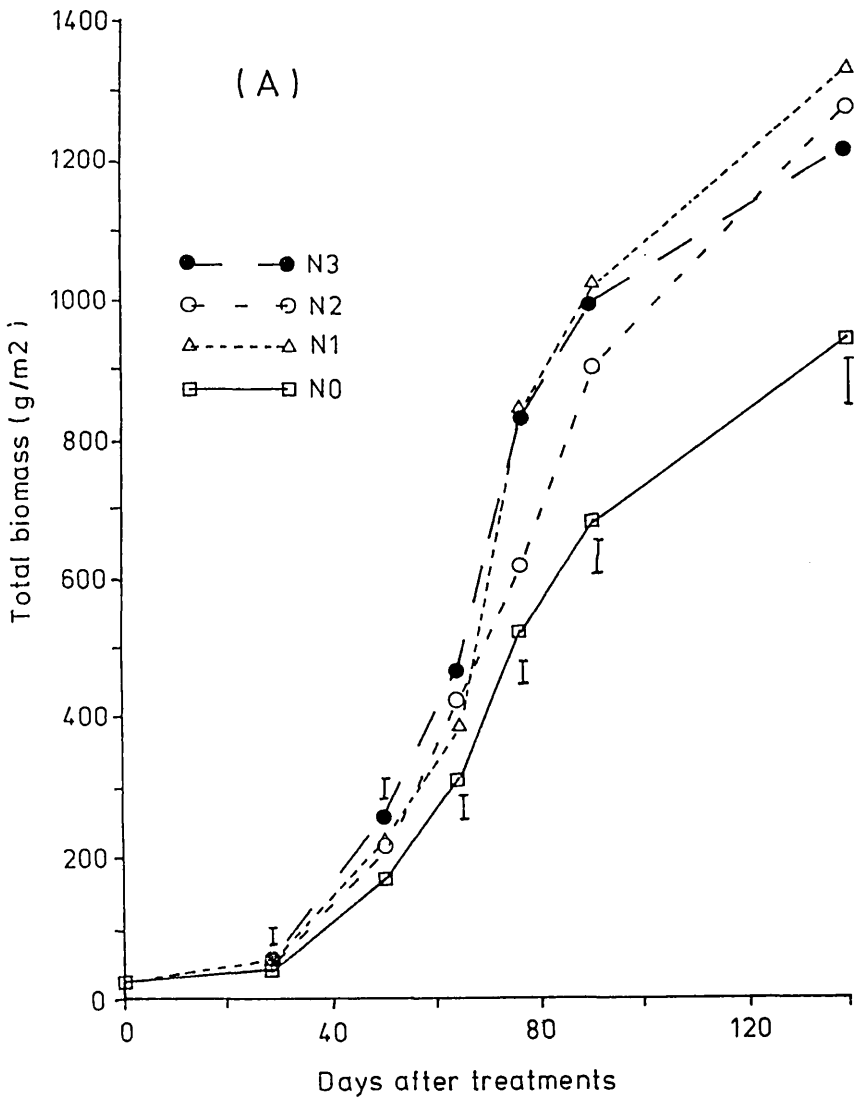


Fig. 3.2 CROP BIOMASS, g m−2 (A) SUFFOLK COULTER AND (B) BAND COULTER (350 plants m−2).



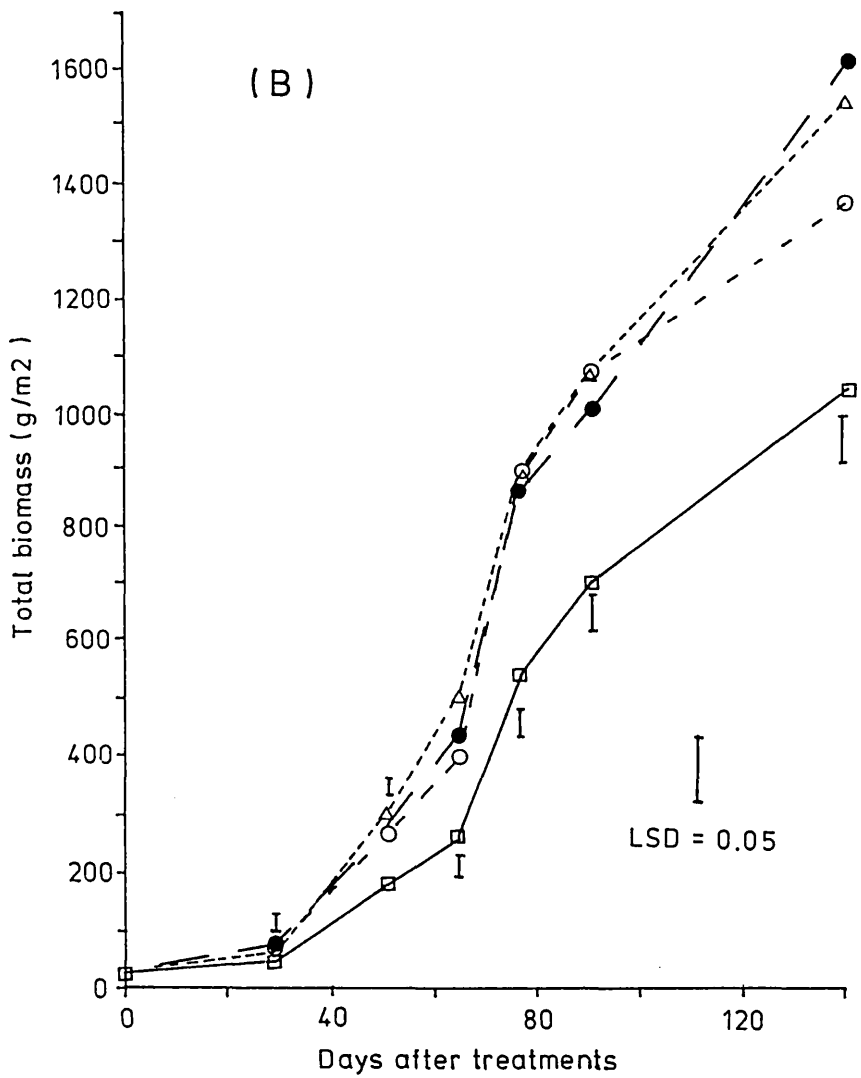


Fig. 3.3 CROP BIOMASS, g m−2 (A) SUFFOLK COULTER AND (B) BAND COULTER (500 plants m−2).

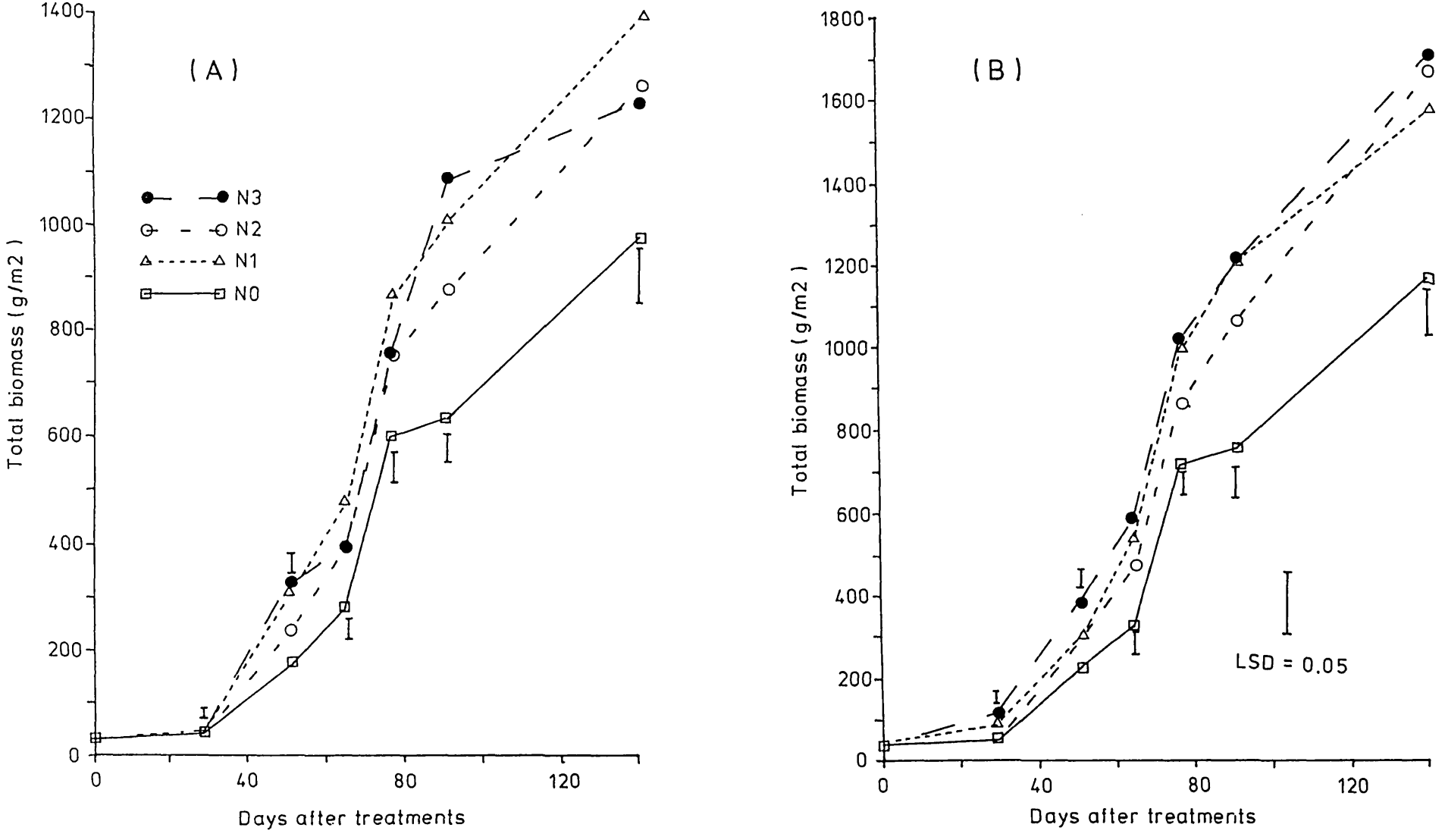


Table 3.4. Dry weight per plant (g) on different sampling (S) dates.

DAD. (Sample).	Nkg /ha.	Suffolk Coulter. Density(seeds m-2). D1 200	D2 350	D3 500	Mean	Band Coulter. Density(seeds m-2). D1 200	D2 350	D3 500	Mean	SED.
141(S1)	_	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	_
	0	0.3	0.2	0.2	0.2	0.3	0.2	0.2	0.2	
	100	0.3	0.3	0.2	0.3	0.3	0.3	0.2	0.3	
170(S2)	175	0.2	0.3	0.3	0.3	0.3	0.4	0.3	0.3	
	250	Not determined				Not determined				
	Mean	0.3	0.3	0.2		0.3	0.3	0.3		0.1
	0	1.1	1.1	0.6	0.9	1.2	0.9	0.6	0.9	
	100	1.4	1.3	1.0	1.2	1.3	1.4	1.0	1.2	
192(S3)	175	1.4	1.4	1.2	1.4	1.6	1.6	1.0	1.4	
	250	1.8	1.6	1.2	1.5	1.9	1.5	1.3	1.6	
	Mean	1.4	1.3	1.0		1.5	1.32	1.0		0.2
	0	3.2	2.1	1.4	2.2	2.4	1.5	1.3	1.7	
	100	3.6	2.9	2.2	2.9	3.1	2.3	1.9	2.4	
209(S4)	175	3.9	2.4	2.4	2.9	3.3	2.7	2.1	2.7	
	250	4.5	3.1	2.2	3.3	3.7	2.5	2.2	2.8	
	Mean	3.8	2.6	2.1		3.1	2.4	1.9		0.4
	0	5.2	3.5	3.1	3.9	4.5	2.9	2.8	3.4	
	100	7.0	4.3	3.8	5.0	5.4	4.7	3.5	4.5	
218(S5)	175	7.0	5.5	4.4	5.6	5.9	5.2	4.1	5.1	
	250	7.7	5.1	4.0	5.6	6.1	4.7	4.0	4.9	
	Mean	6.7	4.6	3.8		5.5	4.4	3.6		0.6
	0	6.3	4.6	3.7	4.9	7.3	3.7	3.3	4.8	
	100	9.5	6.0	4.9	6.8	9.1	6.4	4.9	6.8	
232(S6)	175	10.1	6.6	5.5	7.4	9.0	7.0	5.6	7.2	
	250	11.4	6.9	6.3	8.2	8.8	6.3	5.0	6.7	
	Mean	9.3	6.0	5.1		8.6	5.9	4.7		0.8

DAD = Days after drilling.

Increase in density decreased the dry weight per plant, but this was influenced by the levels of nitrogen and drilling technique. In the band coulter plots, treatment with 250kg/haN decreased the dry weight (Table 3.4). The increase in total dry matter from the band coulter resulted from more plants per unit area on each of the sampling dates (Appendix 3.1). In suffolk coulter plots, at medium and high densities, with 250kg/ha nitrogen, the increase in dry weight was initially similar to the other treatments, but declined after anthesis (Table 3.4). This

decline in dry weight coincided with the death of late tillers in the medium and high densities with the high level of nitrogen (250kg/ha). This result is in agreement with that reported by Darwinkel (1980). This author concluded that at high densities, the later emerged tillers were less important, since they failed to produce ears and therefore, died. In this experiment more tillers were produced at the high nitrogen level (250kg/ha), but less than half contributed to the dry matter after anthesis. The continuous stable increase in dry weight shown in Tables 3.3 and 3.4 was as a result of the increase in ear dry weight after anthesis, with the vegetative part contributing less than half of the total dry weight.

Table 3.5. Regression equations for comparing the slopes of the lines in Figures 3.1, 3.2 and 3.3.

Density x Nitrogen.			Suffokl Coulter.	Band Coulter.
D1	x	N0	Y = 2.58 + 9.17x	Y = 35.13 + 9.43x
D1	x	N1	Y = -67.10 + 13.93x	Y = -56.17 + 14.89x
D1	x	N2	Y = -18.58 + 13.01x	Y = 21.67 + 13.65x
D1	x	N3	Y = -39.78 + 14.71x	Y = -14.67 + 15.79x
SED.			0.98	1.07
D2	x	N0	Y = 42.55 + 8.69x	Y = 13.08 + 9.62x
D2	x	N1	Y = 35.83 + 11.76x	Y = 80.91 + 12.83x
D2	x	N2	Y = 63.06 + 12.54x	Y = 79.16 + 14.03x
D2	x	N3	Y = 121.91 + 11.21x	Y = 31.70 + 14.59x
SED.			1.45	1.46
D3	x	N0	Y = 35.21 + 8.89x	Y = 52.68 + 10.50x
D3	x	N1	Y = 53.91 + 11.61x	Y = 38.00 + 15.02x
D3	x	N2	Y = 93.93 + 12.66x	Y = 117.31 + 14.31x
D3	x	N3	Y = 112.14 + 11.43x	Y = 130.79 + 15.14x
SED.			1.22	1.49

3.3.2.Tiller production.

Wheat grain yield is the product of the following yield components: number of ears per unit area, number of spikelets per ear, number of grains per spikelet and 1000grain weight. In this experiment, tillers were included in the count when 2-4cm or more of the green leaf was

protruding from the subtending leaf-sheath. Tillers with yellow colouration of the youngest leaf were excluded. Tables 3.6 and 3.7 summarise the effect of plant arrangements, density and nitrogen levels on the number of tillers m-2 and number of tillers per plant throughout the growth and developmental period of the crop. The results from these tables indicated that, treatment with zero level of N produced the lowest numbers of vegetative tillers m-2. At the peak period of tillering, during early May 1987, (sample 3), treatment with zero level of N gave 666.9, 768.0, 810.2 tillers m-2 and 852.4, 879.8, 1212.8 tillers m-2 corresponding to the low, medium and high densities for the respective plant arrangements (suffolk and band coulters). Application of 250kg/haN gave 1116.5, 1178.3, 1255.6 and 1329.9, 1369.9, 1629.2 tillers m-2 for the different densities and plant arrangements respectively (Table 3.6). At the same period of growth of the crop (GS32), there was a highly significant increase ($p<0.01$) in the average number of tillers m-2 with the band coulter over the suffolk coulter (1222.6 and 969.6), Table 3.6.

Tables 3.6 and 3.7 show that the highest number of tillers m-2 and tillers per plant were achieved at 250kg/haN at the low and medium densities. At the high density, application of 175kg/haN produced a slightly higher number (NS) of tillers per plant with the suffolk coulter, and with the band coulter a similar numbers of tillers per plant were produced by treatments with 175 and 250kg/haN (Table 3.7). Similar results are shown on Tables 3.8 and 3.9 when data from the first four samples were pooled together with the view of reducing the coefficient of variation. These Tables indicated a consistent increase in the number of tillers m-2 with the increase in density, and the number of tillers per plant resulting from increase in the levels of nitrogen as opposed to Table 3.6, which showed inconsistent response, possibly due to 'background' variation in plant sampling.

Table 3.6. Number of tillers m-2 on different sampling (S) dates.

