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GRAIN YIELD AND QUALITY OF MALTING BARLEY (*Hordeum vulgare* L.) AS INFLUENCED BY NITROGEN

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A. G. Fergusson

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This is to certify that

the work described in this thesis was

planned, implemented and described by

A. G. Fergusson

under our supervision at Lincoln University.

D. J. Moot

Warwick R. Scott

Dr. D. J. Moot

Supervisor

Dr. J. M. de Ruiter

Associate Supervisor

Dr. W. R. Scott

Co-Supervisor

Senior Lecturer

in Plant Science

Lincoln University

Crop Physiologist

Crop & Food Research

Lincoln

Senior Lecturer

in Plant Science

Lincoln University

GRAIN YIELD AND QUALITY OF MALTING BARLEY (*Hordeum vulgare* L.) AS INFLUENCED BY NITROGEN

by A. G. Fergusson

An experiment was run from September 1997 to February 1998 using "Valetta" barley at Lincoln, Canterbury, New Zealand. Grain yield and grain quality were measured in response to different rates and timings of nitrogen (N) fertiliser. Biomass accumulation, leaf response and biomass and nitrogen distributions during grain filling were also measured.

The highest grain yield of 7030 kg ha^{-1} at 0 % moisture (8000 kg ha^{-1} at 14% moisture) with a grain N % of 1.64 was obtained with a single application of 150 kg N ha^{-1} at crop emergence 21 days after sowing (DAS). Grain yields and grain N % decreased with lower N rates while screenings and grain N % increased with additional applications. Harvest index averaged a mean of 47 %, but varied between 44 (nil N fertiliser) up to 57 % (150 kg N fertiliser).

Total biomass was greatest (16020 kg ha^{-1}) in the highest N fertiliser treatment of 150 kg N ha^{-1} at crop emergence with an additional application of 100 kg N ha^{-1} at Zadoks growth stage 18. This treatment produced a peak growth rate of 310 kg biomass ha^{-1} d^{-1} at 87 DAS and a mean growth rate over the linear phase of growth of 205 kg ha^{-1} d^{-1}. All other N treatments had lower growth rates. The linear phase of crop growth was the same for each treatment at around 75 days. Radiation use efficiency was about the same for all treatments at a mean of 2.00 g biomass per MJ photosynthetically active radiation (PAR) intercepted. The differences in total biomass produced were related to the

amount of PAR intercepted, 524 MJ m^{-2} in the highest N fertiliser treatment from 61 to 110 days after sowing, compared with 445 MJ m^{-2} where no N fertiliser was applied. Maximum leaf area index (LAI) was the main contributor to the amount of PAR intercepted, being highest at 3.8 in the high N treatment.

Leaf lamina responses to applied N fertiliser showed that leaves maintained a specific leaf nitrogen level at about 2.0 g N m^{-2} leaf^{1}. To maintain this level, leaves with lower N availability decreased the green area of the lamina when fully emerged. Specific leaf weight (weight per unit green leaf area) was not affected by N fertiliser treatments in any treatments.

Biomass and nitrogen relocated during grain filling was affected by the amount of N available at anthesis and the growth rate at anthesis. In general, the formation of a total plant N pool at anthesis of 2.0 % or less gave acceptable grain quality, and yields greater than 7000 kg ha^{-1} could be expected. The grain yields and quality were more effected by the N pool than the biomass relocation. Excessive plant N (> 2.0 %) from split applications of N fertiliser increased plant growth, rather than reserve assimilate production for grain. This decreased the amount of biomass accumulated in the grain as shown by increased levels of screenings.

It was concluded that at this site, to obtain high yields and acceptable grain quality with the use of N fertiliser in an adequately water supplied malting barley crop, 150 kg ha^{-1} of N fertiliser was required to ensure maximum biomass accumulation but this N needed to be applied at crop emergence.

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LIST OF ABBREVIATIONS

a i	Active ingredient
ANOVA	Analysis of variance
AWC	Available water content
°Cd	Celsius degree days
C	Total biomass
Cm	Maximum crop growth rate
CV	Coefficient of variation
cv	cultivar
DAS	Days after sowing
Dc	Critical deficit
E	Efficiency of PAR
ha	hectare
HI	Harvest index
I	Proportion of solar radiation intercepted
k	extinction coefficient
kg	Kilograms
LAI	Leaf area index
LT	Long term
MJ	Mega Joules
N	Nitrogen
NHI	Nitrogen harvest index
NS	Means not significantly different
PAR	Photosynthetically active radiation
Q	radiation intercepted
r^2	Coefficient of determination
RCB	Randomised complete block
RUE	Radiation use efficiency
SEM	Standard error of the mean
SLN	Specific leaf nitrogen
SLW	Specific leaf weight
SMD	Soil moisture deficit
WMAGR	Weighted mean absolute growth rate

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CHAPTER ONE

General introduction

A challenge facing malting barley (*Hordeum vulgare* L.) growers is how to use nitrogen (N) fertiliser to increase crop yields without compromising the quality of grain for malting by increasing the grain protein content. Recommendations for N fertiliser are dependent on the yield potential, cultivar sown, the nitrogen status of the soil and the end use of the crop (Lieffering *et al*. 1993).

Nitrogen is used to increase grain yields in temperate cereals, including barley, because there is usually a response to fertiliser N in the cropping system in Canterbury, particularly when soil moisture is non limiting. Therefore, the strategic application of N fertiliser is frequently an important management tool used to increase grain yields (Lieffering *et al*. 1993).

In New Zealand, malting barley grain yields average about 4500 kg ha^{-1} (Anon 1997) with a target grain N concentration of less than 2.0 % (de Ruiter *et al*. 1993; Baethgen *et al*. 1995). Thus, N fertiliser can be used to increase grain yields, but its application may also increase the grain N concentration above the 2.0% quality threshold required for malting (McTaggart & Smith 1995).

Baethgen *et al*. (1995) showed that up to 60 kg ha^{-1} N fertiliser applied at sowing increased grain yield but had a small effect on the final grain nitrogen percentage. However, Martin & Daly (1993) showed 200 kg ha^{-1} of N fertiliser applied at late tillering increased the nitrogen content of the grain to 2.0 % compared with 1.3 % when 50 kg N ha^{-1} was applied. Grain yield was also increased by 2500 kg ha^{-1}.

Nitrogen fertiliser increases yields of malting barley in two main ways. Firstly, increased leaf area of the crop enables greater interception of photosynthetically active radiation (PAR) over the growing season (Hay & Walker 1994). Secondly, N may alter the

efficiency of conversion of this intercepted PAR into biomass. When N availability decreases, the biomass produced per MJ PAR of a crop may decline (Hay & Walker 1994). It is expected that as N supply increases and canopy expansion reaches it's potential, more N would be partitioned into existing leaf area to maintain photosynthesis (Grindlay 1997). However, Grindlay (1997) suggested there is a lack of understanding of the effect of leaf N levels in relation to N supply and the relationships between leaf N concentration and biomass production (Grindlay 1997).

This study is trying to determine whether the leaves maintain N concentrations at levels allowing maximum photosynthesis by a decrease in area of the leaf, or whether leaves reduce leaf N while maintaining a maximum area. In particular, we propose to test the hypothesis that plants with decreased nitrogen levels produce only sufficient leaf area to maintain a specific leaf N concentration that is optimal for photosynthesis and biomass production.

1.1 Research objective
The aim was to quantify the effects of N availability on leaf growth, including specific leaf weight, leaf N concentration and leaf senescence, to explain differences in grain yield and grain N concentrations.

Four hypotheses were tested as follows:

1. Grain yield of malting barley crops can be increased without detrimental effects on grain nitrogen content by applying N fertiliser.

2. Nitrogen fertiliser affects canopy characteristics by influencing light interception and radiation use efficiency (RUE) of the crop.

3. Leaf size of malting barley is determined by the available N and the mechanism for this is the maintenance of specific leaf nitrogen concentration by adjustments to leaf size.

4.   N availability affects N pools (accumulated N in plant parts) for grain growth, either from remobilised or current (leaf photosynthesis during grain filling) assimilate.

1.2   Project structure

This thesis is presented in seven chapters (Figure 1.1). Following the general introduction, the literature is reviewed in Chapter Two in relation to other experiments involving malting barley. The effect of applying different N fertiliser treatments on total grain yield and quality, harvest index (HI), yield components and biomass of a malting barley crop is described in Chapter Three. In Chapter Four, differences in canopy development are related to N fertiliser applications and their influence on grain yield.

The influence of N fertiliser on specific leaf N levels (g N m^{-2}), area of leaves and specific leaf weight (mg cm^{-2}) are described in Chapter Five. Details of biomass and nitrogen relocation within plants from different treatments from anthesis to final harvest are reported in Chapter Six and these results are related to the differences in grain N concentration. Finally, the general discussion in Chapter Seven integrates results from the previous chapters.

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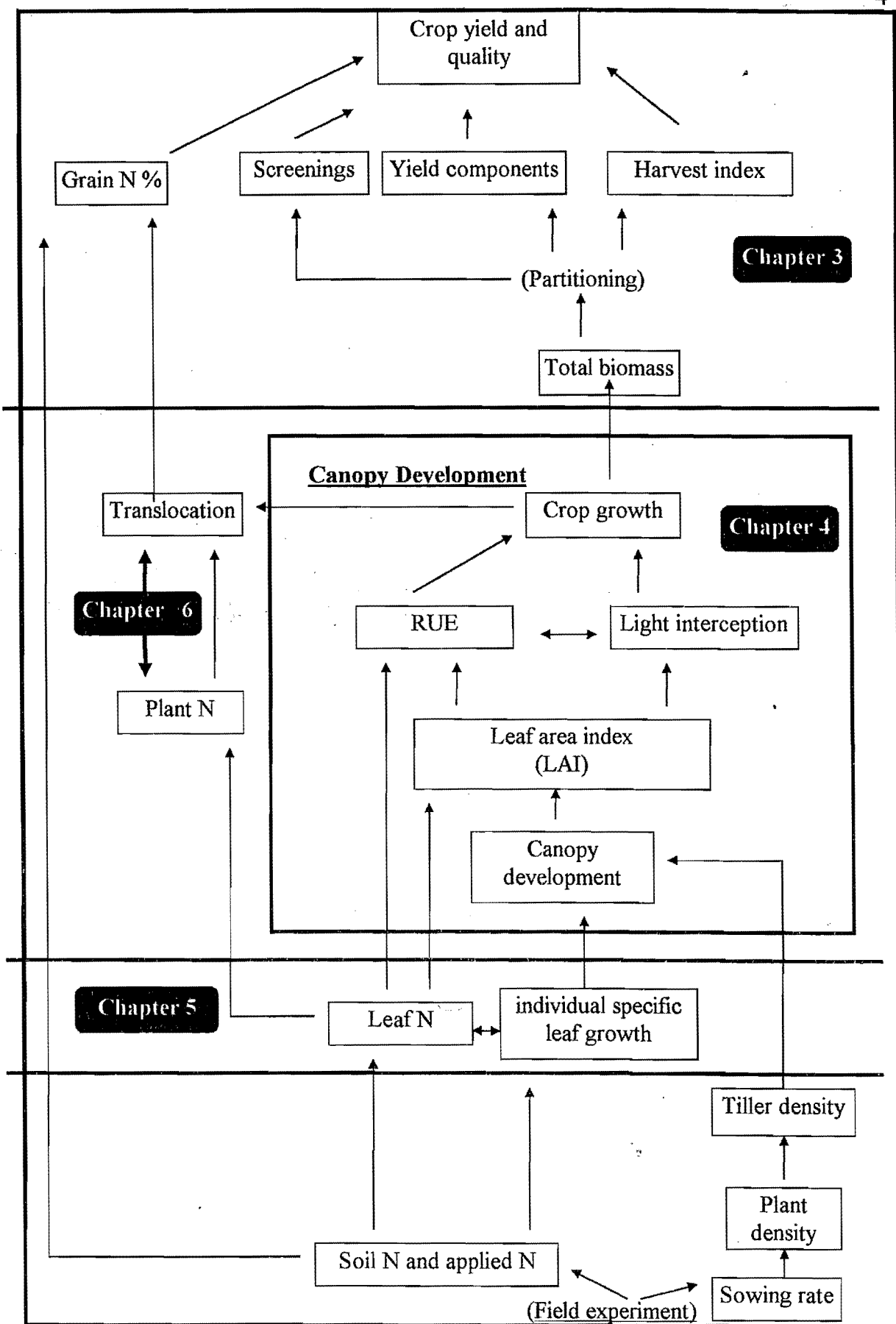
Figure 1.1   Diagrammatic representation of the structure of this study on grain yield and grain quality of malting barley as influenced by N fertiliser.

CHAPTER TWO

Review of the literature

2.1   Background

Barley is an important cereal grown throughout the world for animal feed and human consumption. Barley is also used for distilling and brewing predominantly into beer (Malcom 1983). In New Zealand, approximately 400 000 tonnes of barley is produced each year from 77, 000 ha, mostly in the Canterbury region. This represents about 40 % of all arable crops grown in New Zealand (Anon 1997).

A major determinant of the quality in cereal crops is the nitrogen (N) concentration of the grains. The optimum N concentration of cereal grains is related to their end use. The N % of barley and wheat grains usually varies from 1.2-3.0 % (Martin *et al*. 1989). The grain N % depends on the climatic and soil conditions under which the crop grows. For wheat high N % (> 2.0) is desirable to increase the baking quality of flour. However, barley grains used for malting that have greater than 2.0 % N may decrease the quality of malt produced from the grains (de Ruiter & Haslemore 1996).

Malt quality is closely linked to the N concentration of the grain (de Ruiter & Haslemore 1996). Low protein malts generally do not present a problem to brewers. Hence a quality requirement of barley grown for malting is a grain N concentration of < 2.0% (McTaggart & Smith 1995; de Ruiter *et al*. 1993).

The objective for malting barley crops is to maximise grain yield without decreasing grain quality through excessive grain nitrogen concentration (Baethgen *et al*. 1995; McTaggart & Smith 1995). The use of N fertiliser can increase grain yields, but may also increase grain N %.

The balance of high yield and quality can be achieved provided nitrogen fertiliser is applied early in crop growth, before the end of tillering, and the crops are not subject to water

stress, particularly during grain-filling. This optimises vegetative growth but minimises direct translocation of applied nitrogen to the grain which can occur with late applications of N (Baethgen *et al.* 1995).

There is a very close relationship between N fertiliser and irrigation on grain quality and yield (Thompson *et al.* 1974; Drewitt & Smart 1981; Carter & Fitzgerald 1987). In general, N fertiliser is applied to barley crops at sowing and at tillering, before the start of stem elongation (Ramos *et al.* 1995). For example, Martin & Daly (1993) applied 200 kg N ha^{-1} as a split dressing at sowing and mid tillering and increased grain yield by 2500 kg ha^{-1} but also increased grain N % from 1.3 to 2.2 %.

2.2   Agronomy of malting barley crops

Barley can be sown in spring or autumn. Early sowing affects yield potential by allowing a longer time for biomass accumulation. Yield potential is defined as the maximum above ground grain yield that is able to be grown under optimal conditions, usually with non-limiting water and non-limiting N. Winter barley crops must be sown sufficiently early to satisfy vernalisation requirements (Knight *et al.* 1988) and often require additional controls for pest and disease compared with spring sown crops (Gallagher 1983).

However, modern cultivars have minimal vernalisation requirements and can be used for spring or autumn sowing. In a sowing date experiment, Conry & Hegarty (1992) found a consistent pattern of grain yield response to sowing date. Over a five year period, grain yield averaged 8280 kg ha^{-1} from the earliest sowing, compared with 5610 kg ha^{-1} from crops that were sown 81 days later. Martin & Daly (1993) stated that "When N, irrigation, disease and pest control are optimised, then autumn sowing produces as high or higher yields of higher quality barley than spring sowing". Although higher yields can be obtained from autumn sowing, traditionally the bulk of barley for malting in Canterbury is spring sown (90 %, de Ruiter pers comm). This is presumably because it fits in with other farm practises such as the over wintering of stock and crop rotations on mixed livestock/cropping farms. In this study, cops were spring sown.

2.2.1 Crop establishment

Millner (1983) stated that sowing should occur as early as possible in spring. In New Zealand, this is usually from August to early October. Sowing rates of 120 - 200 kg seed ha^{-1}, depending on seed size, are recommended at approximately 15 cm row spacing and 30 mm seed depth.

Target plant populations are 200-300 plants m^{-2} (Evans & Wardlaw 1976), and in New Zealand, Millner (1983) recommended 200 plants m^{-2} on light land (dry silt loams), and 250 plants m^{-2} on heavier land soil types (moisture retentive alluvial flats). Lower plant populations on lighter soil types helps to conserve available soil water by decreasing the stem and tiller population and reducing the screenings if the crop becomes water stressed.

2.2.2 Soil requirements

2.2.2.1 Ground preparation

Conventional preparation for a malting barley crop usually involves ploughing, followed by power harrows, and a crumbler (Millner 1983). The ideal seed bed is firm, moist, well aerated, and free from weeds. If the area to be sown in barley is immediately out of pasture, a four to six week fallow after ploughing allows burial and decomposition of plant material and decreases the number of pests, such as Argentine stem weevil (*Listronotus bonariensis*) (Close 1983). Direct drilling of seeds is also possible. Hughes & Mitchel (1987) working with a range of cereals showed a mean plant establishment of 68 % under direct drilling compared with 75% in a cultivated seed bed.