DAD.	Nkg /ha.	Suffolk Coulter. Density (seeds m-2). D1 200	D2 350	D3 500	Mean	Band Coulter. Density (seeds m-2). D1 200	D2 350	D3 500	Mean	SED.
141(S1)	_	368.6	438.2	410.6	405.8	253.3	322.7	471.3	349.1	71.6
	0	699.3	787.5	813.5	766.8	719.3	836.8	887.0	814.4	
	100	876.3	1010.5	790.0	892.3	721.3	1212.3	1030.3	988.0	
170(S2)	175	822.3	1046.5	924.0	930.9	981.3	1252.8	1503.0	1245.7	
	250	Not determined				Not determined				
	Mean	798.3	848.2	842.5		807.3	1100.6	1140.1		152.8
	0	666.9	768.0	810.2	748.4	852.4	879.8	1212.8	981.7	
	100	903.7	939.8	1026.4	956.6	1050.0	1149.2	1351.5	1183.6	
192(S3)	175	916.8	838.1	1207.2	987.4	1123.6	1277.8	1444.7	1282.0	
	250	1116.5	1178.3	1255.6	1183.5	1329.9	1369.9	1629.2	1443.0	
	Mean	901.0	931.1	1074.9		1089.0	1169.2	1409.6		79.7
	0	498.6	492.0	529.2	506.6	589.0	559.6	631.6	593.4	
	100	568.5	640.0	651.7	620.1	808.8	524.3	841.4	724.8	
209(S4)	175	725.8	670.3	744.3	713.5	771.7	783.7	862.0	839.1	
	250	626.6	697.8	733.8	686.1	852.0	866.0	901.7	873.2	
	Mean	604.9	625.0	664.8		755.4	683.4	809.2		72.0
	0	282.2	321.0	409.6	337.6	357.0	352.9	461.2	390.4	
	100	372.6	424.0	495.4	430.7	489.4	580.1	602.0	557.2	
218(S5)	175	495.6	552.6	615.9	554.7	623.9	648.7	750.8	674.5	
	250	605.6	652.0	628.8	628.8	663.3	692.1	830.0	728.5	
	Mean	439.0	487.4	537.4		533.4	568.5	661.0		46.4
	0	276.4	295.6	289.2	287.1	330.6	329.3	362.3	340.7	
	100	389.3	421.4	434.6	415.1	503.3	518.7	503.7	508.6	
232(S6)	175	454.0	453.1	528.1	478.4	545.7	567.2	588.3	567.1	
	250	445.5	529.8	586.9	520.7	531.0	540.6	655.3	575.6	
	Mean	391.3	425.9	459.7		477.7	489.0	527.4		48.9
	0	246.0	278.0	318.0	280.7	261.0	289.0	359.0	303.0	
	100	407.0	364.0	367.0	379.3	435.0	408.0	474.0	439.0	
281(S7)	175	424.0	409.0	438.0	423.7	475.0	464.0	499.0	479.3	
	250	498.0	410.0	529.0	479.0	587.0	536.0	613.0	578.7	
	Mean	398.3	365.3	413.0		439.5	424.3	486.3		39.6

Highest numbers of tillers m-2 were achieved at the zero level of nitrogen at all densities around the second week of April (sample 2). Treatments with 100 and 175kg/haN also produced the highest number of tillers m-2 at this time. But this was only applicable to the suffolk coulter treatment. With the band coulter, the maximum number of tillers

m-2 were achieved in early May (sample 3), Table 3.6. For both plant arrangements the number of tillers m-2 increased with the increase in density, but, decreased the number of tillers per plant (Tables 3.6 and 3.7).

Table 3.7. Number of tillers per plant on different sampling (S) dates.

		Suffolk Coulter.				Band Coulter.				
DAD.	Nkg	Density (seeds m-2).				Density (seeds m-2).				
	/ha.	D1	D2	D3		D1	D2	D		
(Sample).		200	350	500	Mean	200	350	500	Mean	SED.
141(S1)	_	3.2	2.9	2.4	2.8	2.8	2.7	2.7	2.7	0.3
	0	5.7	4.5	4.0	4.7	5.6	4.5	3.8	4.6	
	100	6.7	5.4	4.4	5.5	5.4	6.4	4.2	5.3	
170(S2)	175	6.5	5.9	4.8	5.7	7.1	6.6	5.3	6.3	
	250	Not determined				Not determined				
	Mean	6.3	5.3	4.4		6.0	5.8	4.4		0.7
	0	5.7	4.8	3.1	4.5	6.0	4.3	3.4	4.6	
	100	7.6	5.6	4.4	5.9	7.5	5.8	4.4	5.9	
192(S3)	175	7.9	6.8	4.9	6.5	7.6	6.8	4.7	6.4	
	250	9.4	7.1	4.8	7.1	9.2	7.3	5.3	7.3	
	Mean	7.7	6.1	4.3		7.6	6.1	4.5		0.5
	0	5.2	3.3	2.7	3.7	4.5	3.2	2.4	3.4	
	100	6.0	4.4	3.6	4.7	6.4	3.9	3.3	4.5	
209(S4)	175	7.2	4.2	3.8	5.1	6.2	4.3	3.3	4.6	
	250	7.3	4.5	4.0	5.3	6.8	4.9	3.4	5.0	
	Mean	6.4	4.1	3.5		6.0	4.1	3.1		0.4
	0	3.1	2.2	2.1	2.5	2.8	1.8	1.8	2.1	
	100	4.5	3.0	2.5	3.3	4.0	3.1	2.5	3.2	
218(S5)	175	5.1	3.6	3.2	4.0	5.0	3.3	3.1	3.8	
	250	6.3	4.0	3.2	4.5	5.0	3.6	3.2	3.9	
	Mean	4.8	3.2	2.8		4.2	3.0	2.7		0.4
	0	2.8	2.0	1.8	2.2	3.0	1.7	1.6	2.1	
	100	4.2	2.8	2.4	3.1	4.4	3.1	2.2	3.2	
232(S6)	175	5.3	3.2	2.8	3.8	4.7	3.3	2.5	3.5	
	250	5.9	3.7	3.4	4.3	4.5	3.4	2.8	3.6	
	Mean	4.6	2.9	2.6		4.2	2.9	2.3		0.4

DAD = Days after drilling.

3.3.3.Tiller survival and ear formation.

The average number of ears m-2 at final harvest (sample 7), was increased by the band coulter, 450.0 versus 390.7 m-2, for suffolk coulter (Table 3.6). This was confirmed when results were averaged over the last three sampling dates (Table 3.10). The increase in the number of ears m-2 was highly significant ($p<0.01$) with the 100, 175 and 250kg/ha levels of N over the control (0kg/ha); Table 3.6 and 3.10. Application of 250kg/haN gave the highest number of ears m-2 and number of ears per plant (Tables 3.10 and 3.11). Tables 3.6 and 3.7 did not show a consistent increase in the number of ears m-2 and number of ears per plant, probably due to variation in plant population (Appendix 3.1) as mentioned earlier. To reduce this variability, samples taken after ear emergence (samples 5, 6 and 7) were averaged and then analysed. This resulted in a highly significant ($p<0.01$) consistent increase in the number of ears m-2 (Table 3.10). This table also showed a highly significant ($p<0.01$) increase in the number of ears m-2 with increase in density. The increase in density decreased the number of ears per plant (Table 3.11), however, at the low density, increase in the levels of nitrogen increased the number of ears per plant significantly ($p<0.05$).

Table 3.8. Number of tillers m-2 averaged over the first four samples.

	Suffolk Coulter.				Band Coulter.				
Nkg/ha.	Density (seeds m-2).				Density (seeds m-2).				
	D1 200	D2 350	D3 500	Mean	D1 200	D2 350	D3 500	Mean	SED.
0	621.5	682.4	720.2	674.7	720.2	758.7	910.5	796.5	
100	782.8	863.5	822.6	823.0	860.0	1015.3	1074.3	983.2	
175	831.6	935.0	958.5	908.4	958.8	1104.8	1269.9	1111.2	
250	871.4	938.0	989.7	933.0	1109.9	1115.4	1265.5	1163.6	
Mean	776.8	854.7	872.8		912.2	998.6	1130.1		60.0

Table 3.9. Number of tillers per plant averaged over the first four samples.

	Suffolk Coulter.				Band Coulter.				
Nkg/ha.	Density (seeds m-2).				Density (seeds m-2).				
	D1 200	D2 350	D3 500	Mean	D1 200	D2 350	D3 500	Mean	SED.
0	5.6	4.2	3.3	4.4	5.4	4.0	3.2	4.2	
100	6.8	5.1	4.1	5.3	6.4	5.4	4.0	5.3	
175	7.2	5.6	4.5	5.8	6.9	5.9	4.4	5.7	
250	8.3	5.8	4.3	6.1	8.0	6.1	4.4	6.2	
Mean	7.0	5.2	4.1		6.7	5.4	4.0		0.4

Table 3.10. Number of ears m-2 averaged over the last three samples.

	Suffolk Coulter.				Band Coulter.				
Nkg/ha.	Density (seeds m-2).				Density (seeds m-2).				
	D1 200	D2 350	D3 500	Mean	D1 200	D2 350	D3 500	Mean	SED.
0	268.2	298.9	338.9	302.0	328.7	323.7	394.1	348.8	
100	389.6	403.1	432.3	408.3	475.9	502.2	526.6	501.6	
175	457.8	471.3	532.3	487.1	548.2	559.9	612.7	573.6	
250	516.3	530.6	581.6	542.8	596.9	589.5	699.4	628.6	
Mean	408.0	426.0	471.3		487.4	493.8	558.2		26.3

Table 3.11. Number of ears per plant averaged over thes last three samples.

	Suffolk Coulter.				Band Coulter.				
Nkg/ha.	Density (seeds m-2).				Density (seeds m-2).				
	D1 200	D2 350	D3 500	Mean	D1 200	D2 350	D3 500	Mean	SED.
0	3.0	2.1	2.0	2.4	2.9	1.8	1.7	2.1	
100	4.4	2.9	2.5	3.3	4.2	3.1	2.4	3.2	
175	5.2	3.4	3.0	3.9	4.9	3.3	2.8	3.7	
250	6.1	3.8	3.3	4.4	4.7	3.5	3.0	3.7	
Meam	4.7	3.1	2.7		4.2	2.9	2.5		0.3

Table 3.12. Effect of density on the reproductive tillers m-2.

	Suffolk Coulter.				Band Coulter.				
DAD.	Density (seeds m-2).				Density (seeds m-2).				
	D1	D2	D3		D1	D2	D3		
(Sample)	200	350	500	Mean	200	350	500	Mean	SED.
141(S1)	368.6	438.2	410.6	405.8	253.3	322.7	471.8	349.3	_
170(S2)	799.3	948.2	842.5	863.3	807.3	1100.6	1140.1	1016.0	103.0
192(S3)	901.0	931.1	1076.9	969.7	1089.0	1169.2	1409.6	1222.6	42.8
209(S4)	604.9	625.0	664.8	631.6	755.4	683.4	809.2	749.3	31.9
218(S5)	439.0	487.9	537.4	488.1	533.4	568.5	661.0	587.6	25.1
232(S6)	391.3	425.0	459.7	425.3	477.7	489.0	527.4	498.0	27.5
281(S7)	393.8	365.3	413.0	390.7	439.5	424.3	486.3	450.0	20.7

DAD = Days after drilling.

Tables 3.12 and 3.13 show the effects of plant population density on tiller formation and survival. At all sampling dates, the number of tillers m-2 increased with the population density. On May 6th, the maximum tillering stage (GS32), increasing the seed rates from 200 m-2 to 500 m-2 resulted in a significant increase ($P<0.05$) in the number of tillers m-2. Numbers of tillers m-2 increased from 901.0 to 1076.9 and, from 1089.0 to 1409.6 for the suffolk and band coulters respectively. However, there were no significant differences between 200 and 350 seeds m-2 in the suffolk coulter treatment (Table 3.12). Conversely the band coulter plots recorded a significant increase ($P<0.05$) in the number of tillers m-2 with the increase seed rates in the range 200 to 350 m-2 (Table 3.12). Increase in plant population however resulted in decreased number of tillers per plant (Table 3.13). The numbers of tillers per plant at the maximum tillering period (May 6th) decreased from 7.7 to 4.3 and, 7.6 to 4.5 when seed rates were increased from 200 to 500 m-2, corresponding to the suffolk and band coulters treatments respectively. The increase in the number of tillers m-2 and the corresponding decrease

in tillers per plant continued until the final harvest (Tables 3.12 & 3.13).

Table 3.13. Effect of density on the reproductive tillers per plant.

	Suffolk Coulter.				Band Coulter.				
DAD.	Density (seeds m-2).				Density (seeds m-2).				
	D1	D2	D3		D1	D2	D3		
(Sample).	200	350	500	Mean	200	350	500	Mean	SED.
141(S1)	3.2	2.9	2.4	2.8	2.8	2.7	2.7	2.7	_
170(S2)	6.3	5.3	4.4	5.3	6.0	5.8	4.4	5.4	0.5
192(S3)	7.7	6.1	4.3	6.0	7.6	6.1	4.5	6.1	0.3
209(S4)	6.4	4.1	3.5	4.7	6.0	4.1	3.1	4.4	0.2
218(S5)	4.8	3.2	2.8	3.6	4.2	3.0	2.7	3.3	0.2
232(S6)	4.6	2.9	2.6	3.4	4.2	2.9	2.3	3.1	0.2

DAD = Days after drilling.

3.3.4.Number of spikelets per ear.

Table 3.14 shows results for the number of spikelets per ear at anthesis and at plant maturity. For both plant arrangements, spikelets at anthesis and maturity increased significantly ($p<0.05$) with the levels of nitrogen, but decreased with plant population density (Table 3.14). The pattern of spikelet production and survival followed similar trends in all the treatments irrespective of the density and plant arrangements.

The average number of spikelets per ear was increased slightly (NS) with the band coulter. Mean numbers of spikelets per ear for the two plant arrangements were 21.0 and 19.7 for the band versus 20.8 and 19.3 for the suffolk, at anthesis and crop maturity respectively (Table 3.14). Number of spikelets initiated per ear significantly increased ($p<0.05$) with the decrease in density. These were 21.4, 20.6, 20.5 and

12.7, 20.7, 20.5; for the low, medium and high densities, corresponding to suffolk and band coulters. Spikelet survival also increased with the decrease in plant population density (NS). Number of spikelets that survived were 19.9, 19.2, 18.8 and 20.2, 19.6, 19.1; for the respective densities and plant arrangements. Differences in the number of fertile and empty spikelets were observed between the ears within each plant, with the tiller-ears producing fewer fertile spikelets compared to the mainstem-ears.

Table 3.14. Numbers of spikelets per ear at anthesis and plant maturity (values in parenthesis represent percentage spikelets degeneration).

	Suffolk Coulter.				Band Coulter.				
Nkg /ha.	Density (seeds m-2). D1 200	D2 350	D3 500	Mean	Density (seeds m-2). D1 200	D2 350	D3 500	Mean	SED.
					Anthesis.				
0	20.9	19.5	19.8	20.1	20.7	19.6	19.5	19.9	
100	21.4	20.6	20.4	20.8	21.2	20.8	20.2	20.7	
175	21.1	20.6	20.5	20.7	21.9	21.1	20.4	21.1	
250	22.1	21.5	21.1	21.6	22.9	21.4	20.8	21.7	
Mean	21.4	20.6	20.5		21.7	20.7	20.2		0.4
					Maturity.				
0	19.2(8)	17.9(8)	17.4(12)	18.2(9)	18.7(10)	18.5(6)	18.1(7)	18.4(8)	
100	19.8(8)	19.2(7)	18.7(8)	19.2(8)	20.2(5)	19.7(5)	19.2(5)	19.7(5)	
175	20.1(5)	19.8(4)	19.7(4)	19.9(4)	20.6(6)	20.3(4)	19.9(3)	20.3(4)	
250	20.4(8)	19.8(8)	19.5(8)	19.9(8)	21.3(7)	20.0(7)	19.2(8)	20.2(7)	
Mean	19.9(7)	19.2(7)	18.8(8)		20.2(7)	19.6(6)	19.1(6)		0.6

The mean numbers of spikelets per ear averaged over N levels presented in Table 3.14, compares the effects of plant population density. Results showed a significant ($P<0.05$) decrease in the number of spikelets per ear both at anthesis and crop maturity with increase in

the seed rates from 200 m-2 to 350 and 500 m-2. However, there was no significant difference between treatments 350 and 500 seeds m-2 (Table 3.14).

3.3.5.Number of grains per ear.

Numbers of grains per ear were calculated by dividing the number of grains per unit area by the total number of ears recorded at the final harvest (sample 7). Numbers of grains per spikelet were also obtained by dividing the number of grains per unit area by the total number of spikelets recorded from the same area. Tables 3.15 and 3.16 show the results. For both plant arrangements, the lowest number of grains per ear was recorded at the high density (Table 3.15). Mean numbers of grains per ear were higher (NS) in the low density when plots were drilled using the suffolk coulter. But with the band coulter treatment it was slightly favoured by the medium density compared with the low and high densities (Table 3.15). A similar trend was also obtained from the mean number of grains per spikelet for the suffolk coulter. The band coulter recorded similar mean number of grains per spikelet for all the densities (Table 3.16).

The average numbers of grains per ear and number of grains per spikelet for each of the the plant arrangements were slightly higher (NS) with the suffolk coulter than the band coulter. The corresponding values were 42.6, 2.2 for the former and 39.4, 2.1 for the later. Results from Tables 3.15 and 3.16 showed a trend in reduction in the number of grains per ear and number of grains per spikelet, associated with the increase in nitrogen levels. However, the trend did not show a clear consistency with the nitrogen levels in all the treatments.

Table 3.15. Number of grains per ear.

	Suffolk Coulter.				Band Coulter.				
Nkg/ha.	Density (seeds m-2).				Density (seeds m-2).				
	D1 200	D2 350	D3 500	Mean	D1 200	D2 350	D3 500	Mean	SED.
0	47.5	47.0	40.8	45.1	41.1	43.5	38.4	41.0	
100	43.4	43.8	41.7	43.0	40.4	40.6	40.8	40.6	
175	43.6	42.5	39.9	42.0	38.1	41.3	39.4	39.6	
250	41.4	40.1	39.7	40.4	38.0	37.2	33.6	36.3	
Mean	44.0	43.4	40.5		39.4	40.7	38.1		2.3

Table 3.16. Numbers of grains per spikelet.

	Suffolk Coulter.				Band Coulter.				
Nkg/ha.	Density (seeds m-2).				Density (seeds m-2).				
	D1 200	D2 350	D3 500	Mean	D1 200	D2 350	D3 500	Mean	SED.
0	2.5	2.2	2.2	2.3	2.3	2.4	2.1	2.3	
100	2.3	2.1	2.2	2.2	2.2	2.1	2.2	2.2	
175	2.2	2.3	2.1	2.2	1.9	2.1	2.1	2.0	
250	2.2	2.2	2.0	2.1	1.8	1.9	1.8	1.8	
Mean	2.3	2.2	2.1		2.1	2.1	2.1		0.2

3.3.6.Thousand grain weight (86%DM).

The response of grain weight to plant arrangements, density and nitrogen is presented in Table 3.17. The suffolk coulter influenced 1000grain weight slightly (NS), 0.58g at 85%DM, compared to the band coulter (Table 3.17). Grain weight decreased with density (NS). Increasing the levels of N within the range tested (100, 175 and 250kg/ha) decreased grain weight significantly ($p<0.01$) compared to the control (0kg/ha) (Table 3.17). This could have probably resulted from the numbers of grains given by the tiller-ears, since the proportion of total number of grains per plant were higher from the tiller-ears as compared to the mainstem-ears, when plants were treated with nitrogen. These results were in agreement with those reported by Mclaren, (1981) and Darwinkel el al. (1977). These authors reported that grain weight

from the tiller-ears were consistently lower than those obtained from the mainstem-ears.

With the suffolk coulter, the high density recorded the lowest 1000grain weight, 38.3g compared to the low and medium densities which gave 39.3g and 40.5g respectively when plots were treated with 250kg/haN. The band coulter gave the lowest 1000grain at the low density 38.3g; medium and high densities recorded 40.4g and 38.8g at the same levels of nitrogen (250kg/ha), Table 3.17. Regression lines were fitted to the values presented in Figure 3.4, the slopes of the lines decreased significantly ($P<0.05$) with the N levels 100, 175 250kg/ha over the control (0kg/ha).

Table 3.17. Thousand grain weight (g 86%DM).

	Suffolk Coulter.				Band Coulter.				
Nkg/ha.	Density (seeds m-2).				Density (seeds m-2).				
	D1 200	D2 350	D3 500	Mean	D1 200	D2 350	D3 500	Mean	SED.
0	46.2	45.4	45.1	45.6	45.8	44.9	44.9	45.2	
100	43.6	43.7	43.2	43.5	42.6	42.4	42.9	42.6	
175	41.7	41.1	40.9	41.2	40.1	41.1	39.9	40.4	
250	39.3	40.5	38.3	39.4	38.3	40.4	38.8	39.2	
Mean	42.7	42.7	41.9		41.7	42.2	41.6		0.8

3.3.7.Total grain yield (t/ha 86%DM).

The main effect of plant arrangement was examined by comparing this factor at the same density and nitrogen treatment. Results obtained from this experiment indicated that, the suffolk coulter gave a higher grain yield, except at low density (200 seeds m-2), and high density (500 seeds m-2), at 0kg/ha and 100kg/ha nitrogen levels respectively, where yield increase was slightly favoured (NS) by the band coulter. Yields from these treatments were 0.3t/ha and 0.2t/ha greater than those obtained using the suffolk coulter respectively (Table 3.18). The

average yield from the suffolk coulter was higher (NS) by 0.52t/ha than the band coulter. This result is not in agreement with the suggestion put forward by Roger (1984) in Berkshire, who obtained higher total grain yield from the band coulter as opposed to the suffolk coulter.

At both plant arrangements the highest average grain yield was recorded from treatments with 175kg/ha of nitrogen. Grain yield increased with about 2.68, 0.43 and 0.30t/ha over the 0, 100 and 250kg/haN respectively. The yield increases were significantly different ($p<0.05$) from 0 and 100kg/haN , however there was no significant difference between the yield at 175kg/ha and those recorded from 250kg/haN (Table 3.20).

Highest average grain yield from the suffolk coulter was recorded at the medium density, resulting in yield increase of 0.79 and 0.26t/ha over the low and high density (Table 3.18). With the band coulter treatment, the grain yield was highest at the high density with (0.40 and 0.09t/ha) above the low and the medium density (Table 3.18).

In all the three plant population densities, irrespective of plant arrangement, grain yield increased with the levels of nitrogen up to 175kg/ha and then decreased when 250kg/haN was applied, except in the high density with suffolk coulter where grain yield continued to increase at 250kg/haN (Table 3.18). This is in agreement with Archer (1985) who suggested that the optimum levels of N for grain yield for a 7 to 8t/ha crop on chalky soils is approximately 175kg/ha. Grain yield from the band coulter at 175kg/ha nitrogen was the same for the medium and high density, giving a 0.65t/ha yield increase over the low density. Low density plots gave the highest yield with the band coulter at 0kg/haN , but recorded the lowest yield with the suffolk coulter (Table 3.18). When 100kg/haN was applied grain yield from the suffolk coulter was highest at the medium density, but with the band coulter highest grain yield was recorded at the high density (Table 3.18).

Table 3.18. Total grain yield (t/ha 86%DM).

	Suffolk Coulter.				Band Coulter.				
Nkg/ha.	Density (Seeds m-2).				Density (seeds m-2).				
	D1 200	D2 350	D3 500	Mean.	D1 200	D2 350	D3 500	Mean.	SED.
0	5.30	6.04	5.67	5.67	5.61	4.85	5.04	5.17	
100	7.45	8.33	7.71	7.83	7.02	7.63	7.86	7.50	
175	7.80	8.75	8.40	8.32	7.45	8.10	8.10	7.88	
250	7.71	8.32	8.61	8.21	6.91	7.66	7.59	7.39	
Mean	7.07	7.86	7.60		6.75	7.06	7.15		0.5

3.3.8.Harvest index (%HI).

The proportion of grain yield to above ground biological yield (harvest index), showed the highest value at the medium density for both plant arrangements (Table 3.19). The harvest index increased (NS) with the suffolk coulter 59.7% versus 48.2% for the band coulter. The lowest harvest index was recorded at the low density with the suffolk coulter, but the band coulter gave the lowest harvest index at the high density. At the medium density harvest index increased (NS) with the levels of nitrogen for the suffolk coulter treatment (Table 3.19). No consistent trend in harvest index was recorded with the treatments.

Table 3.19. Harvest index (%HI).

	Suffolk Coulter.			Band Coulter.		
Nkg/ha.	Density (seeds m-2).			Density (seeds m-2).		
	D1 200	D2 350	D3 500	D1 200	D2 350	D3 500
0	54.6	64.1	58.5	50.3	46.9	44.0
100	50.0	65.1	61.5	44.2	56.2	47.6
175	59.6	65.9	61.3	49.1	50.5	51.7
250	50.5	68.8	56.5	45.2	48.0	44.5

3.4.Discussion.

The principal objective of experiment 2, was to study the effect of plant arrangement on the development and yield of winter wheat variety-Slejpner by using two drilling systems. In order to determine a range of crop responses to different establishment technique, agronomic practices such as plant population density and different levels of fertilizer N were included as additional main effects of the experimental treatments. Preliminary investigations using an 'informal' experimental design on commercial farms by the Impact on Farming Research (IF) during 1984/85 suggested possible yield advantage from drilling using the band coulter compared to the suffolk coulter normally used in British agriculture. Because the previous findings were informal, no detailed information was given, since results were not statistically analysed. Hence, experiment 2 was designed with the view of exploring the claims in more detail, using a more precise statistically designed experiment.

The inclusion of different plant populations and N levels was agreed in order to find possible treatment combinations that may have resulted in higher biological (biomass) yields, as this information was lacking from the previous establishment work of Rogers and his colleagues presented in 1984 (Butterworth personal communication). Achieving the best combinations of these agronomic factors might provide basic information for future practical recommendations. In order to determine the effect of the drilling techniques, results were compared at the same plant populations and N levels.

Visual plot observations of the two plant establishments, eluded the optimisms with which the experiment was initially set. The initial claim that drilling using the band coulter would result in complete ground cover by the wheat plants, was not achieved. The nature of the seedbed was first considered to be responsible for the incomplete ground cover in 1986/87. The cloddy nature of the chalky soil at Olantigh was

assumed to have affected the efficiency of the band drill. However these assumptions were to be proved incorrect from observations and data obtained in subsequent trials in the following two seasons, using different sites and wheat varieties.

In succeeding trials the milling winter wheat Avalon, (experiment 3) and spring wheat Axona were grown (experiment 1). The pattern of crop establishment and the subsequent biological yields obtained for the three seasons experiments were similar, irrespective of variety and locations. Thus soil type and crop variety were not responsible for the band establishment results obtained in the first (1986/87) growing season (experiment 2). It was concluded after reviewing the results of experiments 1, and 2 that the yield advantage of drilling with a band coulter suggested by previous workers (see literature review pages 35-37) was optimistic, and their inability to present statistical interpretation of the results may have proved misleading to many commercial producers.

3.4.1.Biological yield.

Total dry matter m-2 was consistently higher using the band coulter drilling method (Table 3.3). This resulted from more plants m-2 (Appendix 3.1). In order to further ascertain the cause of increased dry matter with band coulter drilling, individual plant dry weights were calculated (Table 3.4). This demonstrated a trend of increased dry weight with the band system only at the first two sampling dates (S1 and S2) Table 3.4. From 192 days after drilling (S3) plant dry weights were consistently higher with the suffolk coulter drill (Table 3.20).

Biological yield after anthesis is dependent upon the vegetative contribution of non ear bearing tillers, the translocation of assimilates to the grains and post anthesis photosynthesis (Spiertz, 1983; Biscoe and Willington, 1984a). The higher (NS) grain yield

(7.51t/ha) given by the suffolk coulter drilling was linked with a consistently higher (NS) plant dry weight in experiment 2 (Table 3.4). This is similar to the results described by Pearman et al. (1977) at Rothamsted working with the spring wheat cultivar Kleiber. For example, the mean plant dry weight at anthesis (S5) averaged over N levels were 6.73g, 4.6g and 3.83g for the low, medium and high densities respectively. Corresponding values for the band drilling method were 5.48g, 4.38g and 3.6g, hence the reduction in grain yield. However, the lower (NS) grain yield (6.99t/ha) given by the band coulter drilling system is difficult to interpret fully using the results obtained from this trial.

Table 3.20. Summary of total dry matter m-2, dry matter per plant, numbers of tillers m-2 and tillers per plant as infuenced by drilling methods.

Drilling methods.	Sampling						
	S1	S2	S3	S4	S5	S6	S7
			Total dry matter (g) m-2.				
Suffolk	25.8	44.8	214.9	379.1	690.9	872.7	1262.2
Band	27.6	58.8	259.5	428.1	798.4	982.6	1456.6
			Dry weight per plant (g).				
Suffolk	0.11	0.25	1.26	2.83	5.05	6.82	—
Band	0.13	0.27	1.26	4.45	4.48	6.37	—
			Numbers of tillers m-2.				
Suffolk	405.8	829.7	969.0	631.6	487.9	425.6	392.2
Band	349.1	1015.8	1222.6	749.3	587.6	498.0	450.0
			Numbers of tillers per plant.				
Suffolk	2.8	5.4	6.1	4.7	3.6	3.4	—
Band	2.7	5.3	6.0	4.4	3.3	3.1	—

The average results of total dry matter m-2, the individual plant dry weight, total numbers of tillers m-2 and the numbers of tillers per plant are summarised in Table 3.20 so that comparisons can be made

easier. The crop growth rate obtained was higher with the band drilling technique. This resulted from a corresponding increase in total biomass given by this treatment. Crop growth rates during the period from tillering (GS23) to anthesis (S1 to S6) varied from 11.7 to 13.3g m-2/day for the suffolk and band coulters respectively. However, as these mean values were calculated from the means of total dry matter matter change m-2, it is extremely difficult to make precise conclusions regarding the calculated difference of 1.6g m-2/day.

The increase in dry weight per plant obtained from the suffolk coulter drilling system was probably due to the slight increase in the numbers of tillers per plant (Table 3.20). This increase may have been due to reduced interplant competition, resulting from fewer numbers of plants per unit area. The yield components such as numbers of grains per ear and the thousand grain weights were also slightly higher also with the suffolk coulter (Tables 3.15 & 3.17). These might have compensated for the lower numbers of ears m-2, hence the higher grain yield (Table 3.18).

Total dry matter m-2 as well as individual plant dry weight increased significantly ($P<0.05$) with the additional fertilizer N (Tables 3.3 & 3.4). This increase resulted from additional numbers of tillers m-2 and per plant (Tables 3.6 & 3.7). Crop biomass m-2 increased from 39.2g to 65.8g soon after the first split application of N (S2) when N fertilizer was increased from zero to 250kg/ha (Table 3.21). At the final sample (S7), the amounts of dry matter accumulated m-2 with these treatments were 1023.6g and 1521.6g respectively (Table 3.21). Similarly, the individual plant dry weights given by the same treatments increased from 4.82g to 7.45g at anthesis (S6). A summmary of the results is presented in Table 3.21. The corresponding numbers of tillers m-2 and per plant which contributed to the increase in total dry matter yields and the individual plant dry weights are also given (Table 3.22).

Table 3.21. Summary of total dry matter (g m-2) and individual plant dry weight (g) at different rate of N fertilizer.

N (kg/ha).	Sampling.						
	S1	S2	S3	S4	S5	S6	S7
			Total dry matter (g m-2).				
0	26.7	39.2	174.3	298.8	572.9	689.3	1023.6
100	—	45.6	228.0	405.0	726.7	960.3	1442.9
175	—	56.3	254.7	449.5	838.5	1038.3	1449.6
250	—	65.8	292.0	461.2	840.3	1022.7	1521.6
			Dry weight per plant (g).				
0	0.12	0.24	0.91	1.98	3.67	4.82	—
100	—	0.26	1.22	2.67	4.78	6.80	—
175	—	0.29	1.37	2.80	5.35	7.30	—
250	—	—	1.55	3.03	5.47	7.45	—

The additional N resulted in an increased tiller production (Table 3.22), and consequently caused a significant increase ($P<0.05$) in total dry matter m-2 and per plant (Table 3.21). Numerous scientific reports (Hay, 1982; Hay, Galashan and Russell, 1986; Hay and Walker, 1989 and Evans 1980) have described a similar increase in the dry matter of winter wheat resulting from additional N fertilizer caused by increased tillering. Results of this experiment are in agreement with those reported by these authors. However, the highest total dry matter obtained from application of 250kg/haN did not result in similar grain yield for the two drilling systems. The average grain yields recorded from treatment N3 were 8.21 and 7.39t/ha for the suffolk and band coulters respectively. By comparison, treatment with 175kg/haN produced a smaller difference, giving grain yields of 8.32 and 7.88t/ha corresponding to the two drilling techinques (Table 3.18). This may be partly explained by excess tiller production.

The highest numbers of tillers m-2 (Table 3.6) obtained by the application of 250kg/haN may have caused overshading, which would reduce the penetration of photosynthetic active radiation. This in turn would

have limited the photosynthetic capacity of the crop canopy. caused a reduction in grain yield (Pearman et al., 1979). Increase in the number of tillers per plant (Table 3.7) resulting from the application of 250kg/haN may resulted in intraplant competition, therefore decrease the numbers of grains per ear and the thousand grain weight and invariably reduced the total grain yield (Darwinkel, 1978 & 1980).

Table 3.22. Summary of numbers of tillers m-2 and tillers per plant at different levels of N fertilizer.

N (kg/ha).	Sampling.						
	S1	S2	S3	S4	S5	S6	S7
			Numbers of tillers m-2.				
0	377.6	790.6	865.1	550.0	364.0	313.9	291.9
100	—	940.2	1070.1	672.5	494.0	461.9	409.2
175	—	1088.3	1134.7	776.3	614.6	522.8	451.5
250	—	—	1313.3	779.7	678.7	548.2	528.9
			Numbers of tillers per plant.				
0	2.8	4.7	4.6	3.6	2.3	2.2	—
100	—	5.4	5.9	4.6	3.3	3.2	—
175	—	6.0	6.5	4.9	3.9	3.7	—
250	—	—	7.2	5.2	4.2	4.0	—

Although the expected plant populations (Appendix 3.1) were not achieved, the total dry matter yields m-2 increased significantly ($P<0.05$) with the seed rates until anthesis (S6). At the final sampling (S7), the highest and lowest biomass m-2 were recorded from the low and medium densities respectively (Table 3.23). It is difficult to clearly explain the increase in dry matter which was recorded with the low population at the final sample (Table 3.23). It may have been due to late tillering at the lower density. Puckridge and Donald (1967); Darwinkel (1978) reported late tiller production at low densities of 184 and 5 to 100 plants m-2 respectively. This is similar to experiment 2 in which later formed tillers were recorded from the low plant

population (200 seeds m-2). The existence of fresh and green leaves observed on the late tillers must have affected the dry matter recordings during the final sampling.

Increase in total dry matter m-2 with plant population did not influence grain yield in the same way (Table 3.18). The medium density gave higher (NS) grains yield of 0.79 and 0.26t/ha over the low and high densities with the suffolk coulter drilling method. By using the band coulter drilling technique, slight increases in grain yield of 0.40 and 0.09t/ha were recorded from the high compared to the low and medium densities (Table 3.18). The influence of plant population on dry matter production of the wheat variety-Slejpner during the 1986/87 growing season is summarised in Table 3.23. These results indicate a steady increase in total biomass with the corresponding increase in plant population density. However, the converse was true when the individual plant dry weights were compared. The decrease in plant dry weight with the density started to manifest at 192 days after drilling (S3) Table 3.23. This period coincided with the time of maximum tiller production, and probably the start of tiller death caused by intraplant competition.

Table 3.23. The influence of plant population on the total dry matter (g m-2) and dry weight per plant (g).

Population (Seeds m-2).	Sampling.						
	S1	S2	S3	S4	S5	S6	S7
			Total dry matter (g m-2).				
200	18.3	38.5	191.8	375.2	658.4	868.5	1412.7
350	25.8	55.0	337.3	398.2	754.3	935.2	1295.0
500	36.1	62.1	282.6	437.5	821.2	979.3	1370.6
			Dry weight per plant (g).				
200	0.12	0.27	1.46	3.46	6.10	8.94	—
350	0.13	0.28	1.32	2.49	4.49	5.94	—
500	0.13	0.24	1.00	1.96	3.71	4.90	—

3.4.2.Effect of density on the yield components.