2.2.2.2 Soil nitrogen

Soil mineral nitrogen (NO_3^- and NH_4^+), which is readily available for plant uptake, typically constitutes less than 1 - 2% of total soil nitrogen with the remainder being composed of organic N. The amount of mineral N built up depends on many factors including cultivation, paddock history and time of year. Mineral N is made available to plants through mineralisation of organic N (McLaren & Cameron 1996). The mineralisation rate from the organic nitrogen pool is dependant on temperature, moisture, and the carbon to nitrogen ratio of incorporated materials and the microbial population (McLaren & Cameron 1996). The annual amount of N mineralised over a year can range from 10 to 500 kg ha^{-1}

(McLaren & Cameron 1996) and may exceed the amount of N applied as fertiliser. Typical mineralisation rates on Canterbury soils are 1.2 - 1.5 kg N ha^{-1} d^{-1} (Selvarajeh *et al.* 1987).

Therefore, soil nitrogen can increase crop growth of barley by boosting levels of readily available nitrogen for uptake. In situations where cereals are grown on the same land for consecutive years, soil nitrogen may become depleted and limit the growth and yield of temperate cereals (Lieffering *et al.* 1993).

Barley crops require in excess of 200 kg N ha^{-1} for a 7000 kg ha^{-1} grain yield (de Ruiter & Brooking 1994) and this N must be derived from soil available N or applied N. Alternatively, for a physiologically mature crop where all leaves have senesced, a 6000 kg ha^{-1} grain yield with a grain N % of 1.8 would remove about 110 kg N ha^{-1} in addition to N bound in stem and root material. Measurement of available soil N may assist in understanding how a soil system can be managed for efficient uptake of available soil N.

Soil N tests can be used to assist with accurately predicting how much N to apply. Two common soil N tests are outlined below but it should be noted that testing for soil N is difficult because of soil environmental factors (McLaren & Cameron 1996), such as depth of sampling, leaching, rate of mineralisation, stones etc.

2.2.2.2.1 Soil nitrogen tests

Test 1. Profile mineral N test.

A 0.6 m deep column of soil is taken from an area and tested immediately for mineral N by extraction with potassium chloride. However, this test requires large numbers of samples, is time consuming, and is difficult to do on stony soils. The test does not account for N that may become available through mineralisation.

Test 2. Potential mineralisable nitrogen.

This test measures the amount of mineral N in the soil that will be released over the growing season. It is done either by incubation or chemical tests. Incubation involves a measure of immediate mineral N levels compared with the amount of mineral N released after 7 days incubation at 35 ^{0}C. Chemical tests involve acids or alkaline solutions to estimate the potential amount of mineralisable N.

As an alternative to soil testing for N, plant N levels may be determined by sap nitrate tests. However, interpretation of these tests are difficult because of variation in relationships between plant and sap-N concentrations (Reddiex *et al.* 1997) and the diurnal fluctuations in soluble sap N. Alternatively, chlorophyll meter readings, to estimate nitrogen content of leaves have yet to be proven useful in the field. Dynamics of the leaf such as age, water status and cultivar (Reddiex *et al.* 1997) contribute to variation in chlorophyll content and reduce its predictive potential. The chlorophyll meter is likely to be of use only when N is limiting, and only after rigorous calibration (Reddiex *et al.* 1997).

Potential mineralisable nitrogen is difficult to determine accurately on field samples processed in the laboratory. The type of seed bed preparation, time of year and temperatures are just some important governing factors of the amount of N available for a crop. Nevertheless, determination of the amounts of N available to crops is important because of the strong relationships reported with grain yields and quality (eg. de Ruiter & Brooking 1996).

2.2.3   Irrigation

The principle benefit of irrigation on malting barley crops is to ensure optimum above ground biomass and to enable grain-filling to occur at near maximum rates. This enables kernels to fill to their potential. Irrigation can be scheduled to avoid the crop reaching a critical potential soil moisture deficit (Dc), which is the point beyond which crop growth and grain yields are reduced relative to optimal watering treatment (Jamieson *et al.* 1993). For most soils the Dc is about 1/2 of the available water content (AWC), where AWC is the amount of water held in the soil between field capacity (-10 kPa), and permanent wilting point (-1500 kPa) (McLaren & Cameron 1996).

The critical water deficit is affected by the soil AWC and rooting depth. For example, silt loams have a larger AWC (14 % water per unit volume, v/v) than sandy soils (7 % water v/v) (McLaren & Cameron 1996). In most cases spring sown cereals generally have a reduced capacity to extract water from depth than autumn sown crops. van Keulen & Seligman (1987) stated that wheat roots were no longer a sink for assimilates once plants had reached anthesis because root growth had reached its genetic potential at that stage.

Therefore, autumn sown crops explore soil for a longer period because of the longer growth phase pre anthesis. For example, Jamieson *et al.* (1993) showed that autumn sown wheat extracted water up to a depth of 1.5 m compared with 1.0 m for spring sown barley. For barley, Dc ranges from 50 - 100 mm were reported by Jamieson *et al.* (1993) on a *Udic Ustocrept* type soil. Dc values of 75 mm are typical for most Canterbury sandy loam soil types.

In barley crops, grain yield and quality are reduced by a water shortage (Thompson *et al.* 1974; Drewitt & Smart 1981; Carter & Fitzgerald 1987). On light soils, stony silt loams and silt loams, yield responses to irrigation are usually significant. Irrigation also lowers grain N % and increases malt extract (Thompson *et al.* 1974; Drewitt & Smart 1981).

If water is inadequate and N fertiliser is applied, grain N % and screenings increase (Millner 1983; Smart 1983; Martin & Daly 1993). This is because grain-filling is dependant on water grain-filling and diluting grain N laid down during grain development. For example, Jamieson *et al.* (1993) reported a yield reduction of about 25 kg grain yield per mm of water deficit beyond Dc. Jamieson *et al.* (1993) found that barley had 41 % screenings under drought conditions, and concluded that preferential grain-filling of some grains at the expenses of others occurred under conditions of water stress.

In summary, application of N fertiliser can reduce grain quality for malting barley, but the extent of the quality decline is reduced if irrigation is applied (Drewitt & Smart 1981). Irrigation is also likely to increase the grain yield. However, the effect of irrigation on grain yield and quality is complex because of interactions with soil type, paddock history and applied and available N.

2.2.4 Diseases, pests and weeds

Barley is susceptible to a number of seed borne diseases including loose smut (*Ustilago nuda*), covered smut (*U. hordei*), leaf stripe (*Pyrenophora graminea*), net blotch (*P. teres*), spot blotch (*Cochliobolus sativus*), barley yellow dwarf virus (BYDV) and scald (*Rhynchosporium secalis*). Close (1983) also reported barley was susceptible to the seed and soil-borne disease Fusarium (*Fusarium* spp.). These diseases are generally controlled with chemicals (Walton & Sommerville 1995) or appropriate crop rotations (Close 1983).

Take-all (*Gaeumannomyces graminis*) and eyespot (*Pseudocercosporella herpotrichoides*) can be a problem for malting barley crops resulting in the plant bleaching and lodging (Close 1983) leading to decreased yields. Control is through crop rotation or stubble burning of previous crop residues (Close 1983). Take-all can survive on alternative hosts such as couch or twitch (*Agropyron repens*) including the rhizomes. Therefore, chemical control just prior to establishment may not stop infection (Close 1983).

Martin & Daly (1993) indicated aphids can also affect barley crops, either by feeding on the sap of barley (rose grain aphid; *Metopolophium dirhodum*) or by spreading BYDV (cereal aphid; *Rhopalosiphum padi* L.).

Major weeds of barley crops are usually controlled by herbicides. Cover development in spring barley occurs quickly providing effective competition for weeds. Perennial weeds such as couch (*Agropyron repens*), yarrow (*Achillea millefloium*) and Californian thistle (*Cirsium arvense*) should be controlled in the previous winter or autumn before the barley crop is sown (Close 1983).

2.2.5   Fertiliser

2.2.5.1 Nitrogen fertiliser

Numerous studies have reported the effect of applied N fertiliser at differing rates and timing on malting barley grain yields eg. Drewitt & Smart (1981), Martin & Daly (1993), Baethgen *et al.* (1995), Lieffering (1995), McTaggart & Smith (1995), Ramos *et al.* (1995), and de Ruiter & Brooking (1996).

The most effective time to apply nitrogen fertiliser to increase grain yield is during tillering and before the start of stem elongation (Martin *et al.* 1989; Ramos *et al.* 1995). This ensures maximum tiller survival. In the USA, Baethgen *et al.* (1995), reported grain yield increases ranging from 700 to 2370 kg ha^{-1}. The maximum yield was obtained from a split application of 30 kg N ha^{-1} at sowing and an additional 30 kg N ha^{-1} at early tillering, and/or mid-tillering. Early N application increased the number of tillers, and late applications increased their survival. When no late application of N was made, then tiller death can be expected resulting in a decreased yield (Millner 1983).

Other factors contributing to the grain yield response of barley to applied N fertiliser are temperature, available water (Section 2.2.3) and soil nutrient status (Section 2.2.2.2). In non limiting water situations and on N rich sites, there is no significant yield response to applied N (Drewitt & Smart 1981). On N deficient soils where N and irrigation are applied, yield increases and quality can be maintained (Drewitt & Smart 1981).

However, if water and soil N conditions are non-limiting, grain yield increases can be expected from the application of N. Millner (1983) reported that the greatest grain yield (13.2 kg grain^{-1} kg N^{-1}) responses to applied N was from the first 25 kg N ha^{-1}. The efficiency of grain production was reduced to 9.2 kg grain^{-1} kg N^{-1} following an additional 25 kg N ha^{-1}. This was due to a decrease in grain weight and grains per unit area. Hay & Walker (1994) suggested that in experiments showing large increases in crop responses to applied N that the effects were due more to N stress relief, than a direct fertiliser N response.

Because of the importance of irrigation and N applications, crop N management differences have been noted between irrigated and non irrigated properties. A survey of 31 malting barley growers in Canterbury, New Zealand showed that on irrigated farms an average of 120 kg N ha^{-1} was applied. On farms that had no irrigation, an average of 100 kg N ha^{-1} was applied (de Ruiter, unpublished data). In both irrigated and non irrigated crops, excessive grain N concentrations were reported in dry seasons.

2.2.5.2 Other nutrient requirements

Phosphorus has also been identified as a major nutrient required for malting barley (Millner 1983). About 15 - 20 kg P ha^{-1} is removed with a barley crop, and this amount should be reapplied to restore soil levels. If soil Olsen P tests are below 10 at sowing, then there is likely to be a yield response to applying P fertiliser (Millner 1983). Potassium (K) has not been shown in New Zealand to be of any benefit to barley crops. In New Zealand, soils are continually releasing K from large natural soil reserves (Millner 1983; McLaren & Cameron 1996). Sulphur (S) is often applied with super phosphate fertiliser, but S deficiency in New Zealand arable crops has generally not been a problem (McLaren & Cameron 1996).

2.2.6 Grain quality

Characteristics of grain that have known effects on malting quality of barley are grain N % and screenings. Grain N %, must be less than 2.0 % (de Ruiter 1997), and screenings (grain passing 2.38 mm screen) often have higher N % (> 2.0 %) and inconsistent characteristics with poor extract yields.

2.2.6.1 Grain N %

The risk of increasing grain N % above the quality threshold of 2.0 %, occurs with the application of N to increase grain yield (Drewitt & Smart 1981; Martin & Daly 1993; Conry 1995; McTaggart & Smith 1995). McTaggart & Smith (1995) used different forms, rates, and timings of N fertiliser and showed grain N % generally increased with additional fertiliser. For example, grain N % was 1.48 when no nitrogen was applied, but increased to 2.26 % when 150 kg N ha^{-1} in the form of calcium nitrate was applied at sowing.

In an another study by Drewitt & Smart (1981), grain N % increased with increasing amounts of N. They suggested that the increasing grain N % may have been due to the N laid down in the kernel during development not being diluted by carbohydrate synthesis, ie grain-filling was prematurely stopped and kernels did not fill to their potential. Because N application increased the number of ears per unit area and the number of kernels per ear, more carbohydrate was required to fill all kernels. Even when irrigation was applied, grain N and screenings increased. This result means that even if water is non limiting, applying N fertiliser is likely to increase grain N %.

2.2.6.2 Screenings

Screenings in malting barley may not be more than 5 % of total grain yield or the crop will be rejected (Smart 1983; Martin & Daly 1993). Screenings do not meet the maltsters requirements for two reasons, one, they are too small (<2.38 mm width) (Smart 1983), and two, screenings are more likely to have a high N %, greater than 2.0 (de Ruiter & Brooking 1996) which reduces extract percentage and has uneven germination.

Increasing the N supply to a malting barley crop has been shown to increase both the yield and proportion of screenings (Drewitt & Smart 1981; Conry 1995). For example, Martin & Daly (1993), reported that screenings increased from 3.1 % in a grain yield of 4850 kg ha^{-1}, where no N fertiliser was applied, to 15.6 % screenings from a 6770 kg grain yield

ha^{-1} where 200 kg N ha^{-1} was applied as a split dressing between sowing and mid tillering.

Of the factors that interact with N (whether applied or soil available N) irrigation is the most important. Irrigation increases grain yield and maintains a high quality grain when applied in conjunction with N fertiliser. However, the balance between maintaining high yields and high quality is difficult to achieve because of differences in determining how much N is available for crop growth and the variability in response of barley crops to applied N.

2.3 Crop growth and yield

The total grain yield of a cereal crop can be described by yield components (Scott 1983) or by crop growth analysis which relates crop growth and biomass accumulation to environmental conditions (Gallagher *et al.* 1983).

2.3.1 Yield components

The grain yield of barley and other cereals, can be described as the product of three yield components (Equation 2.1; Millner 1983)

Grain yield per unit area = Number of ears per unit area *
Number of kernels per ear *
Mean kernel weight.   (Equation 2.1)

2.3.1.1 Number of ears per unit area

There are number of factors that affect the number of ears per unit area established and maintained through to maturity. These include sowing rate and crop establishment (Section 2.2.1), tillering and tiller survival (Sections 2.2.1: 2.2.2.2: 2.2.3: 2.2.5) and cultivar. However, Millner (1983) and Ramos *et al.* (1995), concluded that the number of ears m^{-2} was the most important component for grain yield. Gallagher *et al.* (1983) reported this could be increased by N management to retain higher numbers of tillers through to maturity.

Baethgen *et al.* (1995) showed the greatest number of tillers (1400 tillers m^{-2}) occurred when 90 kg N ha^{-1} was applied at sowing, rather than as a split application. In that experiment the soil available N at sowing was 30-60 kg ha^{-1}. They concluded this was

sufficient N for the early establishment and survival of a comparatively high population of tillers.

2.3.1.2 Number of kernels per ear

Gallagher (1983) showed that the number of kernels per ear was inversely proportional to the number of ears per unit area. For example, a 35 % decrease in the number of ears m^{-2} increased the number of kernels per ear by 30 %. Therefore, grain yield was highly dependent on the number of kernels per unit area as shown also by de Ruiter & Brooking (1994) at a correlation of 79 %. Gallagher *et al.* (1975) suggested the most important of these was the number of ears per unit area. To obtain a modest grain yield (4500 kg ha^{-1}) Scott (1983) reported that 11250 kernels per m^{-2} , each weighting 40 mg were required. These results highlight that yield is dependant on the number of grains per unit area regardless of whether this is achieved from high numbers of ears or grains per ear.

2.3.1.3 Mean kernel weight

The mean kernel weight has been shown to be dependent on the genotype of the barley grown (Gallagher *et al.* 1975; Russel & Ellis 1988). Gallagher *et al.* (1975) found that from 5 spring barley cultivars, mean kernel weight was relatively stable (eg "Proctor", 34.9 ± 2.8 mg). However, the mean ranged from 29.3 to 41.0 mg over a wide range of environmental and soil conditions.

The final kernel weight may be determined by environmental conditions experienced during grain-filling (Section 2.2.3). The amount of assimilate that is partitioned to the grains varies with environmental conditions (Russel & Ellis 1988). Gallagher *et al.* (1975) commented that when drought or other adverse conditions limited photosynthesis during grain-filling, translocation of stored assimilates produced pre anthesis would help ensure that grain-filling was not limited.

In summary, the yield components approach to describing grain yield provides a "snap shot" at the end crop. The individual yield components are interdependent and have a compensatory response (Baethgen *et al.* 1995), or "plasticity" (Millner 1983; Scott 1983; Wilson 1987). This plasticity among components, and the interaction of genetic and environmental factors on the level of expression of each component, limits the usefulness of

this approach. The results of an experiment are always site and season specific and variation among sites is usually greater than among treatments (Gallagher *et al*. 1983).

Monteith (1977) suggested a functional approach which develops quantitative relationships between crop performance and environmental factors was required to understand yield differences. This functional 'crop growth' approach has been used successfully to describe the growth of several crops (Monteith 1977; Wilson *et al*. 1989) including barley (Gallagher *et al*. 1983).

2.3.2   Crop growth approach

A generally accepted functional approach for crop growth is to describe grain yield per unit area (Y) as the integral of crop growth over time, multiplied by the harvest index (HI) (Equation 2.2; Monteith 1977; Wilson 1987; Reddy *et al*. 1997).

$$Y = HI \int C dt \qquad \text{(Equation 2.2)}$$

where C is the daily rate of above ground biomass production (Wilson 1987).

2.3.2.1 Harvest index

Harvest index (HI) is a description of the amount of economically viable biomass (grain) compared with the total amount of above ground biomass (Donald & Hamblin 1976). Harvest index for barley and wheat is commonly stable at around 0.45 (Wilson 1987; McDonald 1990), varying by little more than 10 % (Gallagher & Biscoe 1978b). Because of stability of HI, the major determinant of grain yield is the daily accumulation of biomass or crop growth rate (C).

2.3.2.2 Crop growth rate

Crop growth rate is linearly related to the amount of solar radiation intercepted and the efficiency with which it used (Equation 2.3),

$$C = E * Q \qquad \text{(Equation 2.3)}$$

where E is the efficiency of the conversion of intercepted solar radiation into biomass or radiation use efficiency (RUE), and Q is the amount of solar radiation intercepted (Wilson 1987; Martin 1996). Gallagher (1983) suggested a typical average daily growth rate for barley in non-limiting conditions was about 170 kg biomass ha^{-1} d^{-1} over the main growing season.

Values for Q differ with the amount of total incoming solar radiation and the proportion of that incoming solar radiation that is intercepted, and expressed as a %. The proportion of total incoming solar radiation intercepted depends on the leaf area index (LAI) of a crop, and leaf angle, and is described by Beer's Law (Equation 2.4),

$$I = [1 - exp (- k \, LAI)] \qquad \text{(Equation 2.4)}$$

where k is the extinction coefficient that depends on canopy architecture and is a function of leaf angle distribution, canopy reflectance and diffuse light absorbance (Hay & Walker 1994).

For temperate cereals the value is typically 0.45 (Jamieson *et al.* 1995), compared with 0.9 for flat leaved clover plants (Hay & Walker 1994). However, Yunusa *et al.* (1993) concluded that using a single k value to describe light interception and biomass production in cereals was inappropriate. They drew this conclusion because of the different values of k obtained from different cultivars of wheat in addition to differences found in k within a cultivar over the same season. For example, between cultivars they found k values of 0.49 in a tall semi-erect large leaved cultivar compared with 0.58 in an erect leaved cultivar. Within a cultivar, k values over the season changed from 0.58 to 0.41 between pre-anthesis and post-anthesis.

The extinction coefficient (k) is determined using Equation 2.5:

$$k = - \ln (1 - I) / LAI \qquad \text{(Equation 2.5)}$$

where I = amount of total solar radiation intercepted and is calculated by using equation 2.6:

$$I = 1 - \text{proportion of solar radiation reaching base of canopy (Equation 2.6)}$$

The RUE is a measure of the biomass produced per MJ of light intercepted by the leaf canopy (Hammer & Wright 1994). RUE is calculated as the slope of the linear relationship between accumulated crop biomass and intercepted solar radiation (Muchow & Sinclair 1994). Photosynthetically active radiation (PAR) accounts for 48 % of total incident radiation (McCree 1966). Experimental data summarised by Hay & Walker (1994) suggest that in non-limiting water situations, RUE in a range of crops, including barley, is around 2.8 g biomass MJ^{-1} PAR. The RUE may increase or decrease depending on canopy architecture, environmental stresses such as drought or high temperatures (Gallagher *et al.* 1983). Gallagher and Biscoe (1978a) found RUE in cereals up to anthesis to be 3.0 g biomass per MJ PAR, but over the whole season of growth RUE averaged 2.2 g biomass per MJ PAR. In comparison, Yunusa *et al.* (1993) found RUE ranged from 1.5 to 2.4 in three different wheat cultivars.

2.3.2.3 Leaf area index

Leaf area index (LAI) is a measure of the area of leaves (single sided) covering a given area of ground. LAI is unitless and increases after crop emergence as leaves appear and expand. As LAI increases, so does the extent of light interception up to the critical LAI at canopy closure, above which at least 95 % of incoming radiation is intercepted. The relationship between LAI and light interception is asymptotic and Evans & Wardlaw (1976) showed that for most cereal crops 95 % light interception occurred when LAI was about 4. In general, peak LAI occurs at anthesis (Ramos *et al.* 1995).

Canopy development is mainly temperature dependant (de Ruiter & Brooking 1996). However it is also sensitive to environmental stresses and crop management (Wilson 1987). Most effects on yield, including nutrient deficiencies, can be interpreted in terms of changes in canopy development, and hence on the ability of the crop to intercept incident PAR during growth (Wilson 1987).

Canopy development is related to the rate of leaf appearance and expansion. The appearance of successive leaves is determined by thermal time, usually calculated as cumulative daily mean temperature above 0 °C. The thermal time between the appearance of successive leaves is termed the phyllochron (McMaster 1997). The phyllochron is

usually stable for a cultivar and not affected by nutrient supply (Hay & Walker 1994). However, when N is in short supply, the rate of leaf expansion (growth) and consequently canopy development is reduced (Figure 2.1; Grindlay 1997).
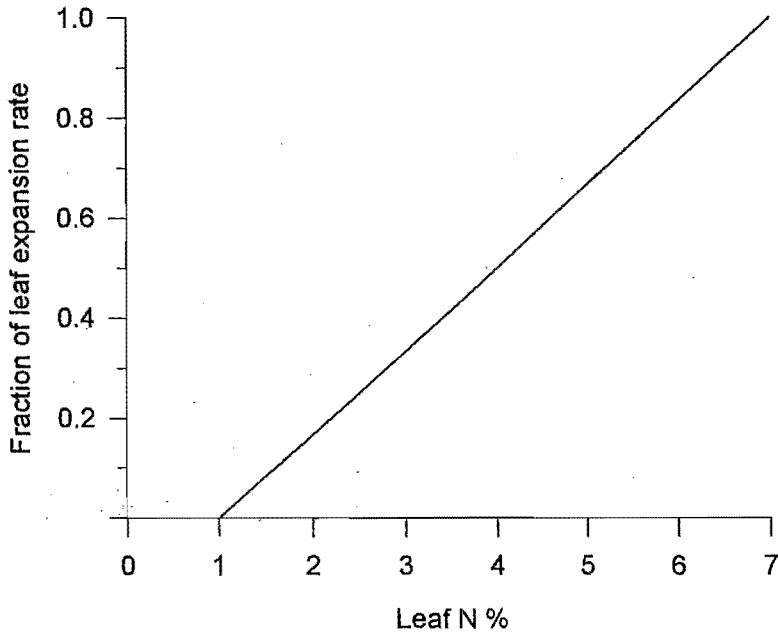
Figure 2.1   Fraction of maximum leaf expansion rate as a function of leaf N content. Data from *Lolium rigidum*; *Triticum aestivum*; and *Lolium perenne*. (Redrawn from van Keulen & Seligman 1987).

Ramos *et al.* (1995) commented, after an eight year experiment with barley, that N influences LAI by increasing the number of leaves per plant by increasing tillers per plant, and not the size of the leaves. When nitrogen was applied at sowing the leaves responded by an increase in their duration (Ramos *et al.* 1995). Conversely, when nitrogen was limiting, Grindlay (1997) suggested the leaves were likely to senesce earlier because the new leaves need nitrogen to survive to grow and assimilate carbon. The implication was that if nitrogen was limited, the plant remobilised nitrogen from older leaves to the new leaves causing earlier leaf senescence of the older leaves which decreased LAI.

In conclusion, any agronomic factors that lead to early canopy closure, such as N fertiliser, lead to increased biomass production through the interception of a greater proportion of the available PAR. Factors that delay canopy closure, such as moisture stress or low plant population (less than 200 p m^{-2}) may cause reduced biomass production and potential grain yield (Equation 2.2).

2.4 Leaf dynamics

Changes in leaf N per unit leaf area, termed specific leaf nitrogen (SLN), in response to N supply may relate to crop biomass production (Grindlay 1997). Relationships between leaf growth according to N availability are possibly specific to species and cultivar and a knowledge of these responses would assist in defining a mechanism for the utilisation of N in barley (Grindlay 1997). It is known that photosynthetic rate responses to light intensity increases as leaf N per unit area increases up to a maximum. Alternatively, as N supply to leaves becomes limiting, the photosynthetic rate decreases, resulting in decreased biomass (Figure 2.2). Photosynthetic rate and consequently biomass production, is also decreased when a decreased amount of light is received at the leaf surface (Figure 2.3).

The green area of a plant is mainly leaves, and although the effect of nitrogen (Figure 2.2) and light (Figure 2.3) on photosynthetic rate and leaf expansion (Figure 2.1) is understood (Grindlay 1997), it has not been quantified in terms of leaf weight, area of leaves, and biomass production efficiency in relation to leaf nitrogen concentration in barley. The current study was undertaken partly to determine the effects of leaf weight, area of leaf and SLN on biomass production in malting barley.
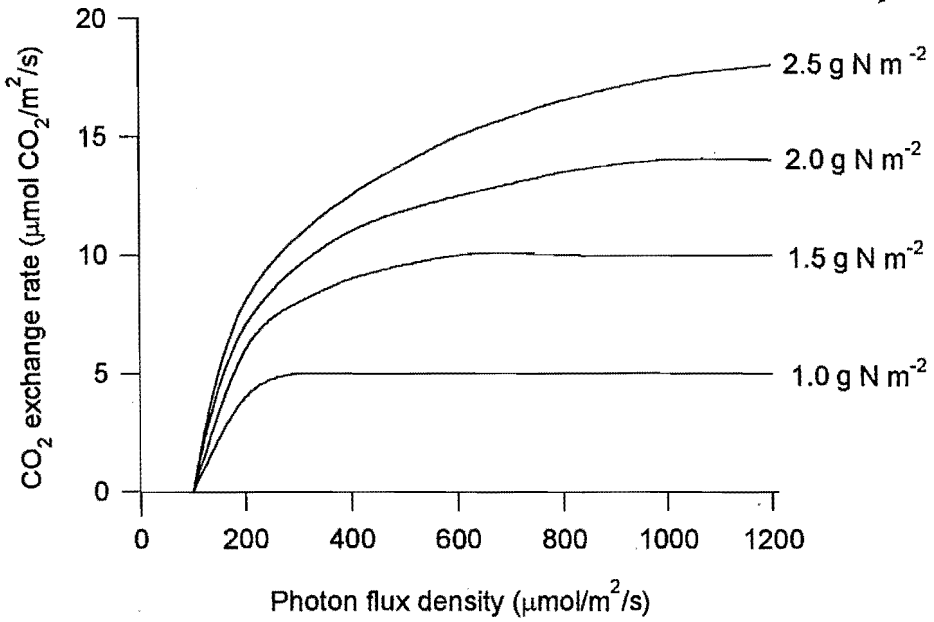
Figure 2.2   The photosynthetic rate of leaves as influenced by leaf N per unit leaf area (Redrawn from Grindlay 1997).
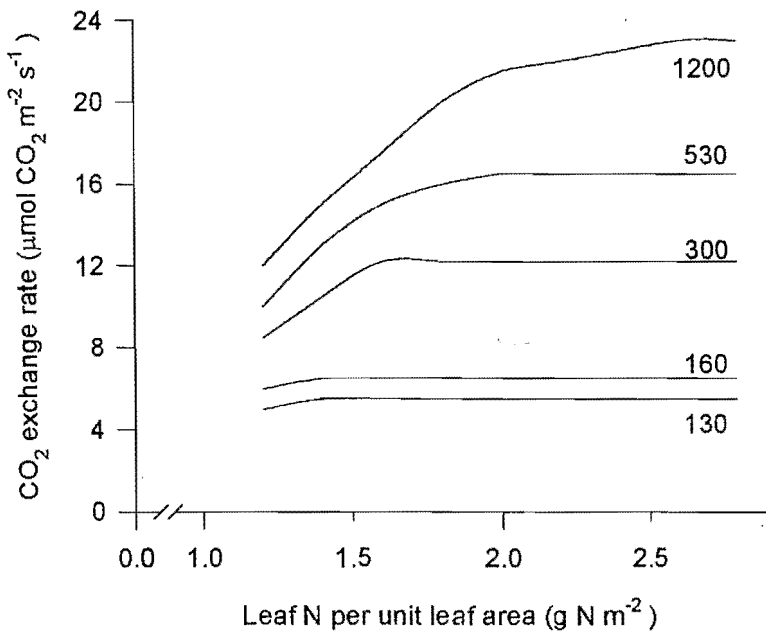
Figure 2.3   Photosynthetic rate (μmol CO_2 m^{-2}) of leaves at differing leaf N levels per unit area as influenced by light (photon flux densities shown on graph). (Redrawn from Grindlay 1997).

2.4.1 Area of leaf

Nitrogen deficiency reduces area of a leaf and consequently canopy expansion. This reduces the amount of radiation intercepted and biomass produced by the canopy with concomitant reductions in growth rate (Reddy *et al.* 1997; Grindlay 1997). An increase in LAI can occur through an increase in the number of leaf bearing organs per unit area, namely main stems and tillers, also individual area of leaf can be increased by increasing N supply which also increases LAI (Hay & Walker 1994).

In contrast, Ramos *et al.* (1995) showed nitrogen fertiliser applied during vegetative growth promotes leaf growth to their maximal size, but does not increase leaf size above the maximum potential size regardless of the amount or timing of applied N (Table 2.1). The area of leaves is constant in Table 2.1 regardless of timing or amount of N supplied. However, it is probable that in that experiment, N was not limiting. The study did not describe when the leaves were sampled, nor whether the lamina only, or lamina + sheath was measured for area.

2.4.2 Leaf nitrogen

Leaf N levels and concentrations are affected by the availability of N. Grindlay (1997) in a review outlined several areas where leaf N concentration changed. Leaf N concentration and levels relate to photosynthetic performance, photo flux densities and leaf position in the canopy. In all descriptions, the leaf N concentration was dynamic. For example, leaf N concentrations decreased in the earlier formed leaves, and N concentrations also changed along the lamina of individual leaves from the middle to the base. Under conditions where N is non-limiting, the relationship between photosynthesis and leaf N concentration is assumed to be linear (Figure 2.4). In this example light was assumed to be non-limiting and that the relationship is linear up to leaf N content of about 6 %. Upper limits for the response were not defined by the authors, but values above 6.0 % N are rare (van Keulen & Seligman 1987).

Table 2.1   Average area of leaves and leaf area index of barley leaves from differing amounts and timings of N fertiliser.

N (kg ha⁻¹) applied at:			
Sowing	Tillering	leaf area (cm^{-2})	LAI
10	30	7.7	1.30
30	10	7.5	1.41
20	20	7.7	1.35
50	30	7.5	1.87
30	50	7.9	2.08
40	40	7.7	2.19
		S.E. = 0.35	S.E. = 0.05

Note. All treatments were 113 plants m^{-2} ± 2. (Adapted from Ramos *et al.* 1995)
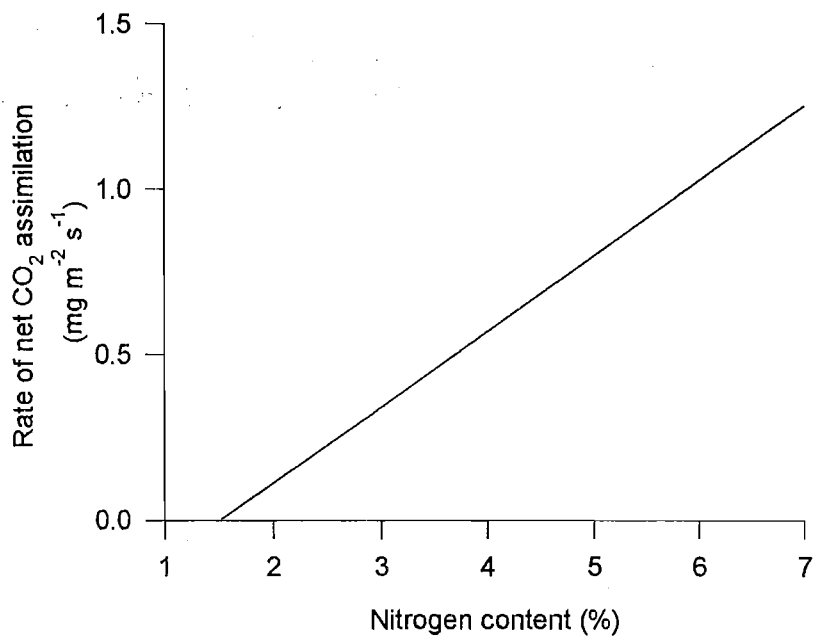
Figure 2.4   Relationship between leaf N % (dry weight) and rate of CO^2 assimilation. Regression line from *Triticum aestivum*; *Oryza sativa*; *Hordeum murinum*; *Phalaris minor*; *Festuca arundinacea*; *Oryza* spp.; *Panicum* spp. (Redrawn from van Keulen & Seligman 1987)

In summary, leaf N concentration affects biomass production. A decrease in N per unit area of leaves decreases photosynthetic rate resulting in a decrease in biomass production.

For malting in Canterbury there are no data which show how leaves respond to different levels of available N. In the present study it is proposed to determine relationships for leaf area under variable N supply.

2.5   Biomass and nitrogen sources for grain-filling

Improved understanding of the processes of accumulation and partitioning of biomass and nitrogen during whole crop development is required to provide sound recommendations for N management inputs (de Ruiter and Brooking 1996). Biomass for grain-filling may come from two sources, biomass produced during the post-anthesis period, and biomass produced pre-anthesis and translocated to the grain post-anthesis (Gallagher *et al.* 1975; Blacklow & Incoll 1981; de Ruiter & Brooking 1996).

The portion of grain weight from remobilisation or current assimilate during the post anthesis period varies (de Ruiter & Brooking 1996). For example, Biscoe *et al.* (1975) showed 30 % of the grain weight came from remobilised stem reserves, and Gallagher *et al.* (1975) showed a variation from 2.0 to 70.0 % due to water stress.