Grain yield in wheat depends on the yield components: number of ears per unit area, number of grains per ear and thousand grain weight. A mutual compensation is usually found between these yield components, for example decrease in 1000grain weight can be compensated for by the increase in number of ears. However, a limitation of one component might not be completely compensated for by the other. In order to achieve a muximum grain yield a favourable crop growth environment is necessary. Grain weight and the final grain yield predominantly depend on the extent of assimilation during the stages of grain filling. It had been reported by many workers including Puckridge and Donald (1967), that, grain production in cereals, especially in wheat, depends heavily on the area and duration of the photosynthetic surfaces of the ear, the flag leaf, and the uppermost node of the stem (peduncle). In all cereals, other than maize, the leaf area index (LAI) decreases gradually after anthesis.

For most crops the effects of plant density are vaguely attributed to interplant competition, and the interaction between light water and nutrients. In experiment 2, growth analysis demonstrated that, the tillering phase was longer in the low plant population density than in the medium and high densities (Table 3.6). Therefore, the number of tillers per plant was largely favoured by the low density (Table 3.7).

Number of grains per ear and grain weight were increased by the low density, but, decreased with the medium and high densities (Tables 3.15 & 3.17). The decrease in number of grains and grain weight with the increase in density probably resulted from reduced carbohydrate supplies from the thinner stems and the leaves. Similar results were described by Fisher, Aquilar and Laing (1977). These authors also reported that, at high densities (>400seeds m-2) there were less reserves of carbohydrate in the ear-bearing shoots before anthesis. Crop respiration

was also higher, which again restricted grain-filling. They also found that up to a level of 30,000 grains m-2, grain yields were higher as number of grains increased, although grain weight gradually decreased.

In experiment 2, mean number of grains m-2 (results not presented) were less than 27,000 in the three densities, but, even in this case number of grains per ear and grain weight decreased with the increase in density (Tables 3.15 & 3.17). The low number of grains m-2 was probably due to the low number of grains per ear, or the inability of this experiment to produce the expected populations of 200, 350 and 500 plants m-2; which should have resulted in maximum number of grains per unit area. Mean numbers of grains per ear in this experiment were 44.0, 43.4, 40.5 and 39.4, 40.7, 38.1; corresponding to the three densities, for the suffolk and band coulters respectively (Table 3.15). The winter wheat, variety-slejpner, normally produces an average number of grains per ear in the range of 45-55. Therefore, the numbers of grains from these treatments were lower than expected.

The average number of spikelets initiated per ear was influenced by the decrease in plant population density (NS) Table 3.14. The fertility of these spikelets on the other hand was reduced by increasing plant population densities. This was reflected in a lower (NS) number of fertile spikelets per ear (Table 3.14) and a slightly lower number of grains per fertile spikelet, in the higher density treatments (Table 3.16). Number of grains per ear was considerably lower at high plant density (Table 3.15), because there were fewer fertile spikelets per ear. Inspite of the lower number of grains per ear, 1000grain weight was also lower with increasing density. This caused a decrease in grain yield in the highest density (Table 3.17). Similar results were reported by Willey and Holliday (1971) in spring and winter barley varieties (Proctor and Rika).

The reproductivity of tillers was affected by plant density (Table 3.6). This probably resulted from several causes: fewer assimilates were produced per tiller, fewer storage resources were available to be translocated, and the partitioning of dry matter between grains and the rest of the plant parts was unfavourable. These suggestions are in agreement with the results described by Darwinkel (1980), who reported a decrease in productivity of tillers per plant from 15.1 to 5.4 when density was increased from 50 to 600 plants m-2. This author also reported that the grain yield per ear decreased because spikelets differentiation, grain set and grain filling were inadequate as a result of an increase in density.

The proportion of tillers which produced ears per plant increased with the decrease in density. At the low density the mean numbers of tillers per plant which produced ears were 4.6 and 4.2, corresponding to the suffolk and band coulters; compared to 2.9, 2.6 and 2.9, 2.3, for medium and high densities for the respective plant arrangements (Table 3.7). However, as the density increased more reproductive tillers were formed per unit area, and despite a higher tiller mortality, more ears were produced m-2 (Table 3.6). Similar results were reported by Darwinkel (1978), working on winter wheat cv. Lely. This author also concluded that, the productivity of individual ears from mainstems as well as from tiller-ears decreased with increasing plant density. Palmer and Madge (1983) also found that increasing seed rates increased the number of ears per unit area while decreasing both the number of grains per ear and grain weight. This was similar to experiment 2, in which the highest number of ears m-2 was recorded at the high density, whilst number of grains per ear and 1000grain weight decreased (Tables 3.15 & 3.17). With increasing density the space per plant diminished and interplant competition increased. At low density the reduced degree of interplant competition prolonged tillering, so that a high number of reproductive tillers per plant survived.

Tillering, ear formation and productivity of an ear-bearing tiller are determined by their location within the crop canopy and by the growing conditions. Physiological processes determine competition for light, the supply of nutrients and water, and the rate of plant development from ear initiation up to plant maturity. Within dense plant communities, competition for nutrients and water from the soil and radiation from sunlight may largely influence ear development. These factors could also have been true in experiment 2, where the low tiller production per plant (Table 3.7) might have resulted from plant competition during tiller development.

Gallagher, Biscoe and Scott (1976), reported from studies on spring barley variety-proctor, that the size of the ear mostly depends upon the conditions prevailing during the growth stages at which initiation, differentiation and fertilization of spikelets take place. This conclusion may also be true for winter wheat. For example, conditions favouring reduced competition between plants at low density favoured survival of more ears per plant; as shown by the results in experiment 2. In this experiment, competition for light (January-March, 1987), at tillering and ear development was probably the most important factor. These periods experienced low temperatures (Appendix 3.2) and long duration of cloud cover which must have reduced the level of solar radiation and therefore, photosynthesis. Total monthly sunshine during this period ranged from 41.8 to 97.6hrs (Appendix 3.4). Therefore, supply of carbohydrates would have been limited which might have affected the physiological processes from tillering to ear formation.

With increasing plant density interplant competition became more severe and additional tillers died. On May 6th (S3), total numbers of tillers m-2 were 901.0, 931.1, 1076.9 and 1089.0, 1169.2, 1409.6 (Table 3.6). By the 20th of May (S4), number of tillers had decreased by 296.1, 306.1, 412.1 and 334.6, 485.8, 600.4, corresponding to the low, medium

and high densities for the suffolk and band coulters respectively (Table 3.6). Tillering also ceased earlier with increase in density. Puckridge and Donald (1967) also described a similar results for winter wheat, variety-Insignia 49.

As the density increased, the number of tillers per plant and their dry weight were reduced (Tables 3.7 & 3.4). Similar results were also reported by Darwinkel (1978). This author concluded that, in high density crops, interplant competition begin earlier, and this affects the numbers of spikelets initiated, numbers of fertile spikelets and the numbers of grains per fertile spikelet and consequently the total numbers of grains per ear. At high density, competition for light may have affected ear development and subsequently ear size. This was in agreement with the results described by Puckridge (1968) in a winter wheat cv. Gabo. This author also reported that, differences in population density can have marked effects on the growth and development of the plants even when the soil volume available to the individual plants is the same. He concluded that light intensity is one of the important factors for wheat development from double ridges to ear emergence. In experiment 2, variation in ear size was noticed shortly after anthesis, which later resulted in fewer numbers of spikelets per ear (Table 3.14). The shorter grain filling period possibly as a result of high radiation, coupled with high temperatures in June, 1987, could have been contributory factors for lower grain yield at the high density.

Although increasing the number of plants per unit area had a negative effect on plant growth and development, it is important to note that, more ears per unit area can only be achieved by increasing plant densities. Table 3.12 demonstrates that, the highest number of ears m-2 was obtained by the high density (500seeds m-2). The low density produced more ears m-2 than the medium density. This means that, plants

in the lowest density over compensated by producing excessive reproductive tillers, and subsequently number of ears m-2. Power and Alessi (1978) reported that, a greater number of tillers per plant was produced at low plant densities in a semi-dwarf spring wheat variety, but, the total number of ears per unit area was mainly influenced by the increase in plant density.

In experiment 2, the percentage of tillers that survived and produced ears at the final sample (S7), decreased with density treatment (Table 3.6). A probable explanation could be that, the amount of light intercepted by a single plant at higher plant density was comparatively low, while at low density more light was available per plant. However, even at the low density, tillers which survived and produced ears were only 44% and 40% corresponding to suffolk and band coulters (Table 3.6). Puckridge and Donald (1967), reported similar results with a percentage tiller mortality of 16.3% and 58.7% when the density was increased from 184 to 1078 seeds m-2. This suggests that even at low densities a hundred percent tiller survival is not possible. Thus, for optimum number of ears per unit area, high density would still be an ideal agronomic practice for an increased yield. Darwinkel et al. (1977),recorded a higher grain yield of 7.04t/ha at 160 seeds m-2 as against grain yield of 6.43t/ha with seeding rate of 80 m-2, using winter wheat cv. Lely in the Netherlands.

At the high density (500 seeds m-2), the number of ears per plant averaged over suffolk and band coulters at crop maturity were about 2.0, as compared to low density which recorded about 4.0 ears per plant (Table 3.7). Average number of ears m-2 for the same densities and the two different drilling systems were 416.7 and 449.7 respectively. Similar results were reported by Joseph, Alley, Brann and Gravelle (1985). These authors reported a decrease in number of ears to about 1.0 per plant, when the seeding rate was increased from 186 to 372 m-2, with

an average plant population of 289 m-2, in red winter wheat cv. Tyler in Virginia, (USA).

In experiment 2, it was observed that, many later-emerged tillers produced ears at the low plant density, and the ear formation of the later formed tillers decreased with the increase in density. This was in agreement with the results reported by Darwinkel (1980), in an experiment using a winter wheat cv. Lely. This author also reported that, to achieve complete light interception, leaf area index (LAI) ranging from 4 to 6 would be the best. However, this must be reported with cautiousness, as high LAI in cereals such as wheat, may be susceptible to diseases and pests especially when high inputs of nitrogen fertilizer are applied, and these may also cause over shading. However, in this experiment, despite the increase in density, severe disease and pests problems which could result in economic yield reduction were not observed during the growing season. This could be as a result of the poor plant establishment in 1986/87 growing season, where the targeted plant population which may have resulted in disease and pest susceptibility was not achieved.

In experiment 2, the medium density (350 seeds m-2) was probably the optimum plant population. Although the lowest number of ears were recorded at this density, for both suffolk and band coulters (Table 3.6), it recorded the highest grain yield. Average total grain yields for this experiment as influenced by the densities, were 6.92, 7.46 and 7.38t/ha corresponding to low, medium and high densities. Therefore, number of ears per unit area was not the main yield determining factor in this experiment. This suggest that in a crop situation with an expected plant population density of 350 m-2 grain yield could be independent of the composition of the ear population. Similar results were also reported by Darwinkel (1978). It could also be argued that, the conditions which allow maximum yield potential of a single plant to

be expressed by plant subsampling on a small area as in this experiment were not those which contributed to high yields per unit area. High grain yield of wheat per unit area as suggested by Nerson (1980), is probably depends upon some degrees of plant competition. It had been reported by Darwinkel (1980), that, at low density tiller growth must be stimulated to compensate for the low number of plants; and that at high plant density growth of plants must be restricted, and reduced plant competition so as to reduce yield lost.

3.4.3.Spikelet initiation and grain set.

In wheat, spikelet initiation is correlated with the double ridge stage of development. To enhance the production and development of spikelets the first split application of N fertilizer in experiment 2 was targeted just before this stage. Application of 250kg/ha N increased spikelets significantly ($p<0.05$) Table 3.14. There was a consistent trend in spikelet increase with the levels of 100, 175 and 250kg/haN over the control. Number of spikelets increased from 20.9, 19.5, 19.8 to 22.1, 21.5, 21.1 and from 20.7, 19.6, 19.5 to 22.9, 21.4, 20.8, with the low, medium and high densities when levels of N was increased from zero to 250kg/ha, for suffolk and band coulters respectively (Table 3.14).

Increasing the levels of N showed a trend towards spikelet survival. At plant maturity, the number of spikelets per ear which survived were 19.2, 17.9, 17.4 to 20.4, 19.8, 19.5 and 18.7, 18.5, 18.1 to 21.3, 20.0, 19.2 corresponding to plant population densities and the drilling systems (Table 3.14). Increasing the levels of N to 175kg/ha reduced percentage spikelet degeneration, with the 250kg/haN having a little effect (Table 3.14). Similar results were also reported by Darwinkel (1983) for three different varieties of winter wheat Caribo, Arminda and Okapi in the Netherlands. Increase in the number of spikelets per ear with the levels 100, 175 and 250kg/haN was attributed

to prolonged ear development. During the growth and developmental period of the crop, it was observed that ear emergence from plots with no N treatments were about 4days earlier than those which were treated with different levels of N. Also, in the N treated plots, days to ear emergence increased with the levels of N. Rawson (1970) reported an increase in the number of spikelets per ear in winter wheat variety-Triple Dirk as a result of slow development caused by short daylenth or low temperatures. These arguments were later substantiated by Allison and Daynard (1976) in the winter Canadian wheat variety-Marquis.

In this field experiment, soil and air temperatures at the experimental site were not monitored, however the meteorological station results were adjacent to the experimental site. Therefore, it could be argued that, the low temperatures experienced during December, 1986 to March, 1987 (Appendix 3.2) might have had an interaction with the levels of N inducing slow reproductive development in this particular variety, this may have contributed to an increase in the number of spikelets per ear. It was argued that the slower development of the basal spikelets required a longer duration of N uptake from the soil. Langer and Hanif (1973) reported an increase in basal spikelets development in a pot experiment with high levels of N supply (150ppm) in winter wheat cv. Aotea. This is also similar to experiment 2, in which increase in the number of spikelets may have resulted from an increase in the basal spikelets.

Although, increasing the levels of N from zero to 250kg/ha increased number of spikelets per ear as shown by the results in Table 3.14, number of grains per ear was reduced (Table 3.15). This was probably due to certain environmental conditions and some management problems which arose from the unfavourable field conditions in the 1986/87 growing season. For example, the low soil moisture emanating from the poor rainfall (Appendix 3.3) during and after anthesis in June,

1987, might have affected grain set. High radiations at this period contributed by a long duration of sunshine (Appendix 3.4), coupled with high temperatures (Appendix 3.2), may have influenced high photorespiration in the plants. This high photorespiration could result in flower abortion, and consequently fewer grains per spikelet as well as numbers of grains per ear.

Number of grains are determined by conditions before anthesis that is, from floret initiation to ear emergence. It depends largely on the initiation, differentiation and further development of the spikelets. The number of well grown spikelets and their fertility determined the number of grains produced. Therefore, in order to stimulate grain set, N treatment should be applied before the onset of anthesis. This would induce grain set and grain survival.

Increasing the levels of N in experiment 2, decreased the number of grains per ear and number of grains per spikelet (Tables 3.15 and 3.16). A possible reason could be intraplant competition, since high levels of N increased reproductive tillers per plant (Table 3.7). These could compete for nutrients, water and sun light. Also tillers that were produced at the later part of the growth period as a result of increased levels of N, may have provided alternative sinks for carbohydrates and consequently affect their supply to the ears for grain set. This would result in low numbers of grains per ear. Batey and Reynish (1976) studied 44 experiments, with five levels of N on commercial farms in Southern England, and noted that, an increase in late tiller initiation induced by high N application led to a corresponding decrease in number of grains per ear and grain sizes. Similar results were also reported by Langer and Liew (1973) in cv. Arawa. This result was similar with those reported by these authors, where high levels of N also influenced late tiller production.

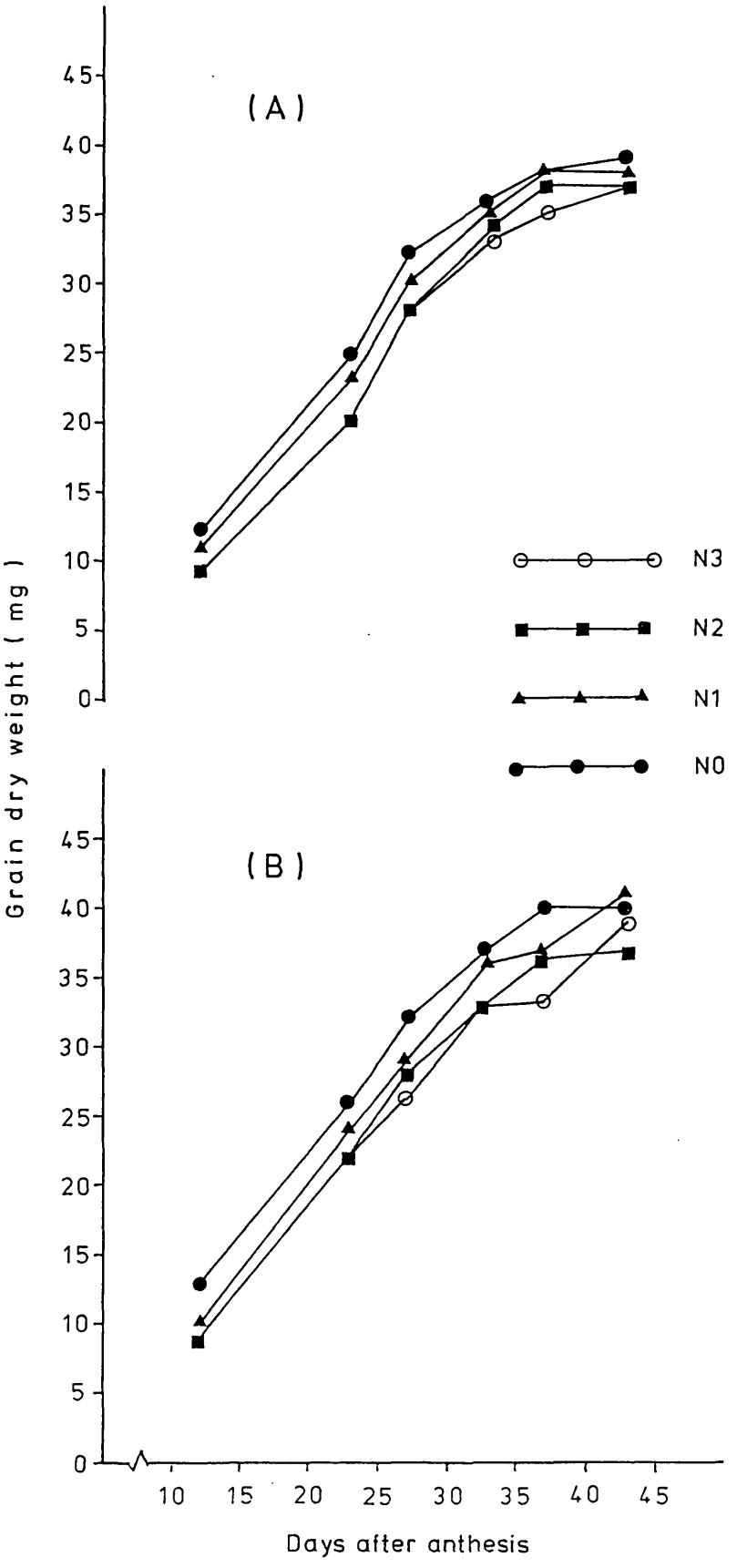
In this experiment the second split application of N was delayed due to dry weather conditions (Appendix 3.3). Therefore, the application of N at growth stage 30 was probably too late to achieve high floret initiation. Langer and Hanif (1973) found in the winter wheat cv. Hilgendort, that florets were more developed 20days after the double ridge stage. These authors concluded that, in order to stimulate floret initiation application of fertilizer N should be carried out immediately after the double ridge stage (floret initiation). The lower number of grains may also have resulted from leaching of soil N which is known to cause incomplete grain-filling (Grylls and Archer, 1984). These grains would be very small in size and could easily be left in chaffs during harvest, or lost in the combine sieves. But, this is only speculative since no estimate of N leaching was carried out. Since florets in the most basal spikelets develop slowly (Langer and Liew, 1973), any factor which affects N availability will influence the production of small or prevent grain set. Increase in the levels of N had no effect on the number of grains per spikelet (Table 3.16). The cause of reduction in the number of grains per ear discussed above did not have a similar effect on the number of grains per spikelet.

3.4.4.Depression in grain weight.

Grain weight is largely established by growing conditions after anthesis. Because of the considerable short period of grain-filling, during the 1986/87 growing season, grain weight was relatively low in experiment 2, (Table 3.17). This variety under average conditions of grain-filling would produce grain weights within the range of 45g to 50g (NIAB 1986).

The ultimate yield of winter wheat is determined not only by the rate of grain growth, but also by its duration. High temperatures in the field after anthesis would impose a major limitation on winter wheat

Fig. 3.4 GRAIN DEVELOPMENT
(A) SUFFOLK COULTER AND (B) BAND COULTER.



yield, through reduction of the duration of grain growth; and consequently reduced final grain size in all floret positions. This is also true for this experiment, where the grain-filling period in the last and first weeks of June and July, 1987 respectively, suffered a high temperature. For example, temperatures on June the 29th, and July 6th, 1987 were 26.6 and 27.3^{o}C respectively (Appendix 3.2). High temperature during the grain-filling period could accelerate protein accumulation in the grains and, therefore, deplete N reserves in the vegetative part of the plant faster (Vos, 1981). This N depletion, especially in the leaves, tends to accelerate leaf senescence and thus reduce photosynthesis quickly, in comparison with the duration of grain-filling. Although in experiment 2, decline in photosynthetic rate with time was not monitored, it could be argued that, the short period of grain-filling may have resulted from early leaf senescence caused by the temperature effects (Appendix 3.2).

The greatest demand of grains for N occurs during the mid-grain filling phase (Spiertz and Ellen, 1978). In this experiment, this period coincided with low soil moisture as a result of low precipitation. This probably affected the N uptake by the crop from the soil. The high temperature at this period could have caused a high photorespiration and therefore affected the amount of carbohydrates that could be available for grain-filling; and consequently reduced grain size. The decrease in grain weight with the increase in N levels was probably contributed by the slow development of the ear, which later on resulted in a late grain growth.

Although grain-filling measurements (from June 29th) did not start at the onset of grain-filling, it is apparent from Figure 3.4 that, grain growth was earlier from plants without the fertilizer N treatments. When plants were treated with N fertilizer, the grain-filling period was extended with the increase in N levels. When grain-

filling studies started on June the 29th, plots with zero level N had grain dry weights of 13mg and 12mg, for the suffolk and band coulters respectively. Treatment with 100kg/ha recorded grain dry weight of 10mg and 11mg; then 175 and 250kg/ha both recorded the same grain dry weight of 9mg each for both the two plant arrangements (Figure 3.4).

Batey and Reynish (1976), reported a similar result with a larger grain size at zero level of N; these authors also concluded that grain size decreased with the increase in N levels from zero to 200kg/ha. Eagle (1968), used 1000grain weight as a test of grain size on winter wheat variety-Maris Huntsman, and found that a marked reduction in grain size occured when N levels were increased from 50 to 200kg/ha. This suggests that,grains from untreated plants might have reached a higher maturity stage and could escape any environmental stress caused by high temperature and low soil moisture which occurred in June, 1987.

The morphological and physiological effects of N are usually associated with greater number of tillers, and with decreased growth per tiller presumably caused by increase competition between neighbouring tillers. In addition, later formed tillers develop more rapidly, and these restricts ear size. So the later the tillers emerge, the worse the chances will be for the growing ear. This argument was also put forward by Darwinkel (1978). Increasing the levels of N produced higher number of reproductive tillers (Tables 3.6 and 3.7). Therefore, intraplant competition among tillers could have resulted in smaller potential grain size and lower grain weight. Also the increase in tiller competition will affect the partitioning of assimlates to the grains which might consequently resulted in smaller grain size with the increase in N levels (Table 3.17).

The combination of smaller potential size of grains per unit area of leaf might result in an inadequate sinks and so decreased grain size, as suggested also by Pearman, Thomas and Thorne (1978), working with

winter wheat, semidwarf variety-Maris Fundin and Hobit and tall varieties-Cappelle-Desprez and Maris Huntsman using eight different rates of N levels, ranging from zero to 210kg/ha in a spring application at Rothamsted Experimental Station. They concluded that decrease in grain weight was associated with the levels of N above 90kg/ha. Results from experiment 2 were similar to the one described by these authors, in which the grain weight also decreased with N levels from 100 to 250kg/ha (Table 3.17). It has been, reported that decrease in grain weight with the increase in N levels is more pronounced in the semi-dwarf varieties (Pearman et al. 1978). This was also true with experiment 2, in which the simi-dwarf variety-slejpner (straw height never exceeded 85cm), showed a decrease in grain size with N levels (Table 3.17).

Increasing the levels of N can also result in late tillers. These are unfavourably situated at the plant base and have a shorter growth period than the mainstem and ear-bearing tillers. Therefore, the carbohydrates supply for grain-filling is restricted and when the grain-filling period would be short as in this experiment, this may have contributed to lower grain weight. Greater proportion of the number of grains per plant are normally contributed by the tiller ears when plants are treated with N, than the mainstem ear. These grains from the tiller ears are relatively smaller as a result of the factors mentioned earlier on, therefore, the corresponding 1000grain weight from the treated plants would obviously decrease (Table 3.17).

When plant arrangements and density effects were not considered in this experiment, the average percentage decreases in grain weight with increase of N fertilizer from zero to 250kg/ha were 6%, 11% and 15%. But, relatively the effect of N levels on grain weight was influenced by low densities (Table 3.17), probably as a result of more reproductive ears produced per plant at the low density. The tillering phase resulted from increasing N levels was longer in the lower population than the

medium and higher population. This could possibly affected the grain development; by delaying the grain set, with a shorter grain filling period, which consequently resulted in smaller grains in the low density, compared to the medium and high densities. This was similar to the results reported by Puckridge and Donald (1967) in wheat and Kirby and Faris (1970) in barley.

Batey and Reynish (1976) reported a larger grain size at zero levels of N in their studies on commercial farms in Southern England. They recorded the lowest grain weight at 200kg/haN. However, many workers have reported an increase in grain weight with the levels of N. The increase in grain weight with the levels of N as reported by Darwinkel (1983), in the winter wheat varieties: Caribo, Arminda and Okapi, was influenced by the increase in leaf area duration (LAD). However, Paris (1986), reported a decrease in grain size with increase in the levels of N levels. In experiment 2, increase in the levels of N resulted in grain shrivelling and consequently lower grain size (Table 3.17).

It had been reported that higher rates of N fertilization increased vegetative growth at the expense of grain production. In this experiment, plants treated with N were taller, had thicker culms broader leaves, and larger ears, while the seeds were actually smaller. Similar results were reported by Gardner and Jackson (1976) in spring wheat. They concluded that increasing the N levels from 112kg/ha to 336kg/ha decreased grain size and promoted the vegetative growth of the crop.

3.4.5.Environmental influence on nitrogen availability.

Winter of the 1986/87 growing season was severe and low temperatures covered almost half of the growing season (December-March), Appendix 3.2. The period from January to June 1987, had relatively low rain fall. Total monthly rain fall during these periods range from

22.3mm to 67.5mm (Appendix 3.3). During the same interval of time, there was high radiation. The total monthly sunshine was in the range of 41.8hrs to 193.1hrs (Appendix 3.4). Later in the month of July, there was a relatively high rainfall, with about 124.2mm (Appendix 3.3). The initial cold, but later dry and then, relatively wet period must have affected the availability of N from the soil. Diez and Sommer (1979) reported that, during a cold period with air temperature of less than 5^{o}C , mineralisation of organic N to inorganic forms was slow, resulting from inactive soil micro-organisms. An increase in soil mineral N was found in the subsequent warmer periods (10-30^{o}C). These authors also reported a decrease in N uptake as a result of low soil moisture (<20mm) which rendered many biological processes inactive.

The low temperature at the beginning of the 1986/87 experimental growing season probably affected the mineralisation of soil organic matter. Although no soil measurements of nitrate availability were taken, plant growth rate was possibly reduced by low soil reserves before the application of inorganic fertilizer N in March. Heavy rain in the later part of the growing season may have leached N from the rootzone, whereas the preceding dry conditions could have limited growth by water stress, with stomatal closure inhibiting photosynthesis.

From experimental studies it can be demonstrated that the response of winter wheat to N is extremely variable. It is greater than for either winter or spring barley (Grylls and Archer, 1984; Johnson, 1984); and is probably greater than for any other controllable factor in the husbandry of this crop. But, despite these considerable qualifications it must be recognised that there is no other body of information available which encompasses more fully the circumstances in which winter wheat is currently grown in England and Wales, or which gives any better account of the variation in N response found in these highly variable conditions, (Sylvester-Bradley, Dampney and Murray, 1984).

N is the nutrient required in the greatest quantity by most crops. It is available from a range of sources, occurring in soil, air and water. For this reason it is difficult to make precise fertilizer N recommendations for crops. One of the main problems in N research is the accounting for the N in a soil-plant system. In soils, there is considerable in, and outflow of N in the course of the year, accompanied by many complex transformations within the 'nitrogen cycle'. The N income of arable soils is derived from such materials as commercial fertilizers, crop residues, green and farm yard manures (FYM), ammonium and nitrate salts brought down by precipitation (rain). In addition there is the fixation of atmospheric N accomplished by certain micro-organisms. The outflow is due to crop removal, drainage, erosion and to losses in a gaseous condition.

The total amount of N in soil is large, it ranges from 1000-3000kg/ha (Cooke,1986), and is related to soil organic matter (SOM) content. This is slowly decomposed by a range of soil micro-organisms (mineralisation) to ammonium N which is usually oxidised to nitrate (nitrification). Both ammonium and nitrate ions can be taken up by the root systems of crop plants. Because mineralisation is a biological process it is influenced by a wide range of environmental conditions; for example soil pH, temperature and water status. As a result only a small proportion of total soil N is made available to crop plants by mineralisation each year. This supply is not adequate to meet the needs of cultivated crops during the period of rapid growth and development. Consequently applications of inorganic N fertilizer to sustain maximum crop growth is of paramount importance.

3.4.6.Response of Slejpner in 1986/87 (experiment 2).

In this experiment the grain filling period was short (4weeks), due to low soil moisture and high radiation during the grain filling stage

in June. This therefore, resulted in a small grain size, with the 250kg/haN treatment. Thousand grain weights ranged from 38.3g to 46.2g and, 38.3g to 45.8g corresponding to the suffolk and band coulter treatments (Table 3.17), as compared to 45g to 50g, normally obtained from this variety (NIAB,1986). This may also have resulted from decrease in N uptake influenced by the low soil moisture contents during the grain filling period, or reduced photosynthesis of flag leaf and plant canopy, and reduced mobilisation of assimilates. Since high levels of N (>200kg/ha) may delay crop development, soil moisture stress during the early month of July may have affected the filling of late developed grains.

If for some of the reasons enumerated above, the supply of N during the stage of stem elongation is not sufficient, fewer reproductive tillers will develop per plant. The competition for nutrient is so great that only dominant tillers will produce ears. Evans (1977) found that N decreased the number of tillers which died when plants were uniformly distributed, but tended to increase it when the spatial distribution was irregular, in an experiment with a winter wheat variety-Maris Huntsman and spring barley variety-Clermont. This was similar to experiment 2, where the band coulter which is claimed to have an ability of distributing seeds in an even and regular form produced more tillers and consequently more ears per unit area at plant maturity (Tables 3.10). In general, as a particular treatment increased the number of reproductive tillers, it decreased the number of grains per ear. Table 3.15 shows a decrease in the number of grains per ear with an increase in the number of tillers per unit area with the band coulter, as compared to that obtained by suffolk coulter. Increase in numbers of tillers m-2 with the levels of N also reduced numbers grains per ear (Tables 3.6 & 3.15).

Growth and development of a crop are the result of the interactive response of plants to weather and soil factors, and result of

manipulating the environment, by some management practices, such as plant arrangement, N topdressing and the control of pests and diseases. Results from this experiment showed that, irrespective of plant arrangement and plant population densities, plants continued to tiller vigorously with the increase in N levels. For example, number of tillers increased from 368.6, 438.2 and 410.6 before N application to 1116.5, 1178.3 and 1255.6 when N levels were increased from zero to 250kg/ha with the suffolk coulter, corresponding to low, medium and high densities. With the band coulter also, number of tillers increased from 253.3, 322.7 and 471.3 before treatments with N to 1329.9, 1369.9 and 1629.2 at the same levels of N and plant population densities (Table 3.5). If all the tillers produced had contributed to the production of final yield, total grain yield from this experiment would have been in the range of 10-12t/ha. Thus, the crop had a very considerable potential for grain production which was obviously not realised in the final grain yield. At each time of development, from tillering until the development of grains, it was apparent from experiment 1 and 2, that plants produced much greater number of yield-components than the number of each component which contributed to final grain yield. Similar results were also reported by Beveridge et al. (1965) in winter wheat variety-Bersee and Cappelle Desprez.

N is the most influential factor for growth and development; being the main building block of protein and enzymes for the plant growth. In cereals, especially winter wheat, N largely affects grain yield and grain quality. High grain yield requires a high supply of N. According to Widdowson et al. (1987) about 215kg/ha N could be taken up by the crop to produce a maximum yield of about 11t/ha. These authors concluded that, uptake by the crop depended on sowing date, soil type, crop variety, cropping history, amount of fertilizer N applied to the soil and the stage of development of the crop. However, high rates of N must be carefully applied to prevent a high incidence of lodging, diseases

and pests. High rates of N also can cause environmental problems resulting from nitrate leaching through the soil to the drains or aquifers causing pollution of the environment. The latter has become a matter of great concern in the present day British Agriculture. The mode of N dressing must closely follow the N demand of the crop during growth and development. Split application of N fertilizer should be employed to reduce nitrate leaching into the soil. In experiment 2, N treatments were applied in a split application at three different stages of the growth of the crop. The first application was at the growth stage (GS20-25), and the second and third applications were at the growth stages (GS30 and GS32 respectively (Zadoks et al. 1974). These treatments were timed to produce high and stable yield of the crop, and to avoid loss of N by leaching.

It is important at this juncture to reflect back to the objectives of this experiment which was principally designed to ascertain (i) the possible increase in grain yield of a winter sown wheat by using the band coulter drilling method, (ii) to study the possible interactions between plant population and N levels with the drilling systems, (iii) exploring the effect of the drilling methods on crop establishment and the influence of this on the total biological yield and, (iv) to assess the performance of the individual plant, plant communities and how these subsequently influence the total biomass m-2, yield components and the final grain yields.

The above results and subsequent discussion have clearly shown that, it was not possible to achieve a complete ground cover of wheat using the band drilling method as previously suggested. However, consistently higher numbers of plant m-2 were recorded from the band drilling method. The reason for this is not precisely known but it may have been linked with drilling depth (see earlier discussion on page 123). This higher number of plants per unit ground area given by the

band drilling technique resulted in a significantly higher ($P<0.05$) total biomass at each of the sampling periods, but individual plant dry weight was decreased. Decrease in individual dry weight corresponded to a reduction in number of grains per ear and the thousand grain weight and consequently the final combine grain yield in comparison to the suffolk coulter drilling system.