The source and manner of the biomass for wheat grains was described in a study by Austin *et al.* (1977). In that study, it was estimated that 48 % of final grain weight came from photosynthesis post-anthesis. The remainder of the grain weight came from relocation of stored assimilates from the stem and leaves. Of the 48 % of grain weight from current photoassimilates, 24 % was assimilated in the grain during the first 10 days post-anthesis. Therefore, grain-filling in the first few days following anthesis was mainly from current photosynthesis.

Stem reserves have been thought to be an important source of assimilates for grain weight (de Ruiter & Brooking 1996), and the stem weight varies according to the demand for assimilates placed on it by grains (Austin *et al.* 1977). For example, Gallagher *et al.* (1975) showed a large contribution through stem weight loss in barley, whereas Austin *et al.* (1977) stated that little or none of the carbon fixed before anthesis was relocated to the grain (7%). Instead, the stem acted as a storage organ for current assimilates, and presumably, because photosynthesis was at the peak at anthesis (as indicted by maximum LAI, Section 2.3.2.3), more assimilate was produced than was able to be partitioned to the

grain. Therefore, the weight of the stem is likely to initially increase and then decline as the canopy begins to senesce. Under decreasing canopy cover the contribution of assimilates from current photosynthesis declines and the assimilates stored during the rapid photosynthesis period post anthesis are then remobilised to the grain (Austin *et al.* 1977).

Nitrogen in the grain at harvest is from two sources, either from nitrogen that was taken up before flowering and stored in the upper leaves and stem, and then remobilised to the grain after flowering (Martin *et al.* 1989), or from the nitrogen that was taken up after flowering and translocated directly to the grain (van Keulen & Seligman 1987).

However, partitioning and remobilisation of N during reproductive growth in grain crops is complex (de Ruiter & Haslemore 1996; Grindlay 1997) as the proportions are influenced by many interacting factors. This makes quantifying the amounts difficult. For example, a nitrogen shortage in vegetative tissue influences the distribution of assimilates between the various organs of the plant (van Keulen & Seligman 1987).

Proportions of N from a developing N pool in malting barley have been quantified (de Ruiter & Brooking 1994). They reported that on average, 63 % of the N in the above ground biomass was derived from soil reserves, and that 87 % of the total N uptake had occurred before anthesis. Therefore, the application of N fertiliser late in crop growth, post-anthesis, may not affect the grain N %. In a later study, de Ruiter & Brooking (1996) concluded that post anthesis N uptake was negatively related to grain N concentration indicating that late N uptake may not be detrimental to grain quality. In crops with increased N reserves at anthesis that were potentially mobile, grain quality was likely to be reduced (de Ruiter and Haslemore 1996). In conclusion, low plant % N reserves at anthesis, coupled with near maximum biomass accumulation is likely to lead to high (> 6000 kg ha^{-1}) grain yields with acceptable quality provided there are no other limiting conditions.

However, the processes of carbon and N accumulation are closely linked during grain-filling (de Ruiter & Brooking 1996). Late N uptake was not detrimental to grain N quality, but the level of mobilisation of N reserves to the grain during grain-filling was (de Ruiter & Haslemore 1996). Therefore, the amount of N taken up and stored at anthesis is an

important pool to identify. Some values for total plant N % at harvest range from 1.2 to 1.69 %, and at anthesis, total plant N concentrations can range from 0.78 to 2.91 % (de Ruiter & Brooking 1994). The higher the amount of N % in the crop at anthesis, the decreased capacity the crop has to uptake N after anthesis (de Ruiter & Brooking 1994).

To ensure that grain-filling is at maximum, and that grain N quality is maintained, biomass accumulation should be at near maximum rates when applications of N fertiliser are made. This ensures that grain-filling is from current assimilate rather than stem reserves (de Ruiter & Haslemore 1996). This can be achieved by maintaining green leaf area through adequate supply of N, timely irrigation and fungal disease control (de Ruiter & Brooking 1996).

2.5.1 Nitrogen harvest index (NHI)

Nitrogen harvest index (NHI) is the proportion of N in the grain compared with the remainder of the nitrogen in the above ground plant material (Blacklow & Incoll 1981). NHI is a crude measure of the efficiency of N taken up to N stored in grain. Values of NHI range from 0.49 to 0.65 (de Ruiter & Brooking 1996). The source of N uptake (soil/applied N fertiliser) may or may not affect the NHI. In most cases NHI is a variable character and may change depending on the relative proportion of N redistributed from pre-anthesis reserves or the contribution from late N uptake during the grain-filling stage (Blacklow & Incoll 1981). Grain quality can be maintained in malting barley if the crop has a high (0.68) NHI (de Ruiter & Brooking 1996). This is because the crops had decreased amounts of N pool reserves at anthesis and a large reliance on late N uptake to maintain grain-filling.

2.6 General conclusion

The main affect of inadequate N supply is on canopy expansion. Reduced canopy cover intercepts less light and consequently produces less dry matter (Grindlay 1997). An understanding of how the canopy changes in response to variations in N supply is important for prediction of impact on grain yield. Grindlay (1997) suggested the following mechanisms for canopy and leaf dynamics. For example, as N per unit leaf area increases, individual area of the leaf increases to maintain a constant N concentration. Alternatively, the area of the leaf may be unchanged but leaf N % and RUE reduced. To maximise final yield and reduce the likelihood of over applications of N fertiliser, an understanding of the

area of a leaf and N levels in the plant could theoretically enable N supplies (Grindlay 1997) and crop canopies to be manipulated.

2.7 Conclusions and experimental aims

The literature suggests that traditional approach of yield description through yield components has benefits. However, an alternative approach that describes crop growth is functional responses to environment. This is more holistic and may lead to more definitive response functions of use in crop management.

A problem relating to the effect of applying N fertiliser, is understanding differences caused by timing and rate. Descriptions of malting barley individual leaf area development and the response of leaf N concentration to N availability may assist in the definition of quantifiable relationships involving water and N effects that assist in maintenance of consistent grain quality.

The aims of this study were:

1.   To quantify the effects of early and late applications of N fertiliser on grain yield, quality and total biomass accumulation in malting barley.

2.   Relate biomass growth to canopy characteristics produced by different levels of nitrogen availability.

3.   To determine if nitrogen availability affects individual leaf size while the leaf maintains a standard nitrogen concentration, or if leaf size is independent of nitrogen concentration in malting barley.

4.   To quantify grain-filling in terms of biomass and nitrogen assimilation and relocation in malting barley as affected by nitrogen availability from plant and soil nitrogen pools.

CHAPTER THREE

Yield and grain quality

3.1   Introduction

High grain yields and acceptable grain quality are required for profitable production of malting barley crops. To achieve this is important to understand how crop yield and quality interact under different N management practises. Average yields in New Zealand are around 4500 kg ha^{-1}, with grain N less than 2.0 %, and screenings less than 5 % of total yield (Martin & Daly 1993; de Ruiter 1997).

In this chapter an experiment is described which had the objective to examine the grain yield and quality of malting barley crops grown with different rates of nitrogen fertiliser. Differences in grain yield are described by traditional yield components analysis (Millner 1983) and by the total biomass and harvest index (HI) of the crops. For the purpose of this study, grain quality is defined by grain N % and the percentage screenings (Section 2.2.6).

The aim of the experiment was to determine yield responses to rate and timing of nitrogen fertiliser applications and the associated effects on grain quality.

3.2   Materials and Methods

3.2.1   Site

The experiment was conducted over the 1997/98 growing season at the Crop & Food Research Farm, Canterbury, New Zealand (43°, 36' S.) on a Templeton shallow silt loam soil (Kear *et al.* 1967) typed as an *Udic Ustocrept*. Soil was tested for nutrients on May 6 1997 by the Soil Fertility Service, Ag Research, Invermay. Levels were adequate for all nutrients tested (Appendix 3.1). The experimental site was in ryegrass for the previous seven years, with herbage being cut and removed annually.

3.2.2 Experimental design

The experiment was a randomised complete block design, with six N fertiliser treatments (Table 3.1) and three replicates in 3 * 25 m plots.

Table 3.1   Nitrogen treatments applied to the experimental barley crops during the 1997/98 season

Treatment	Application date	
(kg N ha^{-1})	16 October	20 November
0	0	0
50	50	0
100	100	0
150	150	0
150/50	150	50
150/100	150	100

The first application of urea (46 % N) was 21 days after sowing (DAS), on 16 October, when the plants were fully emerged. The second application was at 56 DAS (20 November) when plants were at the 7 leaf stage (Zadoks growth stage 18, Zadoks *et al.* 1974). In each plot, half of the area was assigned for sequential destructive harvests throughout the season and the remainder was left for hand harvests to asses yield at maturity. Climate data were collected throughout the experimental period at Broadfield weather station, Crop & Food Research, Lincoln, adjacent to the experimental site.

3.2.3   Crop establishment and management

After conventional cultivation (Section 2.2.2.1), barley (cv. Valetta) seed was sown at 300 viable seeds m^{-2} in 150 mm rows using an Öyjord 9 row cone seeder on 25 September 1997. Seed was treated with Baytan® IM fungicide (active ingredient, a.i. 150 g kg^{-1} triadimenol plus 50 g kg^{-1} imazalil) to protect the crop from seed-borne and foliar diseases. Plant population at 61 DAS was 170 p m^{-2} constituting 65 % of the viable seed sown. Field emergence was considerably lower than expected possibly because of sowing the crop too deep and large soil clods hampering plant growth. This also contributed to variation in replicate variability. Anthesis of the crop started on December 9 (75 DAS) and mid-anthesis was on 16 December.

Water was applied with a side roll irrigator over the growing period to avoid a critical soil water deficit greater than 70 mm. Soil N was measured at sowing and mid-anthesis by sampling each plot to 0.2 m depth and combining duplicate cores. Samples were mixed thoroughly, passed through a 2 mm screen, mixed again and stored at -10 ^{0}C until analyses. The samples were thawed and 4 g fresh weight extracted in 20 ml of 2 M KCL. Nitrate and ammonia levels were determined on a RFA 3000 autoanalyser.

For weed control, Glean™ herbicide @ 9 g a.i. ha^{-1} (a.i. 750 g kg^{-1} chlorsulfuron) was applied on Nov 19 (55 DAS) together with Cougar® @ 300 ml a.i. ha^{-1} (a.i. 100 g l^{-1} diflufenican plus 500 g l^{-1} isoproturon).

3.2.4 Measurements

Two 1.0 m^{-2} quadrats taken at final harvest (130 DAS) from the five inner rows to measure total dry matter, grain yield, ears m^{-2}, thousand seed weight, and grains per ear. Thousand seed weight was calculated as the mean of four random sub-samples (after screenings were removed) from each plot. Grains per ear was calculated by dividing grain yield by thousand seed weight and dividing by ears m^{-2}.

Samples were dried to constant weight at 70 ^{0}C for 48-72 hours, threshed through a Kurt Pelz stationary thresher to remove the grain. Grain was then cleaned and sieved (2.5 mm) through a Kamas Westrup air seed cleaner to remove screenings (Section 2.2.6.2) which were then weighed separately. Samples for grain nitrogen levels were prepared by grinding with a Cyclotec 1093 Sample Mill. Total N content of samples was determined in a mass spectrometer.

3.2.5 Data analysis

An analysis of variance (ANOVA) was used to determine differences amongst treatments. Mean separation was based on LSD tests at the $\alpha = 0.05$ level.

3.3   Results

3.3.1   Grain yield, yield components and harvest index

The highest screened grain yield came from the 150 kg N ha^{-1} treatment, 7030 kg ha^{-1}, equivalent to 8000 kg ha^{-1} at 14 % moisture (Table 3.2). The highest N treatment produced a grain yield of 6430 kg ha^{-1}, which was 1690 kg ha^{-1} more ($p < 0.05$) than the nil N treatment.

The number of ears m^{-2} increased from 630 at nil N fertiliser to 1300 ($p < 0.01$) with 150/100 kg N ha^{-1}. The number of grains ear^{-1} ranged from 13.7 to 19.9 although these differences were not significant (Table 3.2). Kernel weights were also not affected by treatments. The data on ears m^{-2} and grains ear^{-1} showed considerable variation with CV's between 15 and 18 %, higher than usually recorded in experiments of this kind (Baethgen *et al.* 1995; Ramos *et al.* 1995). This large variability was also responsible for some of the lack of statistically significant differences between the treatments. For example, 980 ears m^{-2} was not significantly different from 1300 ears m^{-2}; 13.7 grains ear^{-1} not significantly different from 19.4 grains ear^{-1} (Table 3.2). There was a trend for fewer grains ear^{-1} and lighter kernels with increased applications of N (Table 3.2). However, within individual treatments there was much variability. For example, in the nil N treatment, grains ear^{-1} varied from about 25 to 16.

The data in Table 3.2 also suggested that there was a close inverse relationship between ears m^{-2} and grains ear^{-1}. To test this hypothesis, grains ear^{-1} was plotted against ears m^{-2} for the individual plots (Figure 3.1). For most treatments there was considerable variation among replicates but strong (r^2 - 67 %) inverse relationship between grains ear^{-1} and ears m^{-2} within each treatment.

The product of ears m^{-2} and grains ear^{-1} is grains m^{-2} and although a derived component, it is presented in Table 3.2. It is included because most of the differences in grain yield caused by treatments was associated with differences in grains m^{-2}. The possible reasons for the variability in ears m^{-2} within treatments are discussed in Section 3.4.

3 Soil N

Soil mineral nitrogen levels from samples obtained at sowing were about 10 kg N ha^{-1} over the site (data not shown). At mid-anthesis nitrate (NO_3^-) levels ranged ($p < .001$) from 0.84 kg ha^{-1} in the nil N treatment up to 8.68 in the 150/100 kg N ha^{-1} treatment (Table 3.3). Ammonium (NH_4^+)levels followed a similar trend ($p < 0.05$), ranging from 1.02 kg ha^{-1} at nil N, up to 5.88 when 150/100 kg N ha^{-1} was applied.

3.3.4 Grain N %, screenings and harvest index.

Grain nitrogen % increased from 1.31 in the nil N treatment to 1.83 in the 150/100 kg N ha^{-1} treatment (Table 3.4). None of the treatments exceeded the 2.0 % N content.

As the amount of N fertiliser increased, the percentage of screenings increased (Table 3.4). The proportion of screenings was acceptable in the nil, 50 and 100 kg N ha^{-1} treatments ranging from 2.0 to 3.2 % respectively. However, in the high N treatments, screenings were above the 5 % acceptable level. The highest N treatment gave a screening level of 11.3 %.

Harvest index, the proportion of yield in relation to total above ground biomass, is shown in Table 3.4. Nitrogen applied at 150 kg ha^{-1} gave the highest harvest index when calculated with and without screenings, 57 and 53 % respectively. The lowest HI, 40 %, came from the highest N treatment when calculated as grain only, but this increased to 45 % when screenings were included.

Table 3.3 Soil nitrogen levels (kg ha^{-1}) at anthesis to 20 cm depth

Treatment (kg N ha^{-1})	Nitrate		Ammonia	
0	0.84	b	1.02	b
50	0.74	b	0.94	b
100	1.29	b	2.78	ab
150	1.78	b	3.35	a
150/50*	6.55	a	5.49	a
150/100*	8.68	a	5.88	a

Note. * = treatments where split application of N fertiliser was applied at 56 DAS.
No measure of error given because data was log transformed due to non-normal distribution

Table 3.4 Grain nitrogen, screenings (zero % moisture) and HI from barley grown under different nitrogen fertiliser treatments

Treatment (kg N ha^{-1})	Grain nitrogen (%)		Screenings (%)		Harvest index (%)			
					Grain		Grain + Screenings	
0	1.31	c	2.0	d	43	bc	44	c
50	1.49	bc	3.1	cd	50	ab	51	abc
100	1.60	ab	3.2	cd	52	a	53	ab
150	1.64	ab	7.1	bc	53	a	57	a
150/50*	1.73	ab	10.0	ab	43	bc	48	bc
150/100*	1.83	a	11.3	a	40	c	45	bc
SEM	0.060		0.91		1.8		1.9	

Note. * = treatments where split application of N fertiliser was applied at 56 DAS.

3.4   Discussion

Applied nitrogen increased the grain yield of all crops. (Table 3.2). The highest yield of 7030 kg ha^{-1} was comparable with that reported by Conry (1995), who obtained 7660 kg ha^{-1} at 15 % moisture with 150 kg N ha^{-1} applied and comparable with de Ruiter & Brooking (1996) 7000 kg ha^{-1} with optimal crop management. Baethgen *et al.* (1995) commented that splitting N applications to match crop N requirements was probably the best strategy to achieve high yields while maintaining quality. In the current study, screened grain yields were similar from a single application of 150 kg N ha^{-1} and a split application of 150/100 kg N ha^{-1}. Therefore, the split application of N did not necessarily increase yield in malting barley which differs from other reported results (Martin and Daly 1993). The failure of increased yields from split applications of N may have been due to adequate N levels being derived from the first application of N fertiliser.

The yield component that was most closely related to yield was the number of grains m^{-2} (r^2 = 67 %) (Figure 3.1). The number of ears m^{-2} was a poor indicator (r^2 = 41 %) of yield as was grains ear^{-1} (r^2 = 3 %). This result disagrees with Gallagher *et al.* (1975), Millner (1983) and Ramos *et al.* (1995) who stated that ears m^{-2} was the most important yield component contributing to grain yield. Conversely, Biscoe *et al.* (1975), de Ruiter & Brooking (1994) and de Ruiter & Brooking (1996) stated that grains per unit area was the most important determinant of yield but in turn this was dependant on ears per m^{-2} and showed that grains m^{-2} accounted for most of the variation (79 to 92 %) in grain yields. The variability of components (grains ear^{-1} and ears m^{-2}) within treatments in this experiment indicates that N treatments did not affect these components. Furthermore, the consistency of grains m^{-2} highlights the plasticity of the yield components.

Grains ear^{-1} decreased as stems m^{-2} increased (Figure 3.1) in the current study and this decrease may be explained by the variability in plant spacing within plots. The unusually low plant numbers (170 p m^{-2}) were consistent across plots and gave considerable variation in plant spacing but this was not measured. The variability was compounded by tillering which was reflected in the ears m^{-2}. Therefore, the additional ears m^{-2} came from tiller ears and not a difference in plant numbers. This finding agrees with Ramos *et al.* (1995) who found ears m^{-2} increased with increasing N but there was no effect on grains ear^{-1} or kernel weight.

The non-significant effect of fertiliser N on grains ear^{-1} and kernel weight supports the conclusion made by Wilson (1987) that yield components are not particularly good predictors of yield variation, rather they describe the structure of seed yield. Ears m^{-2} increased in response to applied N fertiliser. This trend differs from that reported by Conry (1995) who stated that with increasing amounts of N fertiliser, ears m^{-2} and grains ear^{-1} increased, but grain weight declined.

Grain N % increased with increasing amounts of applied N, and it is likely that if additional N fertiliser was applied, grain N % levels would have exceeded the upper quality grain N % limits. However, all crops had less than 2.0 % grain N which is considered acceptable for malting quality (McTaggart & Smith 1995; de Ruiter *et al.* 1993). The high applications of N fertiliser did not exceed the 2 % quality limit probably because adequate water was applied over the growth of the crop. This result agrees with Drewitt & Smart (1981) who concluded that when barley is grown on N deficient soils and when N and irrigation are applied, yield responses generally occur and quality can be maintained.

Thermal time accumulation for the whole growth period (emergence to maturity) was 117 degree days above the twenty three year average base (0 degrees). This decreased the growing season by about 8 days (117 C^0 d / 14.3 C^0) (Appendix 3.2). Temperatures were also higher than long term means early in growth. This probably contributed to enhanced developmental rates, and increased rates of organic matter mineralisation. Therefore, N responses were expected to be small during the early development stages.

The net rate of soil nitrogen mineralisation early in the growing season was probably around 1.5 kg ha^{-1} d^{-1} (Selvarajeh *et al.* 1987; pers comm de Ruiter), hence, it is assumed that adequate nitrogen was available for vegetative growth. However, at anthesis the low N treatment crops may have been limited by N supply as indicated by the soil N tests (Table 3.3). As the growing season progressed the amount of soil nitrates was more variable than the amount of ammonia. The increased amount of soil N was probably responsible for maintaining the higher tiller survival.

Harvest indices ranged over about 13 % whether grain yield was determined on whole samples or with screenings removed (Table 3.4) agreeing with Gallagher & Biscoe (1978b).

Conversely, McDonald (1990) stated for cereals HI was a conservative character and a HI of 45 % was commonly expected for barley under differing environmental conditions. The variation in the HI may be related to the screenings. Screenings results are comparable with Martin & Daly (1993) who found similar increases in yield and screenings from similar applications of N fertiliser. There appeared to be a link between screening level and grain number (Table 3.2). The assimilate demand for treatments with high grain numbers is increased and the source of assimilate may have been affected. However, grain-filling is examined more closely in Chapter Six.

3.5 Conclusion

- An application of 150 kg N ha^{-1} at emergence maximised yield while maintaining grain quality. Splitting N did not increase grain yield, but did increase screenings. Grains m^{-2} was most closely associated with yield and the effects of N treatment on kernel weight were small. There was variation in HI which indicates a sink source relationship was being affected.

Appendix 3.1   Soil nutrient levels

Nutrient	P (Olsen)	K	S	Ca	Na	Mg	pH
Level	21	15	5	13	8	21	6

Appendix 3.2   Weather data for the months of 1 October 1997 to 31 January 1998

Climatic conditions			October	Month November	December	January	Totals / means
Temperature (means) (C^0)	Daily	1997/98 LT* mean	12 11.3	14 13.1	15.2 15.7	17.9 17	
	Maximum	1997/98 LT mean	18.2 16.7	21.1 18.4	21.6 21.3	24.5 22.6	
	Minimum	1997/98 LT mean	6.6 6	7.8 8.0	9.4 10.2	12 11.4	
Thermal Time (°Cd) Monthly		1997/98 LT mean	372.7 350.3	419.7 393	470.1 486.7	553.4 527	1874.4 1757.0 (117.4)
Rainfall (mm)		1997/98 LT mean	32 54	22.6 55	42.5 61	17.2 50	114.3 220.0
Radiation (MJ m^{-2})	per month	1997/98 LT mean	600.4 508.4	723.9 603	769.1 672.7	765.5 669.6	2858.9 2453.7 (405.2)
	per day	1997/98 LT mean	19.37 16.4	24.13 20.1	24.81 21.7	24.69 21.6	
Penman evaporation (mm)		1997/98 LT mean	114.9 104.6	149.1 123.9	161.7 142.7	167.6 153.0	593.3 524.2 69.1

* LT: Long term mean from 23 year average data.

CHAPTER FOUR

Biomass accumulation and canopy development

4.1   Introduction

In Chapter Three it was shown that crop grain yield was affected by nitrogen fertiliser treatments. Grain yield ranged from 4740 kg ha^{-1} when no N was applied up to 7030 when 150 kg N ha^{-1} was applied at emergence. In addition to this, HI ranged from 40 to 53, although the effect of N fertiliser was inconsistent. The implication was that differences in grain yield were mainly due to differences in the total biomass produced, with less effect on the efficiency of partitioning of biomass into the grain (Equation 2.2; Section 2.3.2). Differences in the total biomass produced may result from differences in the rate or duration of biomass accumulation. Thus, the first objective of this chapter was to quantify the effect of nitrogen fertiliser on the total biomass produced and the pattern of biomass accumulation over the season.

The daily biomass production of a crop is the product of the amount of solar radiation intercepted (Q), and the efficiency of the conversion (E) of PAR to biomass (Wilson 1987; Martin 1996). Specifically, the total amount of solar radiation intercepted by a crop is influenced by canopy development (Evans & Wardlaw 1976). If the crop canopy is below a critical LAI then Q is below its maximum and consequently potential biomass yield will be lost. Thus, the second objective of this chapter was to determine the critical LAI of the barley crop, defined as when 95 % of the incoming solar radiation was intercepted.

The third objective was to determine how canopy development of the crop, as indicated by differences in LAI over time, was affected by N fertiliser treatments. The LAI is a term that is also referred to as green area index (GAI) (Biscoe *et al.* 1975; Yunusa *et al.* 1993). The terms are frequently used interchangeably when the LAI has been determined from all green surfaces, namely the projected area of leaves, stems and ears as was the case in this experiment. The final objective was to determine conversion efficiency (E) for each of the N fertilised crops. Thus, the overall aim of this chapter is to relate the yield differences

described in Chapter Three to differences in biomass production as a consequence of differences in the amount of solar radiation intercepted or the efficiency of conversion of that radiation to biomass.

4.2. Materials and Methods

4.2.1 Field experiment

Details of the field experiment including crop management, treatments and layout were outlined in Section 3.2.1. In addition, the following measurements and analyses were made.

4.2.2. Measurements

4.2.2.1 Biomass

Biomass samples were taken at seven day intervals from 40 to 130 DAS. This involved the hand harvest to ground level of all plants within two 0.1 m^{-2} quadrats per plot. Biomass weights were obtained by drying samples in a forced air oven at 70 °C to a constant weight.

Logistic curves were fitted to the biomass data using the Maximum Likelihood Programme (MLP) (Ross 1987). The fitted logistic curves had a standard error of less than 5 % and there was no reduction in this from fitting generalised logistic or Gompertz curves. Thus, only results from logistic analysis are presented. The logistic curve (Equation 5.1) is a symmetrical sigmoid curve with four parameters:

$$Y = A + C / (1 + exp (- B (X - M))) \qquad \text{Equation 5.1}$$

where;

A = starting point of curve (0 kg biomass ha^{-1}) at time 0,

C = upper asymptote or maximum biomass (Y) value (kg biomass ha^{-1}),

B = a rate constant for the curve,

M = point of curve inflection on the X axis which represents time to 50 % of maximum biomass which is also the point of maximum growth rate $(kg\ ha^{-1}\ d^{-1})$.

The weighted mean absolute growth rate (WMAGR) is defined as the mean growth rate over the period when the crop accumulated most of the biomass and is derived using Equation 5.2:

$$WMAGR = (B * C) / 6 \qquad \text{Equation 5.2}$$

The duration of exponential growth (DUR) is defined as the period over which the crop accumulated most of the total biomass and is derived using Equation 5.3:

$$DUR = 6 / B \qquad \text{Equation 5.3}$$

The maximum crop growth rate (Cm) was derived using Equation 5.4:

$$Cm = (B * C) / 4 \qquad \text{Equation 5.4}$$

To determine the length of the lag phase from sowing to 5 % of maximum biomass, C * 0.05 was substituted into equation 5.5:

$$X = ((\ln (C / (Y - A) - 1)) / - B) + M \qquad \text{Equation 5.5}$$

4.2.2.2 Canopy development

Canopy development, as quantified by changes in LAI and solar radiation intercepted (I), was measured at seven day intervals from 61 to 96 DAS and then at 109 and 123 DAS in each plot using a LI-COR LAI-2000 Plant Canopy Analyser (LI-COR, Lincoln, NE, U.S.A.). Ten measurements were taken from each plot at late afternoon away from direct sunlight as per manufactures recommendations. From these measurements the extinction coefficient (k) and critical LAI were determined (Section 2.3.2). Values for k were determined from regression analysis (Equation 2.5) of the natural log of the proportion of radiation not intercepted (1-I) against LAI. The critical LAI was estimated from an exponential Equation (2.4) fitted to the relationship between total radiation intercepted (%) and LAI. A linear change in LAI between measurement dates was assumed for non-measurement days.

Values of E for each crop were estimated by dividing the total biomass accumulated (g m^{-2}) by the amount of PAR (48 % of I, McCree 1966) intercepted (Q) for the period between 61 DAS and 110 DAS. To determine Q, the daily PAR received above the crop canopy was multiplied by the percentage intercepted. For example, if on day X there was 50 % interception, percentage as determined from the plant canopy analyser, and the incoming PAR (MJ m^{-2}) was 10, then Q = 5 for that day. Daily incoming PAR was measured adjacent to the experimental site at the Broadfield weather station.

4.2.2.3 Individual leaves

The area of the last fully expanded leaf, defined as when the ligule had emerged, was sampled at seven day intervals up to 82 DAS. From 40 to 61 DAS leaves were sampled from the nil, 50, 100 and 150 kg N ha^{-1} treatments because the split application did not occur until 56 DAS (Section 3.2). From 68 DAS to 82 DAS when the flag leaf was fully emerged, leaves were sampled from all treatments. At each sampling date, 20 leaves were removed from each plot and the mean area was measured using a Licor 3100 area meter (LI-COR, Lincoln, NE, U.S.A.).

4.2.3 Data analysis

The derived parameters from the logistic curves were compared using analysis of variance (ANOVA) to determine differences among treatments. Mean separation was based on LSD tests at the $\alpha = 0.05$ level.

4.3 Results

4.3.1 Biomass accumulation

Biomass accumulation followed a typical sigmoid growth pattern for all N treatments (Figure 4.1a, 4.1b and 4.1c). There was an initial lag phase of slow growth until about 48 DAS (Table 4.1). This was followed by an exponential phase with a mean duration (DUR) of 75 days (Table 4.1). Thus, physiological maturity occurred about 123 DAS (Figure 4.1). The highest biomass (16020 kg ha^{-1}) was produced from the highest (150/100) N fertiliser treatment and was 3000 - 5000 kg ha^{-1} more (p < 0.005) than from the nil, 50 and 100 kg N ha^{-1} treatments.