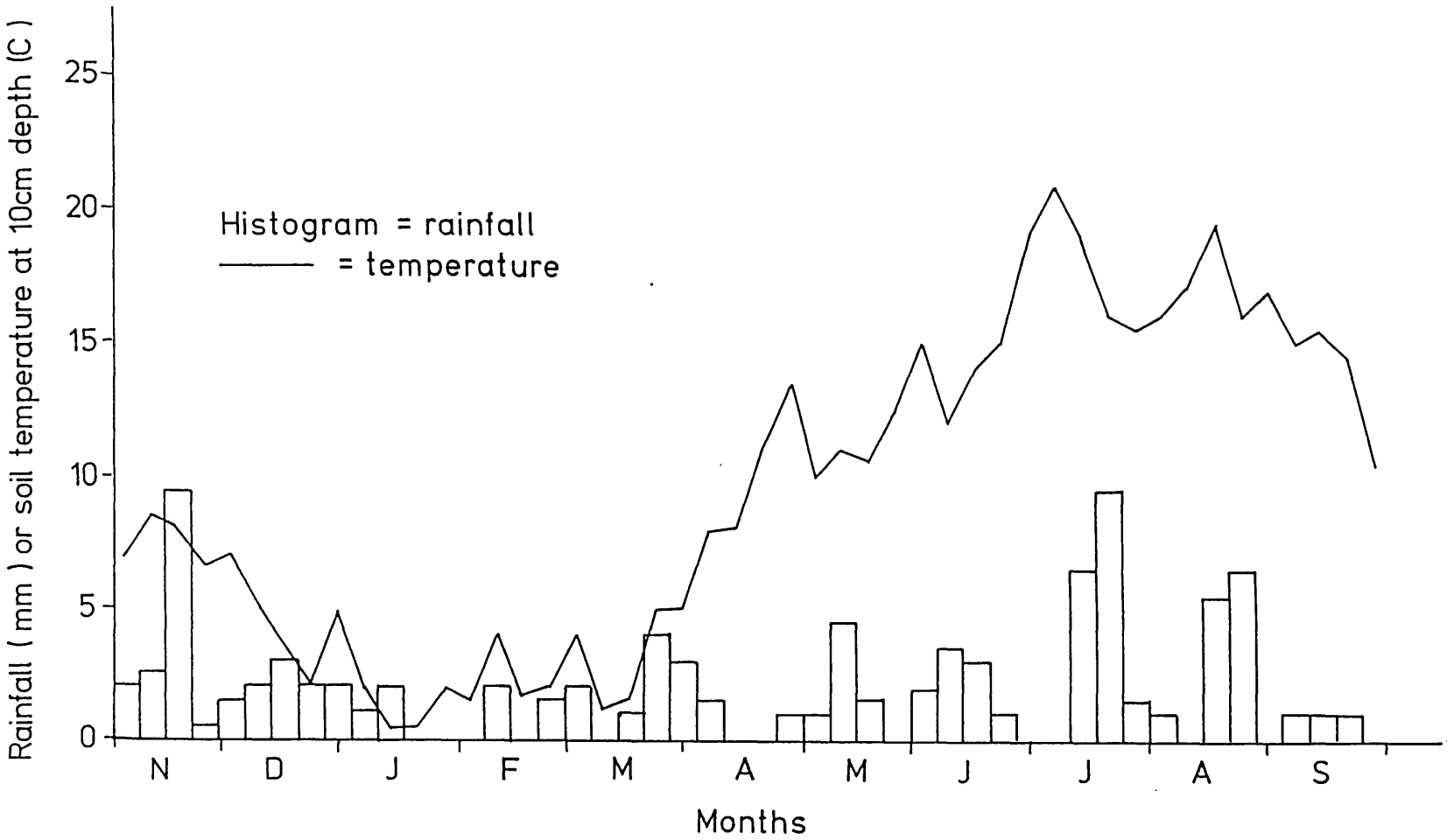
Increase in plant population from 200 to 500 seeds m-2 influenced the total biomass m-2 significantly ($P<0.05$). The increase in total biomass resulted from a corresponding increase in the total number of tillers m-2. However, individual plant dry matter was inversely proportional to the increase in plant population density. This was caused by the fewer numbers of tillers per plant and a reduction in tiller and leaf sizes. The higher (NS) combine grain yield was recorded from the medium (350 seeds m-2) compared to the low and high population densities.

Additional N from 0kg to 250kg/ha increased the total dry matter m-2 and per plant significantly ($P<0.05$). However, grain yields showed an asymptotic response (Table 3.18). Thus, in experiment 2, the optimum level of N fertilizer was 175kg/ha. Albeit this might not be an appropriate amount as a basis for fertilizer recommendations, since these data were obtained from a single season trial. Nevertheless, it may be useful for future fertilizer research programmes on winter wheat.

Treament interactions were not significant in experiment 2. However, there was a slight hint of an interaction between low plant population and the application of 250kg/haN on the numbers of tillers per plant and the corresponding plant dry weight (Tables 3.7 & 3.4). Also, there was (NS) density x drilling effects. For example, grain yield was slightly higher with the medium density in the suffolk coulter drilling system, whilst this effect was recorded at the high density by drilling using the band coulter (Table 3.18).

Therefore, the conclusions arrived at from this experiment were (a) the advantage of obtaining grain yield increase by drilling with the band coulter is untenable (objective 1), (b) no significant drill x density x nitrogen levels were achieved. Only main effects can be used to ascertain commercial recommendations (objective 2) (c) a consistent higher numbers of plants m-2 were achieved by crop establishment using the band drilling method. However, many questions are still left unanswered from the results obtained in this experiment, some are difficult to explain in terms of 'cause and effect' (objective 3) (d) individual plant dry weights given by suffolk coulter drilling technique were higher, this resulted in higher grain yield than the band (objective 4). More detailed studies are therefore required inorder to understand in depth some agronomic and physiological implications related to the study of plant arrangement by using the two drilling methods.

Fig. 3.5 TEMPERATURE AND RAINFALL DURING 1986/87 GROWING SEASON.



SECTION 4.

TIMING OF NITROGEN FERTILIZER ON WINTER WHEAT VR. AVALON.

CHAPTER IV. EXPERIMENT 3. 1989.

Timing of nitrogen fertilizer on winter wheat variety-Avalon.

4.1.Introduction.

Grain yield as well as grain quality can simultaneously be increased by proper timing of N fertilizer application. A sustained N supply until late in the growing season may result in greater flag leaf area duration and photosynthesis, and consequently higher grain protein content (Morris and Pualsen, 1985). In the past, many research works have concentrated upon the attainment of maximum economic yield of feed varieties. However, the production of breadmaking quality wheat is also of potential importance in British cereal production systems, due to the increased demand for quality wheat by the milling industries within the UK and the European Common Market (see literature review on pages 24-25).

Because of the secure future market potential for quality wheat in the UK and the EEC, experiment 3 was designed to study the effects of the band and suffolk drilling systems and time of application of N at different growth stages on the breadmaking quality of the variety-Avalon. The detailed effects of these treatments were only monitored prior to final harvest because a great deal of time and effort was required to carry out experiment 1.

4.2.Materials and methods.

The winter wheat variety-Avalon was grown during the 1988/89 growing season on the Wye College Farm. The experimental site was located on a clay loam soil at little Crabbs following winter Oil seed

rape variety-Ariana. The experimental design was a split plot factorial combination of 2 x 6, with drilling systems and five timing of N application, plus a nil N treatment, as the main factors in six replications. The treatments were randomised to the blocks without any restrictions. Each plot measured 3m x 9m giving a total land area of 36m x 54m (1944m2). The breakdown of the analysis of variance (ANOVA) of the experimental design is presented in Table 4.1.

Plots received no basal application of phosphatic and potassium fertilizers as soil indices were greater than 1. Plots were treated with 175kg/haN at growth stages 21-23, 30, 32, 37-39 and 60. The seed rate was 250kg/ha, giving an estimated plant population of 450 plants m-2. It was drilled on October the 18th, 1988. The subsequent crop protection measures taken during the growing season are described in Table 4.2.

No destructive samples were taken for growth analysis. Thus the plots were left undisturbed until maturity. Samples for reproductive analyses are taken on July 23rd. The following yield components were then assessed: number of ears m-2, number of spikelets per ear and number of grains per ear. Plots were combined using an area of 7m x 1.8m on July 27th in order to obtain the final grain yield and samples for grain quality assessment.

4.2.1.Grain quality assessment.

Protein contents and Hagberg falling number were determined by the same methods described in experiment 1 (sections 2.2.7 and 2.2.8). Grain filling and protein development measurements were not carried out in this experiment.

Table 4.1. Skeleton analysis of variance (ANOVA) for winter wheat experiment 1989.

SOURCE OF VARIATION	df
reps STRATUM	5
reps. drill STRATUM	
Drill	1
Residual (a)	5
TOATAL	6
reps. drill. time STRATUM	
Time	5
Drill x Time	5
Residual (b)	50
TOTAL	60
GRAND TOTAL	71

Table 4.2. Crop protection in 1988/89 winter wheat trials cv. Avalon.

Herbicides.	Rates.	Date applied.
Arelon	3.75l/ha	8:12:88
CMPP	1.75l/ha	8:12:88
CMPP	4.2l/ha	28:3:89
Insecticides.		
Aphox	233.33g/ha	24:5:89
Aphox	261.33g/ha	14:6:89
Fungicides.		
Patrol	1.0l/ha	13:4:89
PP450	0.667l/ha	24:5:89
Faber	1.33l/ha	24:5:89
Legion	2.83l/ha	14:6:89
PGRS.		
Brevis	1.75l/ha	28:3:89

4.3.Results.

Experiment 3 was designed primarily to study the effect of N timing on the yield components, final grain yields and grain quality of the winter wheat variety Avalon. However, in order to make links with experiments 1 and 2, the suffolk and band drilling systems were also

used. Therefore, in the results section and the subsequent discussion, references are made to the different drilling methods. Tables 4.3 and 4.4 present results for the yield components, total grain yield as well as the quality attributes of the winter wheat trial.

4.3.1.Yield components.

Timing of N had no significant effect on the numbers of ears m-2. However, plots which received no N gave the lowest numbers of ears m-2, 463 and 474 for the suffolk and band coulters respectively (Table 4.3). N treatments at GS30 gave a slightly higher numbers of ears m-2 in both drilling systems. Corresponding numbers of ears m-2 given by the the treatment at GS30 were 531 and 535 for the suffolk and band respectively (Table 4.3). In this experiment, contrary to the results given by experiments 1 and 2, the numbers of ears m-2 averaged over timing recorded from the suffolk and band coulters were similar (500 and 501).

N application from GS30 to GS37-39 increased the numbers of spikelets per ear significantly ($P<0.05$) over the nil N treatment. Delay in N application until after GS37-39 had no significant effect on the number of spikelets per ear (Table 4.3). The increase in the number of spilelets per ear with the delay in N was confined only to the suffolk coulter drilling. In case of the band coulter drilling no significant effect of N timing was recorded on number of spikelets per ear. However, treatment with N at GS32 resulted in the highest number of spikelets. The number of spikelets per ear given by the two drilling systems were similar (21.3 and 21.2).

Number of grains per ear was significantly lower ($P<0.05$) when N was delayed until the flag leaf emergence (GS37-39) with the suffolk coulter drilling, while application at GS32 resulted in the highest number of grains per ear. With the band coulter, the lowest number of grains per ear was obtained from N application at GS30 while the highest

was also recorded with the treatment at GS32. The number of grains averaged over the N timing was higher (NS) when plots were drilled using the suffolk coulter (46.2 and 44.1) Table 4.3.

Thousand grain weight was higher with the nil N treatment. In the suffolk coulter drilling this was significant ($P<0.05$) only over the treatment at GS21-23 (tillering) Table 4.3. Application of N at anthesis (GS60) gave a similar thousand grain to the nil N treatment. Results of the thousand grain weight given by band drilling did not follow a similar pattern with those obtained by the suffolk coulter. However, the nil N treatment also recorded the highest thousand grain weight. Unlike the suffolk drilling, the thousand grain weight obtained from the no N treatment was significantly higher ($P<0.05$) from all but, only one treatment, that is when N was applied at anthesis (GS60). Similar to the other yield components, drilling systems had no effect on the thousand grain weight. The averaged values recorded were 43.1g and 42.9g for the suffolk and band coulters respectively.

4.3.2.Total grain yield (t/ha 86%DM).

The lowest total grain yield was obtained from plots which received no N treatment. Total grain yields were 6.3 and 6.4t/ha for the suffolk and band coulters respectively (Table 4.3). N application at the GS30 and GS32 gave a significant ($P<0.05$) yield increase over the no N treatment when plots were drilled using the suffolk coulter, with the N application at GS30 giving the highest yield (Table 4.3). In the band drilling system, a significant ($P<0.05$) yield increase was obtained when N was applied from GS30 to GS37-39). Similar to the suffolk coulter drilling treatment at GS30 also resulted in the highest grain yield. Yield increase up to 0.3 and 0.4t/ha over the treatments at GS32 and GS37-39 respectively (Table 4.3). Grain yields recorded from the two drilling systems were similar (6.8 and 6.9t/ha).

The Table below describes the treatment codes presented on page 234 (Table 4.3).

Treatment codes.	Growth stage.	Calender dates (1989).
N0 Nil nitrogen fertilizer		
NT1	21-23	February 28th
NT2	30	March 12th
NT3	32	March 26th
NT4	37-39	May 4th
NT5	60	June 3rd

Table 4.3. Yield components and yield of a winter wheat variety Avalon treated with N at different growth stages.

	Suffolk Coulter.						Band Coulter.						
Yield comp. and yield.	Treatments.												
	N0	NT1	NT2	NT3	NT4	NT5	N0	NT1	NT2	NT3	NT4	NT5	SED.
Ears m-2	463	473	531	530	473	529	474	489	535	514	500	496	23.1
Sp./ear	20.7	21.4	21.6	21.5	21.2	21.2	21.0	21.2	21.6	21.0	21.1	21.0	0.3
G./ear	47.0	42.7	48.7	48.6	41.6	48.5	44.0	40.9	49.1	46.4	43.1	41.3	2.4
TGW (g)	44.2	42.0	42.6	42.9	43.2	43.9	45.0	41.8	41.8	42.7	42.8	43.2	1.0
GY (t/ha)	6.3	6.4	7.4	7.2	6.7	6.8	6.4	6.6	7.4	7.1	7.0	6.6	0.3

4.3.3.Grain quality.

Results on grain quality are presented in Table 4.4. There was no effect of time of N application on grain moisture contents (Table 4.4). The grain moistures recorded at harvest on July 27th were all below 11%. The harvest period was about one month earlier than the normal harvest time for winter wheat in England.

There was no effect of N timing on grain protein content (Table 4.4). However, treatment with N at various growth stages resulted in a significantly higher ($P<0.05$) increase in percentage crude protein over the nil N treatment in both drilling systems (Table 4.4). Surprisingly even the late application at anthesis did not result in any grain protein increase. The experiment was conducted on a fertile soil, this may have probably prevented the effect of N timing from making any significant impact on grain protein. The percentage protein ranged from 13.0% to only 13.2% with the N timing treatments, whilst the nil N gave 12.3% and 12.1% with the suffolk and band coulters respectively.

Similar to the results given by the grain protein content, there was no effect of N timing on the Hagberg falling number. The differences that occurred in the Hagberg falling number values may have been caused by a 'background' variation in the readings, but not as a result of treatment. The average Hagberg falling number was slightly lower in the band coulter drilling 455 versus 472 obtained from the suffolk coulter technique. This again might be due to the variability in the readings obtained, but can not be associated with the drilling systems per se.

Table 4.4. Quality attributes of winter wheat variety Avalon treated with N at different growth stages.

	Suffolk Coulter.						Band Coulter.						
Grain quality.	Treatments.												
	N0	NT1	NT2	NT3	NT4	NT5	N0	NT1	NT2	NT3	NT4	NT5	SED.
%M.C	9.8	10.4	10.2	10.0	10.3	9.6	9.6	10.6	10.5	10.2	9.8	9.9	0.4
%Protein (%Nx5.7)	12.3	13.1	13.0	13.1	13.1	13.0	12.1	13.1	13.2	13.1	13.0	13.0	0.2
HFN	449	497	491	453	499	442	434	494	440	434	481	449	26.8

4.4.Discussion.

Grain yields as well as grain quality are influenced by the time of N application. The resultant effects of N timing on grain yield are attributed to its influence on the yield components. On the other hand, grain quality may depend upon the amount of N supplied to the grains during the grain filling period. The objective of experiment 3 was to study the effects of N timing on the yield, yield components and the grain quality of winter wheat variety-Avalon. Since growth analysis was not carried out during the growing season, effects of N timing on crop structure and its contribution to the total biological yield cannot be ascertained. The discussion concentrates on the yield, yield components and the attributes of final grain quality. The reader is reminded that

these data were collected in an unusually hot and dry growing season (Appendix 2.4). The effect of this has already been mentioned in the discussion of experiment 1 (pages 124-170).

4.4.1.Yield and yield components.

The time of application of N had no significant effect on the numbers of ears m-2 (Table 4.3) although, application of N at the start of stem extension (GS30) increased (NS) the numbers of ears m-2 by 68 and 61 for the suffolk and band coulters respectively over the control treatment (N0). N fertilization of cereal crops causes increase in tiller population and tiller fertility, with the overall effect determined by the timing of applications (literature review on pages 48-51). In winter cereals, provided that the crop has a sufficient nutrient supply from the soil reserves or from autumn fertilization for the normal proliferation of tillers by early spring the most important factor determining final ear population population density is the tiller mortality during the period just before and including the achievement of GS31 (Baker and Gallagher, 1983; Hay, 1986). Thus, treatment with N at GS30 may have reduced tiller mortality and boosted the numbers of ears m-2. Spiertz and Ellen (1978); Darwinkel (1978 & 1983) reported that N applied before or during tillering may influence tiller production and the final numbers of ears m-2 of winter wheat. The present experimental results did not fully agree with those described by these authors.

The slight increase in the numbers of ears m-2 obtained by the N treatment at GS30 in experiment 3 resulted in a significant ($P<0.05$) increase in grain yield over the control treatment as well as the treatment at GS21-23 (NT1). Grain yield was increased by 1.1 and 1.0t/ha for the suffolk and band coulters compared to the control. Similarly increases in grain yield when compared to those given by the N application at tillering (GS21-23) were 1.0 and 0.8t/ha corresponding to

the two drilling systems (Table 4.3). Wheat grain yield in the range of 9-10t/ha results from crops where higher than the average 550 ears m-2 had been achieved in conjunction with high thousand grain weights (50g) and high numbers of grains per ear (44). Thus, increase in grain yield with the N treatment at GS30 in experiment 3 may have resulted from its positive effect on the number of ears m-2 and as such on the the total number of grains per unit area. Results are in agreement with the findings of Darwinkel (1983), working on winter wheat cultivars Caribo, Okapi and Arminda.