The maximum growth rate occurred at about 85 DAS (M) for all treatments but WMAGR and Cm differed among treatments ($p < 0.05$). The WMAGR ranged from 150 kg ha^{-1} d^{-1} in the nil N treatment to 205 kg ha^{-1} d^{-1} in the 150/100 N treatment. The Cm growth rates followed a similar pattern to the WMAGR across treatments but were about 100 kg ha^{-1} d^{-1} higher (Table 4.1).
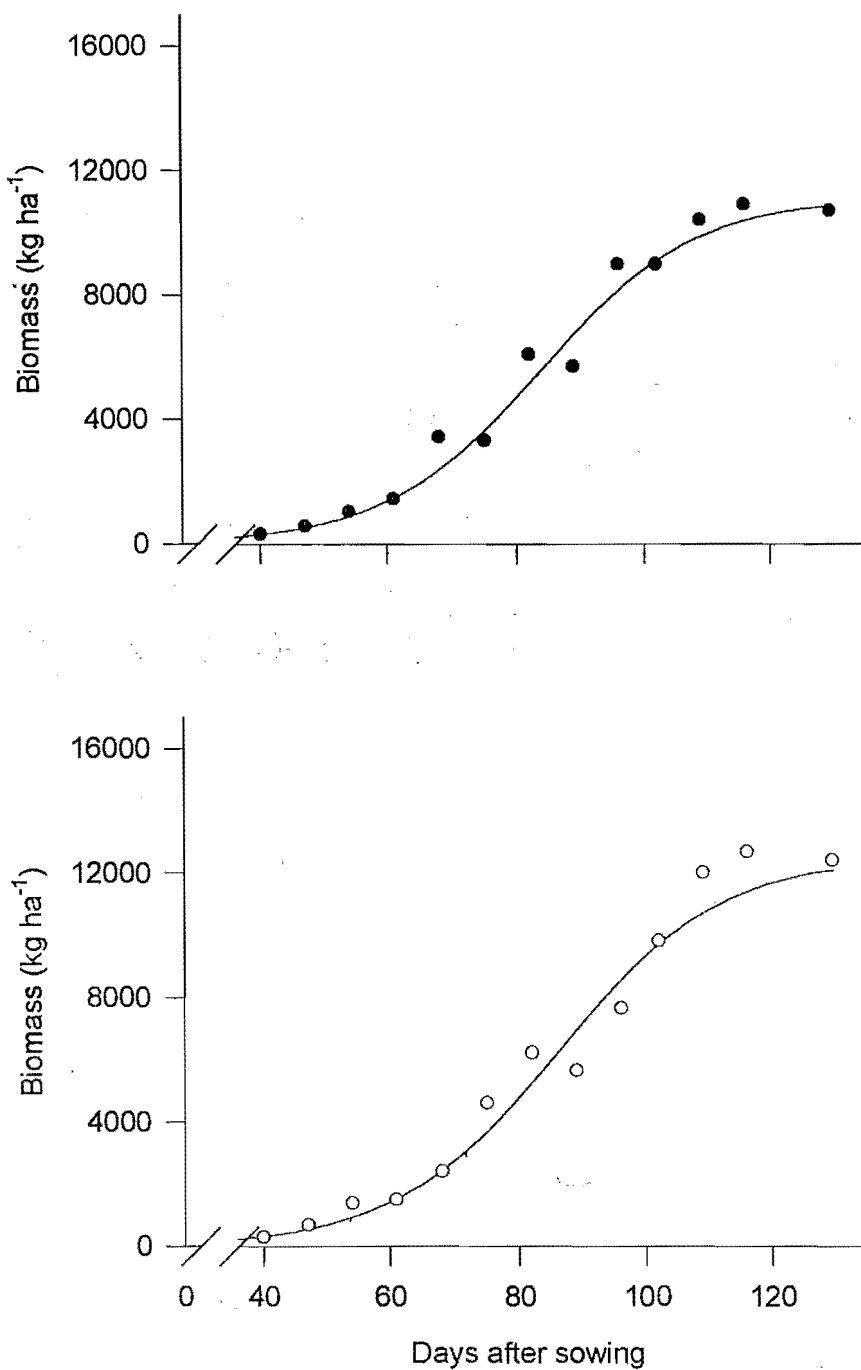
Figure 4.1a   Logistic curves fitted to raw data to show biomass changes over time of barley crops grown with nil (●) or 50 kg N ha^{-1} (○).
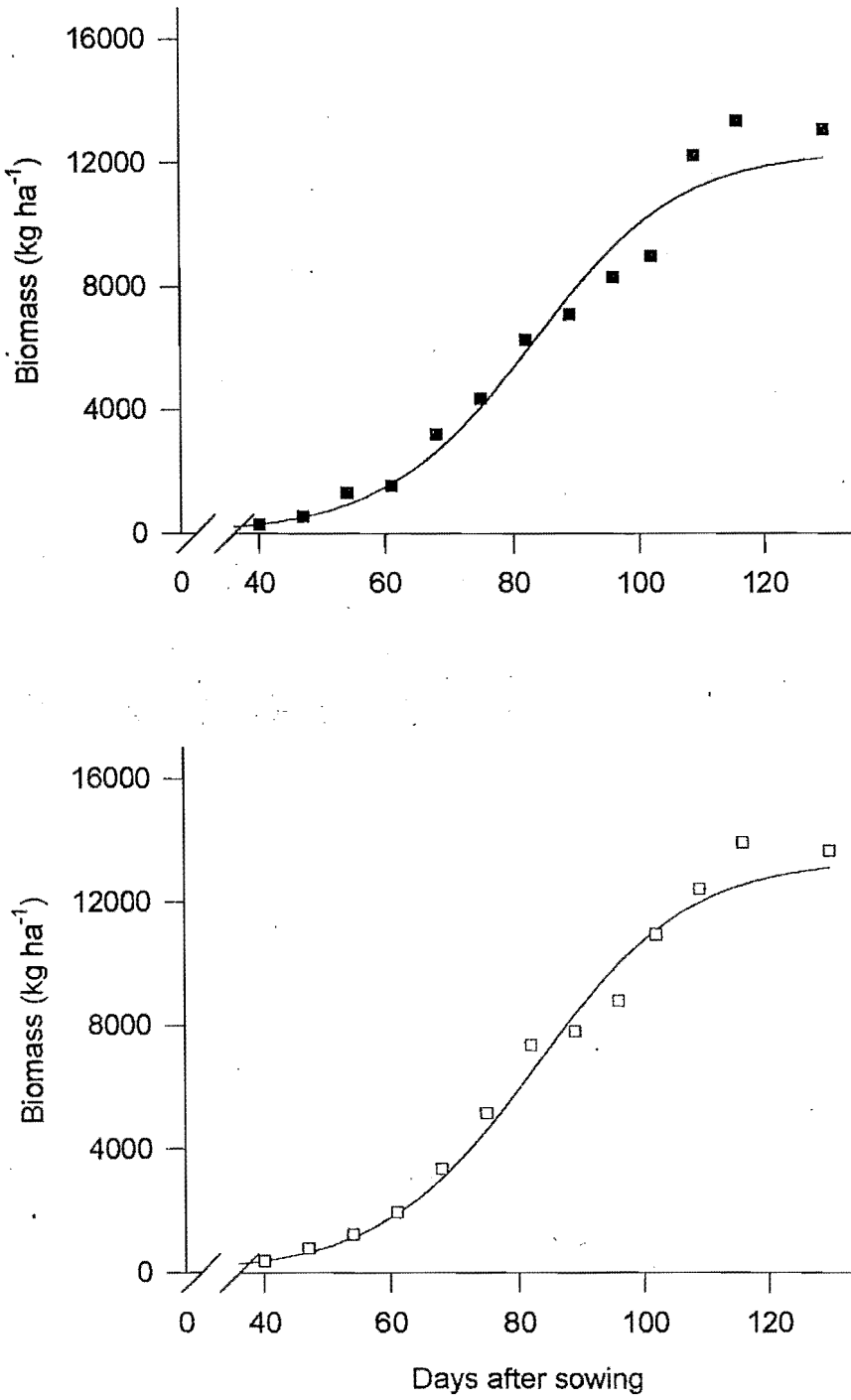
Figure 4.1b   Logistic curves fitted to raw data to show biomass changes over time of barley crops grown with 100 (■) or 150 kg N ha^{-1} (□).
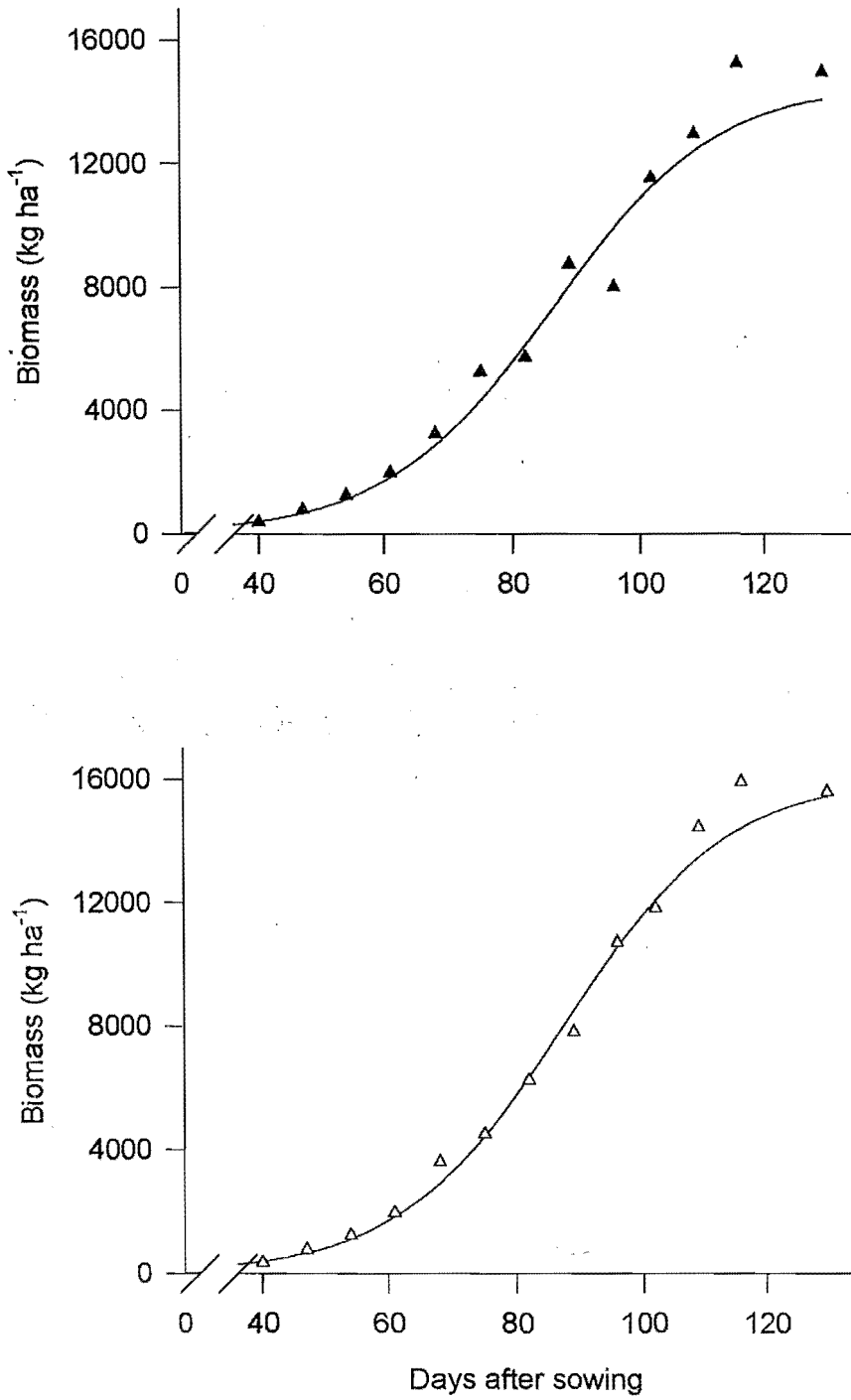
Figure 4.1c Logistic curves fitted to raw data to show biomass changes over time of barley grown with 150/50 (▲) or 150/100 kg N ha^{-1} (△).

Table 4.1 Derived parameters from logistic functions fitted to biomass accumulation over time for barley grown with different N fertiliser treatments

Treatment (kg N ha⁻¹)	C (kg ha⁻¹)		M (days)	WMAGR (kg ha⁻¹ d⁻¹)		Cm (kg ha⁻¹ d⁻¹)		DUR (days)	Lag phase (days)
0	11100	c	84	150	b	225	b	73	48
50	12480	bc	86	160	b	245	b	77	48
100	12360	bc	83	175	ab	265	ab	70	48
150	13380	abc	83	185	ab	275	ab	74	47
150/50*	14560	ab	86	185	ab	280	ab	78	48
150/100*	16020	a	87	205	a	310	a	78	49
SEM	651.5		1.9 (ns)	9.05		13.6		3.8 (ns)	1.3 (ns)

Note. * = treatments where second application of N fertiliser was applied at 56 DAS.

4.3.2 LAI development

The LAI was similar (p < 0.316) among treatments (over the measured period 61-123 DAS) at 61 DAS and ranged from 1.4 in the nil N treatment to 1.8 in the 150 kg N ha⁻¹ treatment (Figure 4.2). The LAI differed (p < 0.001) among treatments from 68 DAS and was generally highest for the 150/100 kg N ha⁻¹ treatment. The maximum LAI for each crop occurred about 88 DAS and then remained constant for approximately 20 days. The maximum LAI was 3.8 for the 150/100 kg N ha⁻¹ treatment compared with 2.2 (p < 0.05) for the nil N treatment. In most cases, the maximum LAI increased with each additional 50 kg N ha⁻¹ (Figure 4.2).

4.3.3 Total solar radiation interception, critical LAI and extinction coefficient

There was an exponential relationship between total solar radiation interception and LAI across all treatments (Figure 4.3). Solar radiation interception increased from about 65 % when the LAI was 1.4, to reach the critical LAI at 4.0. The extinction coefficient (k) was 0.75 and was unaffected by N fertiliser treatments (Figure 4.4).
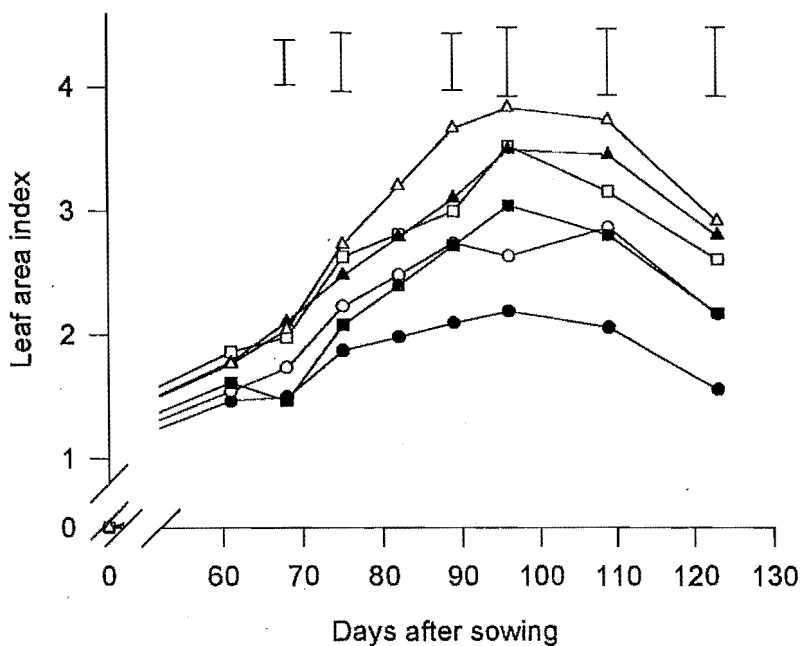
Figure 4.2   Leaf area index (LAI) over time for barley grown under different N fertiliser treatments. Treatments are in kg N ha^{-1} at nil (●), 50 (○), 100 (■), 150 (□), 150/50 (▲) and 150/100 (△). Error bars are LSD.
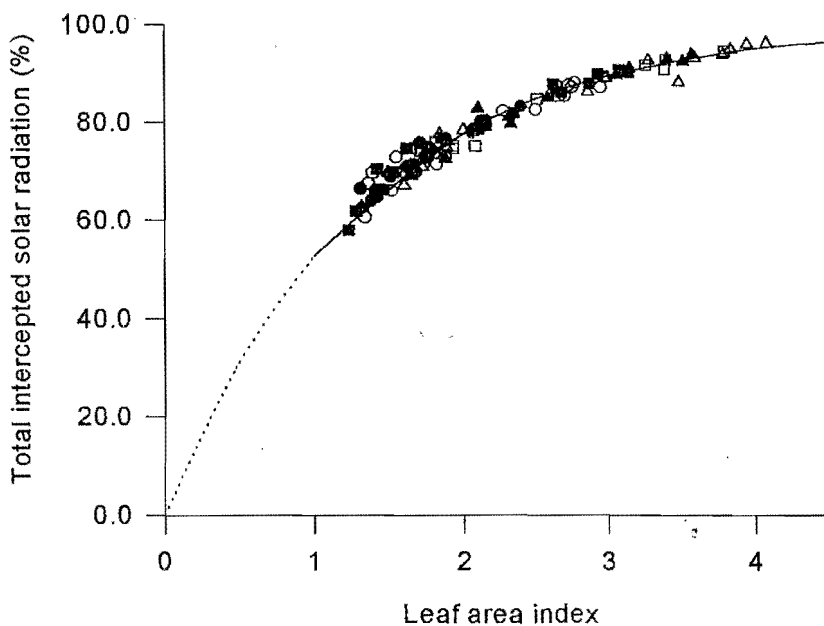
Figure 4.3   Total solar radiation interception (%) against leaf area index for barley grown with different N fertiliser treatments. $R^2 = 92$ %. Y= [1 - *exp* (- 0.75 LAI)]. Treatments are in kg N ha^{-1} at nil (●), 50 (○), 100 (■), 150 (□), 150/50 (▲) and 150/100 (△).

Leaf area index
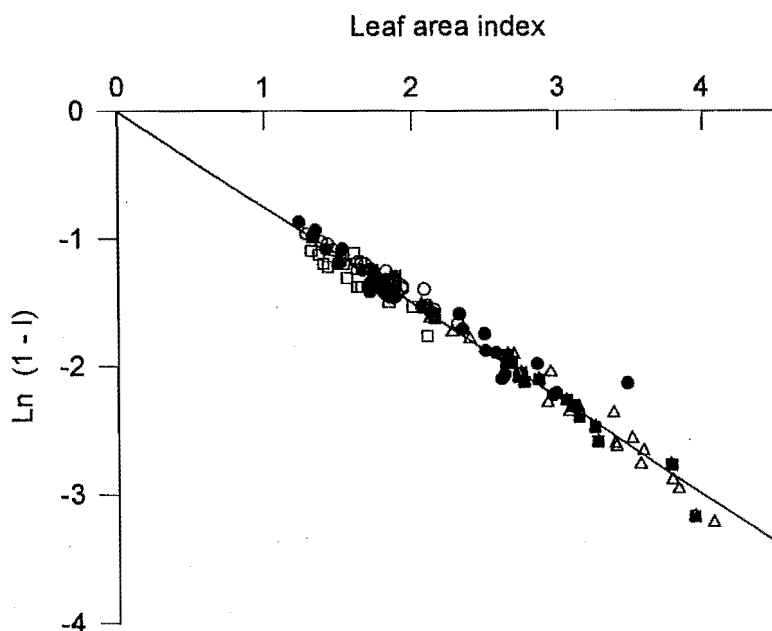
Figure 4.4   The natural log of 1-I against LAI for barley grown with different N fertiliser treatments. $Y = 0.004 - 0.75\ X$. $R^2 = 97\ \%$. Treatments are in kg N ha^{-1} at nil (●), 50 (○), 100 (■), 150 (□), 150/50 (▲) and 150/100 (△).

4.3.4   Radiation use efficiency

Radiation use efficiency (E) (g biomass m^{-2} MJ^{-1} PAR intercepted) for barley had a general mean of 2.00 g biomass m^{-2} MJ^{-1} PAR intercepted (Table 4.2).   The value of E was unaffected ($p < 0.122$) by N fertiliser treatments.

4.3.5   Total solar radiation intercepted

Values for Q differed ($p < 0.001$) among N treatments (Table 4.2) over the measured period from 61 to 123 DAS. The total PAR available from 61 to 123 DAS was 590 MJ PAR m^{-2} and of this 89 % was intercepted by the 150/100 N crop compared with 75 % in the nil N treatment.   The 150/100 N treatment intercepted 524 MJ PAR m^{-2} from 61 to 123 DAS which was about 18 % more than that intercepted by the nil N treatment.

4.3.6 Area of individual leaves

From 40 to 61 DAS there was no difference in the area of each successive leaf among N treatments (Table 4.3). However, at 68 DAS, there was a difference ($p < 0.023$) in the area of leaf eight among treatments. For the 150/100 N treatment the area of leaf eight was 8.2 cm^{-2} compared with 5.9 in the nil N treatment. At 75 and 82 DAS when leaf nine and the flag leaf were measured, there were also differences ($p < 0.05$). For leaf nine, all applied N treatments had a larger area than the nil N treatment and the flag leaf was larger in the 150/100 kg N ha^{-1} treatment than in the nil or 50 kg N ha^{-1} treatments.

Table 4.2　Total PAR intercepted (Q) from 21 to 123 DAS and radiation use efficiency (E) for barley grown with different N fertiliser treatments

Treatment (kg N ha^{-1})	Q (MJ m^{-2})		E (g biomass MJ PAR^{-1})
0	445	c	1.86
50	486	b	1.88
100	481	b	1.98
150	510	a	1.95
150/50*	516	a	2.06
150/100*	524	a	2.24
SEM	3.5		0.10 (ns)

Note.　* = treatments where second application of N fertiliser was applied at 56 DAS.

Table 4.3　Area (cm^{-2}) of last fully emerged leaf at different times after sowing (DAS) from barley crops with different N fertiliser treatments

Treatment (kg N ha^{-1}) DAS	Leaf 4 (40)	5 (47)	6 (54)	7 (61)	8 (68)		9 (75)		Flag (82)	
0	4.7	6.5	7.2	8.0	5.9	b	4.2	b	1.0	b
50	4.3	6.4	8.3	8.4	7.6	a	5.1	ab	1.1	b
100	4.5	6.5	8.0	8.4	7.5	ab	5.4	ab	1.2	ab
150	4.8	6.9	8.2	8.9	8.0	a	6.5	a	1.4	a
150/50*					7.4	ab	6.5	a	1.3	ab
150/100*					8.2	a	5.9	a	1.6	a
SEM	0.32 (ns)	0.34 (ns)	0.37 (ns)	0.58 (ns)	0.38		0.32		0.06	

Note.　* = treatments where second application of N fertiliser was applied at 56 DAS.

4.4   Discussion

The results showed that the yield differences described in Chapter Three resulted from differences in the total amount of biomass (C) produced from each treatment. Highest grain yields came from the 150 kg N ha^{-1} treatment, but highest biomass production came from the highest N treatment (Figure 4.1c; Table 4.1). Total biomass accumulation was higher than the results reported by de Ruiter & Brooking (1996) which ranged from 9500 to 13900 kg ha^{-1}. The differences in harvest index (Chapter Three) partially explain this.

Analysis of the pattern of accumulation showed that biomass differences resulted from faster growth rates (Cm and WMAGR) for the 150/100 N crop (Table 4.1) compared with the nil N plot, 310 and 205 kg ha^{-1}, and 225 and 150 kg ha^{-1} respectively. The Cm rates reported here are lower than those reported by Monteith (1978) who showed for C_3 crops maximum growth rates of 340 - 390 kg ha^{-1} d^{-1}. The WMAGR rates are comparable with Gallagher (1983) at 170 kg ha^{-1}, but slightly higher than Monteith (1978) at 130 kg ha^{-1}. Differences between biomass total and growth rates are possibly due to cultivar differences in duration of growth. Monteith (1978) was reporting on cultivars from 20 years ago, whereas this cultivar of Valetta is only recently released with improved growth characteristics.

From the parameter of Cm, differences within treatments were mostly between the 150/100 and nil and 50 kg N ha^{-1} treatments. The major importance of Cm is an indicator of the potential C. Cm can be considered to be a description of the slope of the curve at M. If this is taken to be an indicator, then the C that is potentially able to be achieved will be greater in the crop with the highest Cm. This is in fact what happened in the current barley crop. As Cm decreased with N treatments, C also declined.

However, Cm is only a partial explanation of the crop growth characteristics because it is an instantaneous measure. The WMAGR is a description of the crop growth rate over the period where most of C was obtained. The WMAGR for the current crops was similar to Gallagher (1983) at an overall mean of 177 kg ha^{-1}. Increasing N application increased the WMAGR over all treatments. However, these parameters are only results of the growth of the crop and do not explain why increased biomass and growth rates occurred.

In contrast to growth rate, the duration of growth amongst treatments was the same. This was expected since development is mainly temperature dependant (Monteith 1981) and is only affected under extreme nitrogen or water stress (van Keulen & Seligman 1987).

Total biomass (C) is the product of radiation use efficiency (E) of conversion of intercepted PAR multiplied by the quantity of PAR intercepted (Q). If either of these parameters is increased, then increased biomass production can be expected. Because Q is affected by LAI, the results presented on LAI (Figure 4.2) give an indication of potential Q. In the current barley crop LAI was generally increased with increasing addition of N fertiliser which increased the potential of the crop to accumulate Q. The LAI is related to the growth parameters presented in Table 4.1. Therefore, part of the increased growth rates is simply a reflection of increased LAI rather than an increase in RUE. However, RUE was trending to increase with additional inputs of N (Table 4.2) but not to the levels reported in Chapter Two. This may be because of the low plant population.

Increasing leaf area improved the proportion of solar radiation interception and resulted in an increase in biomass production. In the current experiment, LAI's were higher in the high N treatments, and decreased with decreased amounts of applied N. Stimulation of biomass production is conserved by the fact that radiation becomes saturating when LAI has a value of about 4, at this point, at an extinction coefficient of -0.45, about 85 % (95% in current study) of incident radiation is intercepted (Porter & Jamieson 1996). Therefore, to obtain maximum crop growth rates, barley crops should be managed to have a LAI of 4.0 to intercept maximum solar radiation and as a result, to accumulate maximum biomass.

Total intercepted radiation % was related to LAI (Figure 4.3). The treatments followed increases in solar radiation with increases in LAI. Therefore, increased solar radiation interception is the direct result of LAI. However, the manner in which the solar radiation is intercepted is dependant on the extinction coefficient. In the current barley crop, the extinction coefficient (0.75) indicated more prostrate leaves than is reported to be typical of a cereal crop (Jamieson *et al.* 1995), although this value is comparable to Yunusa *et al.* (1993) who established a wheat crop with similar plant populations, (150 m^{-2}). Perhaps the lower than typical (0.45) extinction coefficient was due to variability in plant population and

tillering (Chapter Three), although it was not affected by N fertiliser application (Figure 4.4).

The E in the current study was unaffected by N fertiliser treatments (Table 4.2). A shortage of N reduces the photosynthetic rate of leaves (Grindlay 1997) but this did not occur in the current crop and is investigated further in the following chapter. Therefore, the major differences in C, Cm and WMAGR were through the amount of PAR intercepted.

The increased LAI is explained by two variables. The first is the increased number of leaf bearing organs per unit area. In Chapter Three, stems m^{-2} increased with increased applications of N fertiliser. In addition to this, Table 4.3 showed an increased individual leaf area as N fertiliser application rate was increased in later developed leaves. The combined effect of these two factors increased Q. A constant E, multiplied by the increased Q resulted in the higher biomass produced with increased N application rate.

In summary, individual leaf area was increased with increased levels of N which also stimulated the production of more leaves per unit area from the increased number of tillers (Chapter Three). This resulted in more PAR intercepted. Despite this, the conversion efficiency of Q into biomass was not increased by additional N fertiliser. Increases in individual leaf area and leaf number both increased LAI. This increased LAI at a constant E produced more growth over the growing period which resulted in more biomass that when l multiplied by HI gave grain yield differences as reported in Chapter Three.

4.5   Conclusion

- Greatest amounts of biomass were produced from crops that had the highest levels of PAR interception which came from increased LAI. Although E can be altered by N availability, it was not altered in these field grown crops of barley. To maximise grain yield, large amounts of biomass converted through a increased HI gave higher yields.

CHAPTER FIVE

Specific leaf nitrogen, area and survival of leaves

5.1   Introduction

In the previous chapter it was concluded that the most biomass produced was from the treatments that intercepted the most PAR. In the 150/100 N treatment 524 MJ^{-1} PAR m^{-2} was intercepted compared with 445 in the nil N treatment. The increased PAR intercepted was from higher leaf area indices of treatments that had an increased amount of available N. This resulted from larger areas of individual leaves and an increased number of leaves per unit area. The efficiency of the conversion of the intercepted radiation into biomass was constant for all treatments at about 2.00 g biomass MJ^{-1} PAR m^{-2}. Therefore, if efficiency is constant, an increased area of leaf increases biomass production, provided leaf N levels are maintained. The objective of this chapter is to determine the area and nitrogen levels over time of leaves to determine structural and functional differences within leaves when supplied with different levels of N fertiliser.

Also in this chapter, the survival rate of leaves is investigated. Specifically, the leaves emerged with different areas (Chapter Four) but the N availability from the different applied N fertiliser levels may alter the duration of the leaves (van Keulen and Seligman 1987). The longer leaves are maintained, the more PAR they are able to intercept and as a result, more biomass is produced.

Grindlay (1997) commented that leaf responses to applied N are not known in terms of leaf weight, leaf area and leaf biomass production efficiency. As a canopy develops, leaves continue to appear and elongate and this increases the amount of PAR intercepted by the canopy. The leaves respond to N in different ways (Section 2.4), and this affects the development of the canopy. For example, photosynthetic rate decreases when leaf N per unit area declines (specific leaf nitrogen, SLN) below about 2.0 g N m^{-2} of leaf (Grindlay 1997) and this could be considered as an optimum level. Alternatively, the area of a leaf decreases when N is short (Chapter Four and Hay & Walker 1994). However, these

measures of leaf response to N have not been quantified in malting barley. Therefore, the aim of this chapter was to determine whether nitrogen availability affects leaf size while the leaf maintains a standard nitrogen concentration, or if leaf size is independent of nitrogen concentration resulting in uniform leaf size and differing N levels in malting barley leaves.

5.2   Materials and Methods

5.2.1   Field experiment

Details of the field experiment including crop management, treatments and layout were outlined in Section 3.2.1. In addition, the following measurements and analysis were made.

5.2.2.   Measurements

Leaf sampling dates were at 14 day intervals between 40 and 82 DAS. From each plot, twenty of the last fully expanded (defined as having an auricle showing) leaves were selected for sampling. Over time these were leaves four, six, eight and the flag leaf. Leaf four and leaf six were measured over four treatment levels because these leaves were fully expanded before a split application of N was applied at 56 DAS (Section 3.2). Leaf areas were measured using a Licor 3100 area meter (LI-COR, Lincoln, NE, U.S.A.). Leaf weight was obtained by oven drying samples to constant weight at 70 C°. All leaves were then ground using a cyclotech mill and total N % determined by mass spectrometer.

At each sampling date, the number of green leaves from 20 randomly selected stems was counted and from this leaf survival was calculated. In addition to the counts done up to anthesis (82 DAS), additional sampling dates for survival were taken 14 and 28 days post anthesis.

5.3.3   Data Analysis

Regression analysis and analysis of variance (ANOVA) was used to determine differences amongst treatments. Mean separation was based on LSD tests at the $\alpha = 0.05$ level.

5.3   Results

5.3.1.1 Specific leaf nitrogen at leaf emergence

Specific leaf nitrogen (SLN) levels when measured at emergence (fully expanded) were between 2.0 and 4.0 g N m^{-2} for all leaves (Table 5.1a, 5.1b). With the exception of leaf six, as increased amounts of N were applied the SLN levels remained unchanged by the

treatments (p = 0.310). Leaf six increased (p < 0.008) SLN from 2.2 g N m^{-2} at nil N to 2.9 in the 150 kg N ha^{-1} treatment (Table 5.1a). This was the only significant mean separation of all analyses of SLN levels made at emergence. Therefore, area changed with differing N availability, while SLN levels remained reasonably constant.

Leaf four was higher in SLN than all other leaves, with a mean over all treatments at emergence of 3.8 g N m^{-2} (p = 0.37). Leaf eight had about the same SLN levels as leaves six and the flag leaf ranging from 2.3 to 2.9 g N m^{-2} (p = 0.25) (Table 5.1b). The SLN of the flag leaf ranged from 2.5 to 3.4 g N m^{-2}, but was not significantly affected (p = 0.310) by any of the treatments.

5.3.1.1 Specific leaf nitrogen over time

The SLN levels declined with age within each leaf and treatment (Table 5.1, 5.1b). From 40 to 54 DAS, leaf four on average decreased (p < 0.001) from 3.8 to 2.8 g N m^{-2} and there was no difference within any of the treatments (p = 0.746). Leaf six declined (p < 0.001) across all treatments from 2.6 to 2.3 to 1.9 g N m^{-2} from 54 to 68 to 82 DAS respectively. For leaf six at 68 DAS, within treatments, the SLN level ranged from 1.9 in the nil N treatment, to 2.6 in the highest N treatment. At 82 DAS in leaf six, the SLN levels increased (p<0.001) from 1.4 g N m^{-2} in the nil N to 2.4 in the 150/100 kg N ha^{-1} treatment.

Over time, leaf eight was not significantly different (p < 0.150) in SLN from 68 to 82 DAS, at 2.5 g N m^{-2} - 2.3 respectively (Table 5.1b). However, within treatments at 82 DAS, the highest rate of N increased the SLN level to 2.8 g N m^{-2} compared with 1.7 in the nil N treatment.

Table 5.1a   Specific leaf nitrogen (SLN) levels (g N m^{-2}) of leaf four and six from barley grown under different N fertiliser treatments

Treatment	Leaf							
	Four		Six					
	Days after sowing							
(kg N ha^{-1})	40	54	54		68		82	
0	4.0	2.8	2.2	b	1.9	b	1.4	c
50	4.0	2.7	2.5	ab	2.2	a	1.9	b
100	3.6	2.7	2.8	a	2.4	ab	2.0	ab
150	3.6	2.9	2.9	a	2.5	a	2.1	ab
150/50*					2.4	ab	2.1	ab
150/100*					2.6	a	2.4	a
SEM	0.37 (ns)	0.18 (ns)	0.97		0.12		0.09	

Note. * = treatments where split application of N fertiliser was applied at 56 DAS.

Table 5.1b   Specific leaf nitrogen (SLN) levels (g N m^{-2}) of leaf eight and flag leaf of malting barley grown under different N fertiliser treatments

Treatment	Leaf		
	Eight		Flag
	Days after sowing		
(kg N ha^{-1})	68	82	82
0	2.3	1.7 b	2.5
50	2.5	2.2 ab	3.0
100	2.6	2.2 ab	2.9
150	2.9	2.4 ab	2.9
150/50*	2.4	2.4 ab	3.4
150/100*	2.7	2.8 a	3.1
SEM	0.25 (ns)	0.16	0.25 (ns)

Note. * = treatments where split application of N fertiliser was applied at 56 DAS.

5.3.2   Leaf area

The green areas of the measured leaves at emergence are reported in the previous chapter (Table 4.3). Therefore only the area over time are reported here (Table 5.2). In leaf four, between sampling dates the mean green area of leaves did not change (p = 0.302), an average of 4.6 cm^{-2} at 40 DAS to 4.3 at 54 DAS. Leaf four was therefore unaffected by any of the treatments.

Leaf six decreased from a mean green area of 8.0 cm^{-2} at 54 DAS to 7.5 to 6.6 at 68 and 82 DAS respectively. Between 54 and 68 DAS the mean green area was not different (p< 0.075) but was between 68 and 82 DAS (p < 0.001). Within treatments, the green area of leaf six was not different at 54 DAS (Chapter Four) but at 68 and 82 was (p < 0.048) (Table 5.2). The trend was for leaves to increase area with increased N applications.

Leaf eight mean area was the same between 68 and 82 DAS (p< 0.442) indicating that this leaf was not responding to N stresses. However, within treatments, the area of the leaf was different (Table 4.3, Table 5.2). In Chapter Four, leaf eight was different in area between the nil N treatment and the treatments where N fertiliser had been applied. In Table 5.3, 14 days post emergence (82 DAS) leaf eight was showing a similar trend. In the treatments where N was applied the area of the leaves was bigger than the nil N treatment.

Table 5.2　　　Individual leaf green areas (cm^{-2}) post leaf emergence for leaves four, six and eight in barley grown with different N fertiliser treatments

Treatment	Leaf							
	Four	Six					Eight	
		Days after sowing						
(kg N ha^{-1})	54	68		82			82	
0	4.2	6.6	b	5.7	b		6.2	b
50	4.4	7.6	ab	6.5	ab		7.3	ab
100	4.3	7.7	ab	6.4	ab		6.7	ab
150	4.5	8.2	ab	6.5	a		7.5	ab
150/50*		8.1	ab	7.3	a		8.4	a
150/100*		8.5	a	7.0	a		7.3	ab
SEM	0.18 (ns)	0.36		0.24			0.38	

Note. * = treatments where split application of N fertiliser was applied at 56 DAS.

5.3.3 Leaf survival

Analysis of the leaf survival rate showed at anthesis all (p < 0.331) leaves were alive at levels of 90% or more from leaf 6 through to the flag leaf. When measured 14 days post anthesis, leaf 7 through to the flag leaf were at least 90 % alive, but leaf six had declined only about 52 % across all treatments (p = 0.236). At 28 days post anthesis, leaf six had

completely senesced over all treatments, leaf seven had senesced to an average of 22 % survival across all treatments (p = 0.584).

Leaf eight was beginning to show differences (p<0.113) in survival rate ranging from 52 % survival rate in the nil N treatment to a mean of 81 % in treatments that had N applied at 28 days after anthesis. Leaf nine was showing some differences, although not significant (p =0.058). For example, in leaf nine, 100 % survival was found in the 150 kg N ha^{-1} treatment, but only 88 % in the nil N treatment. The flag leaf was highly significantly different (p < 0.001) where only 38 % of the flag leaf was alive in the nil N treatment, but in all other treatments, 86 % was alive. In general, the differences were between the nil N and the remaining treatments.