Experiment 3 was conducted on a site previously cropped with Oilseed rape (soil N index 1). This means that residual soil N may have been high on the site which might have affected the response of the crop to the applied N. Successful responses to N fertilizer treatment are best obtained when crops are grown on the soil following a previous cereal crop (Widdowson et al. 1987). However, this practice may result in some disease incidences, such as 'Take-all' (Gaeumannomyces graminis) especially when wheat crops are grown continuously. Soil structural stability may also be weakened, and when an individual field is cropped continuously with cereals, there will tend to be an inevitable increase in variable costs for both sprays and fertilizer per tonne of grain yield. Therefore, the effect of one cereal crop upon another and the occurrence of beneficial or detrimental consequences is a key factor to an important agronomic and economic decision making.

In an experiment studying the amount of soil residual N after the previous crop Widdowson et al. (1987), obtained 159kg nitrate N/ha from soil previously cropped with potatoes (break crop) compared to only 20kg from soil following Oats (cereal). Although nitrate N measurements were not carried outin experiment 3, it is possible to suggest that the previous rapeseed crop grown at the experimental site may have left sufficient amount of residual fertility in the soil which was later

mineralised into inorganic N.

It is well established in a number of trials that the introduction of a break crop into cereal rotations can considerably improve the yield of the first wheat following the break. Many growers have found oilseed rape to be the ideal break crop in cereal dominated rotations (Almond, Dawkins and Askew, 1986). Experiments have shown that the yield of the first wheat after rape is improved by 9% (MAFF, 1983). The inclusion of oilseed rape in the rotation also provides a number of other advantages. There is an opportunity for cheaper, and in some cases more effective, control of grass weeds such as blackgrass (Alopecurus mysuroides). Because of its deep and extensive root systems oilseed rape can provide a more friable tilth, perhaps resulting in better seedbeds for the following cereal. Residual N has been estimated to range from about 20kg/ha to 115kg/ha on soils previously cropped with oilseed rape (Chapman, 1982). However, it is doubtful whether this can affect the final yield of the following cereals because winter wheat plants are not very much responsive to N during early growth.

The latter part of the above review on the role of oilseed rape as a break crop may have been applicable in experiment 3, thus contributing to the soil fertility at the experimental site in 1988/89 growing season. The site also has a long history of treatments with 'pig slurry', which in turn may have been another source of residual soil N that affected the response of the crop to the applied N. Visual observation of crop growth in the field revealed no differences in appearances. Thus, it was extremely difficult to distinguish the treated plots from the untreated ones. The lack of differences in crop appearance was continued until crop maturity.

The timing of N had no effect on the numbers of spikelets per ear (Table 4.3). It was surprising that, even the application at the tillering stage (GS21-23) did not influence the numbers of spikelets.

These results are contrary to those of experiments 1 and 2, in which the early N treatments (T1) applied before tillering influenced spikelets formation of a spring wheat variety (see experiment 1). The treatments with different levels of N from 100-250kg/ha in experiment 2 also gave a higher numbers of spikelets per ear than the control (0kg/ha). The lack of increase in numbers of spikelets in experiment 3 may have been due to a delay in N application.

Langer and Liew (1973), reported that N treatment can only influence spikelets production if it is applied before the double-ridge stage. Since it is difficult to match growth stage and the reproductive development of cereals, N application at GS21-23 may have been too late to effect any significant change in the numbers of spikelets. However, it is not clear from the results of experiment 3 whether this type of response was only confined to the fertile as well as the total numbers of spikelets per ear. Because there is no data on the latter, it is difficult to draw a concise conclusion. Thus, the increase in grain yield recorded from the treatment at GS30 and the slight increase (NS) with the application at GS32 (Table 4.3) did not result from any increase in the number of spikelets per ear, but may have been due to the slight increase in the number of ears m-2.

The numbers of grains per ear and the final grain yield were closely related (Table 4.3). However, in the suffolk coulter the mean number of grains per ear recorded from the N treatment at GS30, GS32 and the application of N at anthesis (GS60) were similar. This was not the case in the band coulter drilling method. With this drilling system, the highest numbers of grains per ear were obtained from the N application at GS30 and then treatment at GS32. The reasons for the differences in response to the N timing beween the suffolk and band coulter drilling methods in respect of the number of grains per ear is not known. However, there may be some physiological explanations which are beyond

the scope of these results.

The main yield components which contributed to the increase in grain yield in experiment 3 were the numbers of ears m-2 and the numbers of grains per ear (Table 4.3). This is in agreement with the results reported by Evans (1977), who described grain yield increase resulting from the corresponding increase in the number of grains m-2 caused by an increase in the number of ears. Thus, application of N at GS30 and GS32 may have influenced tiller survival and florets initiation and development which consequently resulted in more grain set and development hence, the subsequent increase in grain yield.

The thousand grain weight given by the control treatment was higher in both drilling methods. However, the treatment at anthesis (NT5) was similar to the nil N (Table 4.3). This increase in thousand grain weight recorded from the control treatment was only significant over the treatment at GS21-23 with suffolk coulter drilling method. In the band coulter drilling system, grain weight was significantly higher ($P<0.05$) with the control treatment over all but one treatment (NT5). Thousand grain weight of unfertilized cereals are often greater than the treated ones (see experiment 2), since the numbers of ears from the control plots were lower (NS). Similar explanation can also be linked with the N treatment at anthesis. Application at this stage have no effect on the numbers of ears m-2 as well as the numbers of grains per ear may can influence intraplant or intergrain competition. More over N applied at anthesis may influence grain filling and consequently increase thousand grain weight.

The overall results given by the time of N application in experiment 3 did not produce a highly significant increase in the yield and the yield components as reported by some workers in winter wheat. Many factors including those mentioned earlier as well as environmental may have affected the response of this variety to N timing during the

1988/89 growing season. The most prominent amongst these environmental factors were the low rainfall and high temperatures (Appendix 2.4). For example, the last N treatment at anthesis was applied when the soil surface was completely dry. More over, no rainfall was recorded for about two weeks from there on. Under an optimum growth conditions defined by rainfall and temperatures, N application at anthesis would influence the increase in thousand grain weight. Spiertz and Van der Haar (1976) reported an increase in grain yield of winter wheat resulting from the application of N at anthesis. This increase in grain yield was due to more numbers of grains per ear and increase grain weight. This suggestion was supported by the results described by Spiertz and Ellen (1978).

4.4.2.Quality.

The effect of time of application of N on grain quality is usually associated with its influence on grain protein given by %N x 5.7 at 14% moisture content. In experiment 3 grain protein was not affected by N timing. The average percentage grain protein recorded from the treated plots ranged from 13.0% to only 13.2% for both the suffolk and band coulters. However, application of N at various growth stages resulted in a significant increase ($P<0.05$) in grain protein over the control treatment (Table 4.4).

Although N application caused an increase in grain protein, the magnitude was relatively small. Treatments with nil N gave grain protein content greater than 11.5% regarded as the minimum value for the Intervention standard (Table 4.4). Thus, crop response to N from the field previously cropped with Oilseed rape may have been obscurred by the existing soil N. Also, grain yield increase obtained from the timing treatments were less than 1.5t/ha when compared to the yields given by the control treatments.

It is important to remember that the experiment was not designed to study the effect of the previous crop on the performance of winter wheat. Therefore the contribution of the soil N left after the oilseed rape crop was only coincidental. However, it is important to note the possible grain quality advantage that may be achieved from growing winter wheat after a breakcrop such as the rapeseed. Such practice may help to reduce the cost of N fertilizer precurement for application on winter wheat without a highly significant loss of grain yield.

Although protein content of the grain was increased with timing treatment over the control, the Hagberg falling number was not affected. Winter wheat variety-Avalon is intrinsically associated with high falling number and a more responsive variety to N fertilizer in regard to increase in Hagberg falling number (McDonald and Vaidyanathan, 1987). However, there is no information available on whether timing of N may increase the falling number value of these variety. Most research results available in the literature only tested the amount of N fertilizer (Gooding et al., 1986; McDonald and Vaiyanathan, 1987), but the time of application had been neglected.

Results of this experiment showed that, Hagberg falling number of winter wheat such as the variety Avalon is unlikely to be affected by the time of application of N, especially when the summer period is unusually dry such as 1989. The results are contrary to those obtained from the spring wheat variety-Axona grown in the same year, albeit at different location (experiment 1). In experiment 1 both the amount and the time of application resulted in a trend in increased Hagberg falling number.

The average falling number recorded from experiment 3 was relatively higher than those reported by some workers inluding Gooding et al. (1986); McDonald and Vaidyanathan (1987) McDonald (1988) who tested different levels of N. Pre-harvest weather conditions in 1989

were considerably drier (Appendix 2.4) hence excombine grain moisture contents were low (10.1%) Table 4.4. This low grain moisture may have reduced the activity of the enzyme α-amylase thus resulted in high Hagberg falling number. The average Hagberg falling number obtained from the suffolk and band coulters were 472 and 455 respectively. The increase in 17 units with the suffolk coulter treatment can not be explained from the results in terms of 'cause and effect'. The difference may have been due to a background variation in the reading.

It is thus arguable whether, the results on falling number given by experiment 3 was caused by quantity, time of application, source of N or an interaction with other major and minor nutrients, or probably as a results in variation in the falling number reading. This may require more future studies.

From this result it can be concluded that timing of N on a soil previously cropped with oilseed rape is unlikely to be worthwhile strategy since it provides very little advantage with respect to grain yield and grain quality. Application of N on such soils is only likely to be worth considering where there is a sign of soil N deficiency. Results also indicate that, although N applied at GS30 increased grain yield this was not reflected in grain protein and Hagberg falling number. These results raise uncertainties about (a) whether timing of N on winter wheat is effective to create an impact on the grain quality such as obtained from spring wheat varieties (experiment 1) and (b) whether the extra grain protein achieved by delaying the application of N on winter wheat results in a higher level of premium being paid than would have been obtained by applying at an earlier growth stage.

Unless a late N application strategy does attract a higher premium, it would seem best to conclude that, in the absence of any soil N deficiency at the latter growth stages, any programme for delayed N application on winter wheat later than that required for grain yield

should not be practiced. Further work is needed to study the causes of the lack of proper response of winter wheat to the timing of N when grown after breakcrop. There is at present little evidence from the results obtained in this experiment to establish the nature of the response of grain protein content to the time of application of N on winter wheat. And the seasonal and soil N effects revealed here need further investigations. Work is also required to develop a means of predicting the amount of N taken up by the crop before anthesis, so that crops can be selected that will benefit from the late N application before or at anthesis (GS60).

SECTION 5.

GENERAL DISCUSSION.

CHAPTER V.

5.1.General discussion.

The influence of spatial arrangement on crop productivity has been reviewed (pages 35-37). The ideal, in terms of crop physiology is to obtain a uniform plant distribution which provides an environment for development in which resources are shared. However, this pattern is often ignored in commercial practices such as forage maize production in order to allow access for harvesting machinery.

A prime objective of my first study was to compare the effect of spatial arrangements (which was varied using two drilling methods) on the growth and yield of a winter sown wheat (variety-Slejpner). These were tested using three plant population densities with four levels of N from zero to 250kg/ha. The experiment (presented in the thesis as experiment 2) was drilled using suffolk and band coulters in October 1986, in anticipation of my arrival the following spring term. It proved a bonus to start a postgraduate study with a 'ready made' trial. Within two weeks of the start of my training programme, plots were demarcated for the application of the N treatments.

Extensive crop growth analyses were carried out in the first year in order to create an adequate data bank from which ideas for the subsequent agronomic trials could be developed. Over 20 different parameters were measured, albeit not all of these data were analysed statistically. Results from the first year trial created many inexplicable problems and questions, which were not easy to answer by experimental replication in the following seasons. For example, the consistently higher total dry matter m-2 and plant population obtained by using the band coulter which resulted in a reduced final combine

grain yield was difficult to explain in terms of the 'cause and effect'. It also proved impossible to obtain complete ground cover using the band coulter. Because of these experimental difficulties it was decided to introduce additional objectives. For example, other agronomic practices such as rate and timing of N and their effects on grain yield and quality were added. However, the two drilling methods remained unchanged and were used as main effects in all of the experiments.

In the second year, plant population was reduced to only two because of the management problems that were created by deciding to introduce the effect of N timing. Even with this reduction, the total number of experimental plots was still high (144). Consequently it was therefore impossible to sample all of them on a single day for the purpose of growth analysis. This necessitated the best decision of how to take plant samples for detailed study. The low population alone was chosen for this purpose, whilst the high population plots were used solely for grain filling measurements and the subsequent assessment of protein accumulation. However, samples were taken from all plots at maturity for a final reproductive analysis. On reflection, it may have been unwise to have used two sowing densities in experiments 1 and 2. It is possible to 'lose sight' of experimental objectives when so much time is required for growth analysis techniques on a wide range of agronomic treatments.

In 1988, a small 'commercial' trial area was also set simultaneously with the main experiment for comparative purposes. Results from this are not presented in the text, but are summarised in Appendix 2.3. It may be valuable for future agronomic studies to include such sites which are not constrained by the edge effects of surrounding long, narrow plots. This additional 'trial' was meant to compare the normal commercial split method of N fertilization on spring wheat and a single application timed at a particular growth stage of the crop. The

grain yield recorded from this area was slightly lower than values obtained from the experimental plots (experiment 1), although N fertilization in the former was in two split applications at GS20 and GS32. The average yield was 5.0t/ha, compared to 5.7, 5.4 and 5.2t/ha given by N application as a single dose at the growth stages 12-13, 30 and 32 in the main experiment. However, grain quality measured by the average protein contents was slightly greater (12.5%) than the treatments with N fertilizer at GS12-13 and 30 (11.7% and 12.3%) but, relatively lower than when N was given at GS32 (12.9%). This indicates that, for spring wheat varieties such as Axona, it may be uneconomical to apply N fertilizer more than once, most especially when the fixed costs of labour and machinery use are put together.

During the final year (1989), both winter and spring sown wheats were drilled. The former was designed to study the effect of time of application of N on the yield, yield components and the final grain quality of Avalon (experiment 3), whilst the latter was a replicate of the previous spring trial. Only one plant population was drilled during the third year, although in both trials the two drilling systems were still maintained as the main treatments effect. All the necessary growth analysis, grain and protein development studies in the spring sown trial were similar to the second year trial so that a detailed comparison between the two seasons results could be achieved.

In agronomic field research work, it is important to define clearly the objectives of the experiment before the start of the programme, in order to design an experiment that can be replicated over a period of successive growing seasons. However, such practices may lead to a continuous repetetive growth analysis measurements of variables for the specified period of study. This may consequently result in a huge data bank with complicated interactions, that cannot be used to solve a single agronomic problem. It can be a disadvantage to postgraduates to

utilize package computer programmes which can digest large quantities of data. It is much more important to develop the skills and techniques which provide the base for carrying out subsequent scientific work. This can often be achieved by collecting and analysing smaller quantities of data. In developing countries where computer facilities are scarce this approach is much more helpful.

Although some of the experiments described in this thesis are not linked together, for example experiments 2 and 3 drilled in October 1986 and 1988, results obtained from them are useful for a broadbase recommendations for a future research and development plan.

5.1.1.Plant arrangement.

In all years the effect of plant arrangement was studied, using the suffolk and band coulter drilling systems. The numbers of plants m-2 was found to be higher using the band coulter drilling method in all these trials. This increased the total dry matter m-2, but reduced the individual plant dry weight and combine grain yields (NS). However, it was not possible to obtain comparative grain yield results in the replicated spring wheat trials of 1988 and 1989 due to the differences in the date of sowing and the variation in weather conditions. With regards to the winter sown trials of October 1986 and 1988, comparisons between grain yields were also made difficult as a result of differences in variety, seasonal experimental locations as well as heterogeneous treatments. Experiment 2, grown during 1986/87 studied the effects of treatments combinations such as drilling pattern, plant population and the rate of N fertilizer using the winter wheat variety-Slejpner (chapter 3), whilst in 1988/89 growing season (chapter 4) only the two drilling methods and timing of N on Avalon was considered.

Experiments 1 and 3, that studied grain quality indicated that this variable was not affected by drilling method, despite the reduction in

grain yield recorded from the band coulter drilling system. The decrease in grain yield by this drilling technique may have influenced grain quality, because this effect has been shown in several trials (literature review). As grain protein content was not influenced in this studies, it can be concluded that, there is no economic benefit derived in changing from the normal suffolk coulter to the use of band coulter drilling method. This has been fully discussed in section 2.4.1.2 on pages 134-135.

5.1.2.Plant population.

The number of reproductive tillers m-2 was higher with increased plant population in both experiments 1 and 2. Increase in total tillers m-2 resulted in a significant increase in dry matter m-2. However, number of tillers per plant and their dry weights were inversely related to plant density (chapter 3). In experiment 1, the effect of plant population on these variables could not be studied in detail, since crop growth analysis was performed only on the low population. However, the number of ears m-2 recorded at the final harvest was higher with increased plant population in both experiments. This increase in the total numbers of ears per unit area decreased the size of the ears and the other yield components such as as number of spikelets per ear, number of grains per ear and the thousand grain weights.

In experiment 2, the average grain yield showed an asympotic response to increase in plant population. Thus, higher grain yield (NS) was obtained from the medium density as compared to the the low and high densities. In the spring wheat trials (experiment 1), the increase in seed rates from 400 to 550 m-2 resulted in a slight increase in grain yield, despite the reduction in the numbers of spikelets per ear, numbers of grains per ear and the thousand grain weight. There was no significant effect of density on grain protein contents. Results for

Hagberg falling number could not be compared since these was obtained from only one density. On the basis of the results recorded in 1988, the effect of plant population was omitted in 1989. Instead, the high population (550 seeds m-2) was drilled because of the grain yield advantage derived from it in 1988.

Although grain yield was favoured by the medium and the high densities in experiments 1 and 2 respectively, it is difficult to conclude and make practical recommendations from the results of these experiment vis a vis plant populations. This situation arose due to inconsistencies in the densities in all years. However, with regards to the first and second year trials reported in this thesis as experiments 2 and 1 respectively, it seems reasonable to suggest that, in winter wheat production systems, a plant population of 350 seeds m-2 might be optimum. But, this must be reported with caution, since agronomic recommendations based on one growing season may be misleading. More studies which include a wider range of plant population are required in order to explore response curves. Similarly the spring sown trials considered different plant population only in the second year, even though the decision to abandon the low population was arrived at on the basis of the previous year's results.

An important point to make from the results of this postgraduate study in regards to plant population, is, the possible advantage in high seed rate when growing spring wheat varieties such Axona. Since these varieties have a relatively shorter growth period limited by the short growing season, the chances of compensation by means of tiller production from low plant populations (poor establishment) is untenable. Thus there may be an economic benefit in using high plant population wich results in high numbers of ears m-2 from which high grain yields can be obtained. Since the increase in plant population had no effect on grain quality in results of experiment 1, an increase in grain yield in

the absence of any effect on grain protein and other quality attributes would pay for the extra variable cost of the seeds. However, when deciding on an optimum plant population other factors other than the cost of seeds are very important. Environmental factors which determine the date of sowing and the subsequent growth of the crop must be kept in mind before any firm recommendations of plant population are made to the farmers.

In a dry and hot growing season as experienced in 1989 (Plate 4), a high seed rate that may establish to produce sufficient plants per unit area is recommended for use. This will compensate for the fewer numbers of tillers per plant caused by moisture stress. Similarly when drilling is delayed by the cold, wet condition as in 1988 growing season it is important to minimisethe risk of poor establishment. This is especially important for two reasons. (i) It may serve as an insurance to suppress the growth of weeds such as Blackgrass (Alopecurus myosuroides) and Couchgrass (Elymus repens) which grow very fast on heavy clay soils in the spring. This suggestion is based on the experience acquired in 1988 at Burgate (experiment 1). (ii) When seeds are drilled late the time lapse between germination and maturity is shortened. Thus less tillers are produced by the crop to result in maximum grain yield, since plants must reach a successive developmental stages within the specified growth period.

Under Nigerian growing conditions, wheat is grown under irrigation, and the production region is confine to the northern part of the country, where rainfall duration is relatively short (less than 6months) and temperatures are extremely high (30-35^{o}C). Thus, crop growth rate is higher than those obtained in experiment 1, more over the growth period is very short, ranging from four to five months only (November to March). This high crop growth rate caused by high temperatures coupled with a short growth period results in the formation of fewer tillers per

plant, and even those that are formed die before booting (GS45). Therefore, the number of ears m-2 at harvest are comparatively lower than those obtained from Axona in experiment 1, since these ears are only given by the mainstem tillers. To achieve an economic yield in wheat production systems in Nigeria, it is important to use a high seed rate ranging from 600-750 m-2. This will result in a reasonable numbers of ears m-2 at crop maturity. Thus, there is a bright future of plant population research in Nigerian agriculture.

5.1.3.Nitrogen.

In experiment 1, data from growth analysis indicated a significant increase ($P<0.05$) in total dry matter m-2 with rate of N. However the magnitude by which this was increased was not similar to the winter trials in 1986/87 (experiment 2). This was due to the reduced ability of spring varieties to respond in terms of tillering to N treatment. Since the growth period of the latter is short compared to the former the amount of dry matter accumulated during crop growth was less. Although crop biomass was increased with the rate of N in both the winter and spring varieties, the grain yield response was asymptotic in the winter wheat trials of experiment 2. Thus, the highest grain yield was recorded from the 175kg/haN compared to the treatments with 0, 100 and 250kg/ha. In experiment 1, there was no significant difference between the N levels 80, 125 and 170kg/ha on the grain yield of spring wheat.

The decrease in grain yield with the application of 250kg/haN in experiment 2 (chapter 3) was due to lower numbers of grains per ear and thousand grain weight probably resulting from intraplant competition, since this level of N resulted in higher number of tillers m-2 and per plant. These results are in agreement with those reported by Darwinkel (1978, 1980 and 1983); Mclaren (1981). Increase in N level did not result in significant additional tiller formation per plant in the

spring wheat variety (experiment 1), therefore intraplant competition was reduced, hence grain yields were not affected at the high level of N (170kg/ha). However, number of grains per ear and thousand grain weight were slightly reduced but this was less compared to those of experiment 2.

The most dramatic effect of N level in experiment 1 was obtained from the grain quality data. Grain size, already mentioned above was slightly reduced with the rate of N in both seasons. Rate of protein accumulation during grain filling and the excombine grain protein significantly increased with the levels of N. The effect of N level on this variable was especially expressed during the dry weather of 1989. This applied only to the comparison between individual N levels but not the average protein content of the grain per se. When average grain protein contents are taken into consideration, the 1988 results were slightly higher probably due to the dry period during grain filling in 1989 which may have affected the N uptake and subsequent supply into the grains to boost grain protein content. Hagberg falling number was not affected by N levels in 1988, although in the following season a trend in increased falling number was detected. The seasonal differences of N levels on the falling number results is not fully understood.

N timing consituted a most important objective of experiments 1 and 3. Early N application at growth stages 12-13 in 1988 and 14 of 1989 gave a significant increase in total dry matter m-2 and per plant (chapter 2). The increase in dry matter was caused by its influence on tiller production and survival. Grain yield was also increased with the early timing (T1) in 1988, due to an increase in the numbers of ears m-2, numbers of grains per ear although thousand grain weight decreased. In 1989, opposite results were obtained from this parameter. completely opposite. Although the number of ears m-2 was similar to 1988, both the numbers of grains per ear and thousand grain weight decreased with the

early N application but increased with late treatments. This increase in number of grains and grain weight was able to compensate for the lower numbers of ears m-2 at the late N treatments which consequently resulted in an increased grain yield. In experiment 3 application of N at GS30 on the winter wheat variety gave the highest numbers of ears m-2 as well the total grain yield. The increase in grain yield with N timing was greater in the winter compared to the spring variety of experiments 3 and 1 respectively.

The effect of N timing was greater on grain quality than on crop biomass and grain yield (experiment 1). Grain moisture contents increased slightly with delay in N application in 1988. This increase was not recorded in 1989 growing season due to the hot and dry summer which caused uniform grain drying. The average excombine grain moisture content in 1989 was less than 11% compared to the 1988 growing season which recorded grain moisture contents above 17%. The winter variety Avalon used in experiment 3 also recorded grain moisture contents less than 11% at harvest. Because of the dry summer in 1989, crop maturity was accelerated, hence harvest was about a month earlier compared to the previous growing seasons. The hot and dry summer during the grain filling period affected the final grain yield of both the spring and winter trials in 1989. However the average grain yields recorded from these trials were still higher (5.6 and 6.8t/ha) respectively than those obtained from the college farm areas (3.7 and 4.6t/ha) surrounding the experimental plots. The earlier experimental drillings of the spring wheat and the timing of N application in the winter variety may have caused the grain yield increases.

Grain protein (%N x 5.7) was consistently higher with late N treatments in both seasons (experiment 1). The influence of N timing on grain protein was more clearly shown in 1988, most especially when the T2 and T3 treatments results were compared. Initial protein deposition

in the grains (Figure 2.2) revealed this during grain development. In 1988, soon after anthesis, the grain protein contents given by the T1, T2 and T3 treatments were significantly different from each other this was later confirmed by using regression lines to test the differences between treatments. However, in 1989 the differences between these treatments were not significant (Figure 2.3). The pattern of grain protein accumulation continued until crop maturity. Excombine protein contents also increased significantly with the delay in N application in 1988, whilst in 1989 no differences were detected between the T2 and T3 treatments, although these values were significantly different from T1. The similarity in grain protein contents with these treatments (T2 and T3) was due to lack of rainfall between the time N was applied at T2 and the subsequent treatment at T3. Therefore, the treatments behaved as if both were applied on the same date. This rainfall 'saga' also had the same effect on the winter trial, such that grain protein did not differ with the timing treatments, although this resulted in an increase grain protein content over the control treatment.

The detail grain quality analysis included the determination of the Hagberg falling number. Effect of this variable on breadmaking quality has been reviewed in section 1.4.2, and the procedure used to determine it is fully described in the materials and methods of experiment 1 pages 68-69. Data on Hagberg falling number are averaged over drilling methods (experiment 1). Thus, comparisons can only be made between N levels and the timing effects, and the interactions between these treatments if any. However, in experiment 3, results were presented for the individual drilling techniques. Results on the falling number did not differ with the N timing in 1988. However, data of the 1989 growing season showed a trend in increase in falling number (experiment 1). Although this conclusion is open to some criticism because there is not enough evidence to suggest that this increase was really due to the timing effect. The increase may have due to background variation in the

readings. In the winter wheat trial, Hagberg falling number was not affected by N timing.

Results on Hagberg falling number differed with the seasons. However, this was not surprising, since falling number is influenced by the moisture content of the grains before harvest. Grain moisture contents at harvest in 1989 was comparatively lower, hence the increase in falling number (experiment 1). The low moisture contents (<11%) may have caused the embryo in the grain to become inactive and therefore reduced the activity of the enzyme α-amylase, whilst the relatively higher (>17%) moisture in grains before harvest in 1988 may have influenced its activity. In an experiment to test the effect of fungicide on Hagberg falling number Gooding et al. (1987), reported a decreased in falling number due to a delay in grain drying. Thus, the lower falling number in 1988 in comparison to 1989 may have been linked with higher (>17%) grain moisture at harvest. This can also be used to explain the excess falling number recorded from experiment 3 using winter wheat Avalon.

Field work experiments are controlled by many environmental factors. The most notorious of all is the weather, which fluctuates quickly. This obviously influenced the in results obtained in these studies. Nevertheless, these data provide a means upon which certain basic recommendations can be made.

The results of this study confirm that an application of 175kg/haN is the optimum level for winter wheat grain production. However, an additional amount of N is feasible if the crop is grown for forage. Probably this may sound encouraging to the 'whole crop' wheat postgrauate research programme bieng carried out at Wye College, although the economic implication of growing wheat crop for making silage is open to question. In the quality spring wheat varieties, an increase in grain protein can be achieved with higher N levels than the

suggested optimum (125kg/ha). However, the effect on grain yield is very small compared to grain quality, which might be increased even further with the proper time of its application. Late application at GS32 produced the highest grain protein without any significant decrease in grain yield of the spring variety. With the early drilled crop grain yield and protein content were both increase as shown by the 1989 growing season results. Unlike spring wheat, the effect of N timing on the grain quality of winter variety is relatively small, especially when crops are drilled after break crop such as oilseed rape.

In conclusion, it is worth mentioning that it is difficult in field trials such as this to obtain consistent results due to seasonal differences and the lack of precise dates and growth stages for the application of the treatments. The inability to relate optimum time of N application to the exact growth stage has been accepted as the main reason for the failure to establish the optimum time for N application to cereals. Field experiments can only be used to produce guide lines. Until research scientists are able to determine much more accurately the environmental factors affecting growth stages and to eliminate or standardize the time-lag between the application and availability of nitrogenous fertilizer obtaining consistent results from agronomic experiments will remain a problem.

In Nigeria, future research programmes should be geared towards N fertilization. Because soils of the savanah region of Nigeria, where wheat is grown have low moisture and organic matter, additional N is needed in crop production systems. Due to insufficient soil N most cereal growers in Nigeria mix crops like sorghum, maize and millet with legumes such as beans to increase the N status of the soil in addition to inorganic N fertilizer. High N fertilizer is thus recommended to increase the yields of wheat grown under irrigation in northern Nigeria. Since leaching is minimised due to low rainfall, application of high

levels of N will not result in environmental problems such as obtained under temperate conditions in the UK.

APPENDICES.

Appendix 2.1. Summary of plant counts on different sampling dates (spring wheat experiment, 1988 and 1989).

Coulter.	Numbers of samples.							
	1	2	3	4	5	6	7	8
					1988			
Suffolk	298	280	260	250	249	227	227	218
Band	317	286	279	272	270	266	262	261
Mean	308	283	270	261	260	247	245	240
SED	4.0	7.7	10.2	6.0	7.6	15.5	6.5	8.0
					1989			
Suffolk	336	308	293	288	277	266	_	_
Band	390	330	326	315	310	298	_	_
Mean	363	319	310	302	294	282	_	_
SED	4.1	11.9	15.7	6.7	9.1	8.4	_	_

Appendix 2.2. Details of the experimental treatment on sowing date of Axona in 1989.

Treatment codes.	Sowing dates.	NT m-2.	TDM m-2 (g).	NGPE	TGW (g).	TGY (t/ha).
S1	March 1st 1989					
S2	March 13th 1989					
S3	March 22nd 1989					
S4*	April 14th 1989	734	587	18.8	36.1	1.8

*Similar sowing date with the 1988 trial.

TDM = Total dry matter at anthesis. NT = Number of tillers at GS30.
NGPE = Number of grains per ear at harvest.
TGW = Excombine thousand grain weight. TGY = Total combine grain yield.

Appendix 2.3. Yield and quality attributes of 'commercial' farm trial for the 1988 growing season using spring wheat, variety-Axona.

	Suffolk Coulter.			Band Coulter.			
	Rate of nitrogen (kg/ha).						
	80	125	170	80	125	170	SED.
T.G.Y. (t/ha)	5.1	5.5	5.6	4.4	4.8	4.7	0.3
T.G.W. (g)	41.5	40.9	40.9	41.5	41.4	40.1	0.7
M.C. (%)	15.1	14.7	14.6	15.5	15.2	15.1	0.1
Protein (%)	11.8	12.4	13.1	12.2	12.5	13.1	0.2

Appendix 2.4. Weather data for spring wheat growing season during 1988 and 1989 at Wye.

Months.	Max. T. °C.	Min. T. °C.	S. T °C at 10cm.	OHU	Day Degrees (6 °C.	TMR (mm)	TMSS (hrs).
			1988				
April	11.9	5.0	8.4	148.6	88.5	50.7	172.7
May	16.1	8.5	12.9	375.4	197.3	72.8	208.2
June	17.4	10.0	15.5	443.9	231.8	9.3	150.7
July	19.0	11.6	16.1	557.5	288.5	71.2	202.4
August	20.9	11.6	17.0	600.4	316.9	19.7	209.8
September	17.9	10.3	13.6	466.9	242.7	37.1	128.8
			1989				
February	9.4	2.8	4.6	43.4	41.0	42.8	92.3
March	12.1	4.4	6.7	141.2	90.3	62.1	106.7
April	10.3	3.6	7.3	81.1	56.5	95.8	120.6
May	18.6	8.3	15.0	446.2	234.6	1.3	278.6
June	19.8	9.7	16.5	491.1	265.2	54.4	219.6
July	23.8	13.6	19.8	706.2	393.2	38.0	237.0
August	22.2	12.3	18.1	646.3	352.6	15.5	235.2

T = Temperature, S.T = Soil temperature at 10cm depth.
OHU = Ontario heat units
TMR = Total monthly rainfall, TMSS = Total monthly sunshine.
Day degrees recorded at 6 °C base temperature.

Appendex 3.1. A summary of the means of plant population counts on different sampling dates (winter wheat experiment 1986/87).

		Suffolk Coulter.			Band Coulter.			
DAD.	Nkg/ha.	Density (seeds m-2).			Density (seeds m-2).			
		D1	D2	D3	D1	D2	D3	
(sample)		200	350	500	200	350	500	SED.
S1	_	172	230	289	143	146	281	_
S2	0	122	178	265	129	229	265	
	100	130	189	202	133	217	259	
	175	126	192	197	137	230	286	
	250	Not determined			Not determined			21.5
S3	0	117	162	206	143	206	314	
	100	119	168	232	141	199	307	
	175	117	160	249	149	191	306	
	250	119	166	269	144	189	308	7.6
S4	0	98	152	200	131	177	264	
	100	95	147	184	127	178	256	
	175	101	161	198	125	183	263	
	250	98	155	184	126	177	269	7.7
S5	0	91	150	195	125	197	256	
	100	95	143	199	127	190	244	
	175	98	152	195	125	197	245	
	250	97	164	197	135	192	258	8.8
S6	0	82	151	172	111	197	229	
	100	93	154	179	115	170	231	
	175	87	147	189	116	179	233	
	250	95	148	173	121	166	236	18.1

Appendix 3.2. Temperature ^{o}C - 1986/87 (experiment 2).

Months.	Mean Max.	Mean Min.	H.Temp.	Dates.	L.Temp.	Dates.	S.Temp.
10.86	15.6	8.0	20.4	7	-4.9	24	-
11.86	11.4	4.8	14.2	1	-5.5	30	-
12.86	8.9	2.5	13.2	2	-7.4	15	6.6
1.87	2.4	-2.0	10.7	1	-2.8	12	3.8
2.87	6.3	0.8	14.6	28	-12.5	1	3.9
3.87	7.0	0.5	11.1	17	-14.1	13	4.8
4.87	14.9	5.7	21.7	29	-5.5	13	9.4
5.87	14.4	6.1	20.6	9	-3.3	8	11.9
6.87	17.7	9.6	26.6	29	-1.7	15	14.8
7.87	20.5	12.4	27.3	6	1.6	26	17.5
8.87	20.9	11.5	27.6	21	1.7	6	17.4

H. Temp. = Highest temperature, S.Temp. = Soil temperature at 10cm.

Appendix 3.3. Monthly rainfall (mm) - 1986/87.

Months.	Total	Heaviest	Dates.
10.86	83.3	21.9	14
11.86	101.1	28.7	20
12.86	74.0	10.7	15
1.87	22.3	5.5	11
2.87	36.6	11.5	13
3.87	55.5	10.8	1
4.87	31.6	9.0	1
5.87	51.3	15.3	14
6.87	67.5	9.6	17
7.87	124.2	24.4	17
8.87	95.8	36.3	21

Appendix 3.4. Monthly sunshine (hrs) - 1986/87.

Months.	Total.	Maximum.	Dates.
10.86	122.1	9.6	4
11.86	70.8	6.9	20
12.86	72.9	6.9	9
1.87	41.8	8.5	31
2.87	66.7	8.1	24
3.87	97.6	10.1	29
4.87	187.1	12.9	28
5.87	193.1	13.8	9
6.87	127.4	12.2	29
7.87	190.5	15.1	4
8.87	173.9	12.5	26

*Source: Wye College Meteorological Station.

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