5.3.4 Specific leaf weight

Leaf 4 and leaf 6 showed the weakest relationship between area and weight, R^2 = 22.9 % and 15.7 % respectively (Figure 5.1.a). These leaves were measured at 40 and 54 DAS respectively and their response to applied N was variable. Leaf eight showed the strongest relationship (R^2 = 80.1%) when sampled at 68 DAS (Figure 5.1.a) and this was the strongest relationship obtained from all sampling data. The flag leaf was smaller and lighter than leaves four, six and eight (Figure 5.1.b), but the relationship between area and weight was relatively strong (R^2 = 55.0%). The flag leaf showed a similar response to other measured leaves by increasing area and weight as the amount of applied N increased. The regressions of area and weight within treatments gave SLW which was leaf four 6.2 mg cm^{-2}; leaf six 6.8; leaf eight 5.46 and flag leaf 7.28.
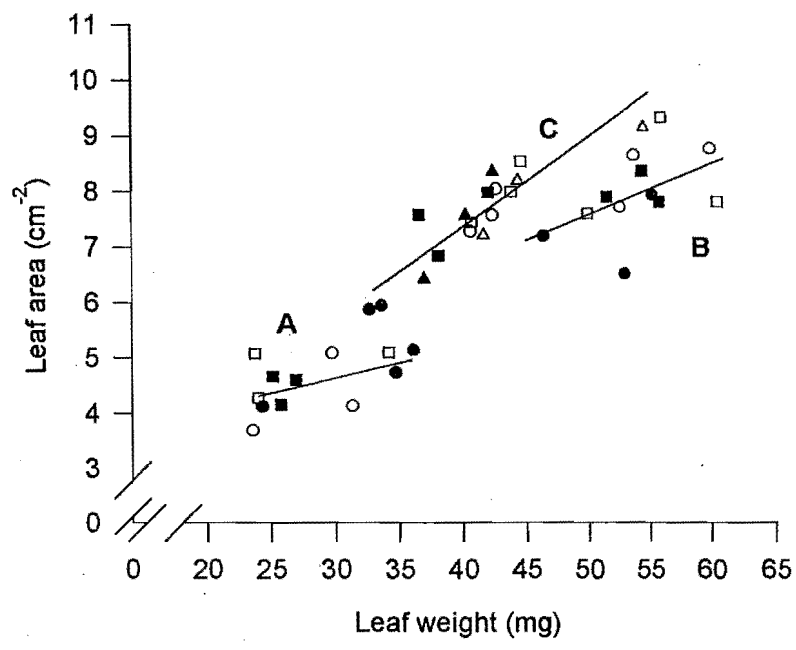
Figure 5.1.a   The relationship between leaf area and leaf weight in three malting
barley leaves grown under different N fertiliser treatments.
Relationships are A = Leaf 4 (Y= 2.97 + 0.0561 x, R^2 = 22.9%).
B = Leaf 6 (Y = 3.02 + 0.913 x, R^2 = 15.7%). C = Leaf 8 (Y = 0.905 +
. 0.161 x, r^2 = 80.1%). Treatments are in kg N ha^{-1} at nil ($\bullet$), 50 ($\circ$), 100
($\blacksquare$), 150 ($\square$), 150/50 ($\blacktriangle$) and 150/100 ($\triangle$).
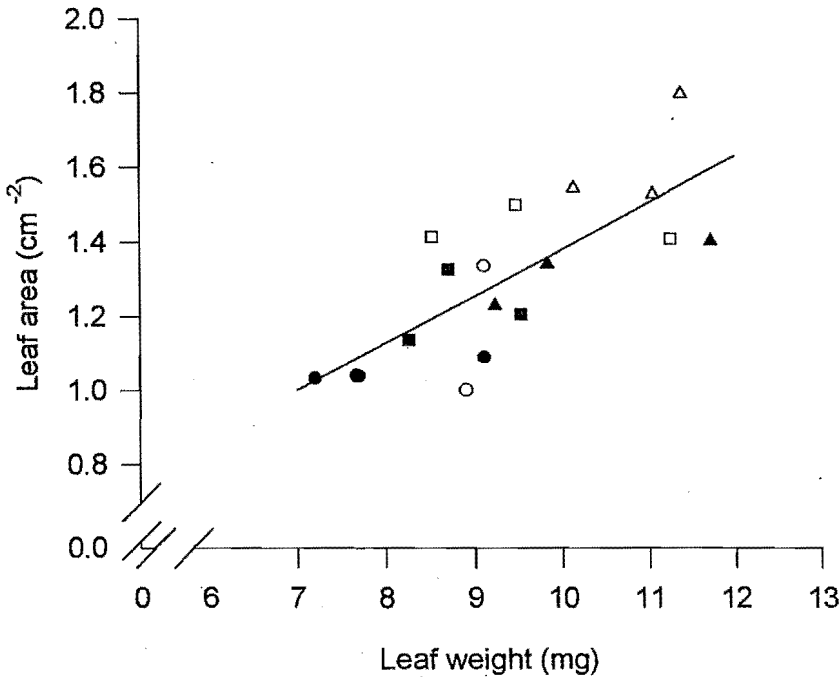
Figure 5.1.b The relationship between leaf area and leaf weight in the flag leaf of malting barley grown under different N fertiliser treatments sampled at 82 DAS. The relationship is $Y = 0.119 + 0.126\,x$, $r^2 = 55.0\%$. Treatments are in kg N ha^{-1} at nil (●), 50 (○), 100 (■), 150 (□), 150/50 (▲) and 150/100 (△).

5.4   Discussion

There were two main findings in the results. The first was the effect of the applied N treatments on the SLN levels of the leaves when fully emerged and then over the life of the leaves. When leaves had emerged, there was no differences in the SLN level between treatments, except in leaf 6 (Table 5.1a, 5.1b). Therefore the leaves initially responded to available N by adjusting leaf size to maintain optimal levels of SLN presumably for photosynthesis.

Over time, the SLN levels and areas of leaves began to become dynamic in the way they reacted to available N. In leaf six, 28 days after the leaf had emerged, the SLN level was still above 2.0 g N m^{-2} in the treatments receiving 100 or more kg N ha^{-1} (Table 5.1a). Above this SLN level is considered to be about the optimum for photosynthesis (Grindlay 1997). The same trend occurred in leaf eight at 14 days after emergence (Table 5.1b). In the nil N treatment, SLN levels fell below 2.0 g N m^{-2} after about 14 days indicating that

this treatment may have been relocating N to the new emerging leaves. However, the leaves that emerged after leaf six, namely leaf eight and the flag leaf, were effected in the area they achieved, but still had adequate levels for photosynthesis. Therefore, the initial SLN levels achieved are at a level high enough for photosynthesis, but the availability of N quickly relocated the mobile N in the leaves to the newly emerging leaves.

The second most important response to available N was the area of the lamina when measured at fully expanded. Up until leaf eight, there was no differences in areas of emerged leaves among the treatments (Chapter Four). For leaf eight, nine and the flag leaf, the area of lamina when the leaf had emerged was larger with increased N applications. The effect of N was to influence the size the leaf reached when measured at full emergence (Hay & Walker 1994).

The different area the leaves reached contrasts in part with previous work by Ramos *et al.* (1995), who showed that regardless of the amount of N supplied to the crop during vegetative growth, all leaves reached the same area. However, the current study showed decreasing leaf area in response to decreasing amounts of applied N, but mainly between nil N treatment and all other treatments (Table 5.2). Therefore, when N is not limiting, area of leaves can be expected to reach genetic potential regardless of N treatments. However, when N becomes limiting, leaves do respond to decreasing amounts of available N by reducing size even though this study showed large variability.

In general, the area of each leaf decreased over time and with lower amounts of applied N (Table 5.2). This agrees with Grindlay (1997) and Reddy *et al.* (1997). The reduced leaf size resulted in decreased PAR interception, and hence lower biomass production (Chapter Four).

The effect of N availability was to decrease area, but maintain N levels high enough for photosynthesis. The other way the plants maintained SLN levels was through senescence of lower leaves at earlier times in the nil N treatment compared with treatments that had N fertiliser applied. In the nil N treatment, the leaf survival rate of leaves nine and the flag leaf was significantly lower than all other treatments. Decreased survival rates indicate that

leaf life was being affected by a low N status of the crop. Only when crops are severely stressed does phenological development become affected (van Keulen and Seligman 1987).

Leaf survival rate up until anthesis was the same over all treatments. There was probably enough N in the soil for plant growth and leaf survival not to be effected (Chapter Three) although LAI, leaf size and biomass production were affected. However, after anthesis and at the onset of grain filling, soil N levels had depleted to levels probably not sufficient for growth, therefore plants went into a self destruction mode to ensure newly emerging leaves were supplied with enough N for growth and consequently their survival was decreased.

The fact that SLW was constant over the treatments within leaves indicates that a leaf maintains a specific weight, although the SLW of each leaf was different. Hence, as the leaves were exposed to more or less nitrogen they maintained a definite unit area weight and SLN at emergence. Because weight per unit area did not change within a leaf, the implication is leaves expand to dilute the N to a constant level which is confirmed by the fairly constant E reported in Chapter Four.

Photosynthetic rate and consequently biomass production, is also decreased when a decreased amount of PAR is received at leaves lower in the canopy (Figure 2.3). However, in the current crops of barley, PAR was still reaching the base of the canopy (Chapter Four). Therefore, decreasing SLN levels were not related to decreased PAR at the leaf surface. Alternatively, as N supply to leaves becomes limiting, the photosynthetic rate decreases, resulting in decreased biomass (Figure 2.3) and although the overall RUE was not significantly different (Chapter Four) it was trending to decrease in the low N treatments ($p = 0.169$). In summary, N levels affect biomass production through changing the response of leaves to the applied N fertiliser. Structurally, decreasing available N decreases the emerged area of leaves. Functionally, the leaves initially maintain a N level adequate for maximum photosynthesis (> 2.0 g N m^{-2}, Grindlay 1997) but in crops with decreased available N, the SLN levels declined over time.

5.5 Conclusion

- Leaves in malting barley react to available N by adjusting area to maintain a N concentration that maximises photosynthesis. Leaf size is not independent of nitrogen concentration in malting barley, but dependant on it. After emergence, leaves remobilise or maintain a SLN level that is dependant on N availability. Therefore, as N availability decreases, malting barley leaves decrease in area at emergence which then intercepts a decreased amount of PAR and produces less biomass.

CHAPTER SIX

Biomass and nitrogen relocation to grains
during grain filling

6.1   Introduction

In Chapter Five it was shown that leaves responded to N fertiliser applied when measured with auricle showing by increasing their area of leaf but maintaining SLN. The increase in the area of individual leaves contributed to an increase in the above ground biomass because the LAI was below the critical level for most crops (Chapter Four) ie. below 95 % light interception. As the leaves aged, SLN and area decreased indicating relocation of biomass and N. In Chapter Four it was shown that increased biomass resulted in increased grain yield, but the greatest biomass production in the 150/100 kg N ha^{-1} treatment did not translate into the greatest grain yields. The split applications of N fertiliser also decreased grain quality by increasing screenings to an unacceptable level. The rates of biomass accumulation was greatest at anthesis, and Austin *et al.* (1977) reported that large amounts of photoassimilates are produced during the period of maximum leaf area (anthesis) and are either partitioned directly to the grain, or temporarily stored in the stem and relocated at a later stage. The first objective of this chapter was to quantify the effect of nitrogen fertiliser on the amount of biomass relocated between anthesis and final harvest.

The size of N pools at anthesis may have an influence on the pattern of relocation of assimilates and N between anthesis and final harvest (de Ruiter & Brooking 1994). Nitrogen accumulated and stored before anthesis, plus N taken up after anthesis, are both important sources for final grain N % (Martin *et al.* 1989). The pattern of biomass accumulation was described in Chapter Four. In this chapter the development pattern of a N pool is described. The second objective of this chapter is to examine and quantify the development of N pools in grain and remaining (total - grain) biomass. Because the amount of N relocated to the grain may influence the grain quality characteristics (Section 2.5), the final objective of this chapter is to quantify the amount of N relocated in the period from anthesis to final harvest.

6.2 Materials and Methods

6.2.1 Crop description

Details of the field experiment including crop management, treatments and layout were outlined in Section 3.2.1. In addition, the following measurements and analyses were made.

6.2.2 Measurements

Biomass samples was taken from the crop at 40, 54, 68, 82 (anthesis) and 130 (final harvest) DAS. This involved hand harvest to ground level of all plants within two 0.1 m^{-2} quadrats per plot. Biomass weights were obtained by drying samples in a forced air oven at 70 C° to a constant weight.

Before drying a subsample of 20 stems were selected at random. These subsample stems were dissected and grouped into dead material, non-fully expanded leaves and stem (leaf sheaths, pseudo stem, stem) and chaff (awns and rachis). The complete ears including partially filled grain were included at the mid-anthesis measurement, but grain was separated at final harvest. Measurements on grain were from samples retained for biomass and yield components (Chapter Three). All samples were oven dried at 70 °C for 48 - 72 hours and then weighed. For determining nitrogen contents of dissected samples (eg stems, grain, etc), all samples were ground in a Cyclotech mill and analysed for nitrogen using a Mass spectrometer.

6.2.3. Data analysis

An analysis of variance (ANOVA) was used to determine differences amongst treatments. Mean separation was based on LSD tests at the $\alpha = 0.05$ level.

6.3 Results

6.3.1 Biomass

At anthesis, the total biomass ranged from 5080 kg ha^{-1} in the nil N treatment up to 6510 kg ha^{-1} in the 150 kg N ha^{-1} treatment (Table 6.1). In most cases, crops receiving 150 kg N ha^{-1} or more had greater biomass than the nil to 100 kg N ha^{-1} treatments. The total biomass consisted of awn + rachis, stem and fully expanded leaves (lamina only). The awn and rachis weight was similar in all treatments. However, stem weight tended to be heavier

in the 150 kg N ha^{-1} (p < 0.094) treatment at 5120 kg ha^{-1} compared with 4120 in the nil N treatment. Leaf weight differences were strongly significant (p < 0.001) at anthesis. For example, the total weight of leaves in the 150/100 N treatment was 1110 kg ha^{-1}, and those in the nil N treatment had 18 % less weight.

The biomass at final harvest consisted of screenings, grain, awn + rachis, dead material and stem (Table 6.2). The awns and rachis were assumed not to change in weight between anthesis and final harvest (Table 6.1 and 6.2) (Gallagher *et al.* 1975). The proportion of dead material was not different among treatments (Table 6.2). Stem weight ha^{-1} was heavier in the split N fertiliser treatments (p < 0.05) when compared with single N applications. In the single N treatments, stem weight was stable at approximately 5440 kg ha^{-1} (Table 6.2)

The change in biomass between anthesis and final harvest was significantly different (p < 0.05) among N treatments (Table 6.3), the general trend showed that N application promoted increases in biomass. Specifically, biomass in the nil to 150 kg N ha^{-1} treatments all increased by around 6650 kg, but the split application treatments increased by 8450 and 9670 kg biomass ha^{-1} in the 150/50 and 150/100 kg N ha^{-1} treatments respectively.

The change of biomass (excluding the grain) was marginally different (p < 0.072) among the treatments (Table 6.3). In the 150 kg N ha^{-1} treatment, relocation of biomass was evident as there was a net loss of 700 kg biomass ha^{-1} during grain filling. The 100 kg N ha^{-1} treatment also showed that relocation of reserves was important. The loss of biomass most likely came from leaf weight loss (Table 6.1). In all other treatments, there was net positive changes biomass between anthesis and final harvest (exclusive of the increased weight that came from grain + screenings). This response was greatest in the 150/100 kg N ha^{-1} treatment with 2420 kg of biomass ha^{-1} accumulated in the period.

Table 6.1   Total biomass and plant component weights (kg ha^{-1}) comprising the total biomass at anthesis in barley grown with different N fertiliser treatments

Treatment (kg N ha^{-1})	Total biomass		Awns + rachis	Stem	Leaves	
0	5080	c	350	4120	610	d
50	5270	c	340	4230	690	cd
100	5860	b	340	4740	780	bcd
150	6510	a	420	5120	970	ab
150/50*	6110	ab	430	4730	950	abc
150/100*	6350	a	430	4810	1110	a
SEM	292.5		28.4 (ns)	234.7 (ns)	60.8	

Note. * = treatments where second application of N fertiliser was applied at 56 DAS.

Table 6.2   Total biomass and biomass components (kg ha^{-1}) at final harvest (130 DAS) from barley grown with different N fertiliser treatments

Treatment (kg N ha^{-1})	Total biomass final		Screenings		Grain		Awn + rachis	Dead material	Stem	
0	11100	c	95	b	4740	b	350	255	5660	b
50	12480	bc	195	b	6150	a	340	165	5630	b
100	12360	bc	210	b	6350	a	340	160	5300	b
150	13380	abc	540	a	7030	a	420	220	5170	b
150/50*	14560	ab	695	a	6280	a	430	255	6900	ab
150/100*	16020	a	820	a	6430	a	430	370	7970	a
SEM	651.5		69.1		200.0		28.4 (ns)	44.7 (ns)	498.1	

Note. * = treatments where second application of N fertiliser was applied at 56 DAS.

Table 6.3   Biomass increase (kg ha^{-1}) between anthesis and final harvest, grain yield including screenings, and portion of biomass relocated to grains during grain filling in barley grown with different N fertiliser treatments

Treatment (kg N ha^{-1})	Biomass increase from anthesis to final harvest		Grain + screenings		Change of biomass (excluding grain + screenings)
0	6020	c	4830	c	1190
50	7210	abc	6340	bc	870
100	6500	bc	6550	bc	-50
150	6870	bc	7570	a	-700
150/50*	8450	ab	6980	ab	1470
150/100*	9670	a	7250	ab	2420
SEM	748.6		207.2		653.3 (ns)

Note. * = treatments where second application of N fertiliser was applied at 56 DAS.

6.3.2 Nitrogen

For the period from 40 through to 82 DAS the % N declined in the whole plant for the three treatments sampled (nil, 150 and 150/100 kg N ha^{-1}) (Figure 6.1). At 40 and 54 DAS, total N % was not significantly different among N treatments, mean N % being 4.9 and 2.9 % respectively. However, at 68 DAS, nil N treatment had significantly ($p < 0.05$) less % N than the other treatments. At anthesis (82 DAS) the N % was different ($p < 0.05$) among treatments, rising from 0.98 % for the nil N treatment to 2.55 in the 150/100 kg N ha^{-1} treatment.

The total amount of nitrogen ha^{-1} followed the opposite trend to % N accumulated in the biomass with increasing time from sowing (Figure 6.2). At 40 DAS, the total N accumulated was 14.5 kg ha^{-1} in the nil N treatment, compared with 19.5 in the 150 kg N ha^{-1} treatment. For the remaining sample dates there was more ($p < 0.05$) biomass N ha^{-1} in the higher N treatments than in the nil N treatment. At anthesis, the pool of N accumulated was 49, 127 and 162 kg ha^{-1} in the nil, 150 and 150/100 kg N ha^{-1} treatments respectively.
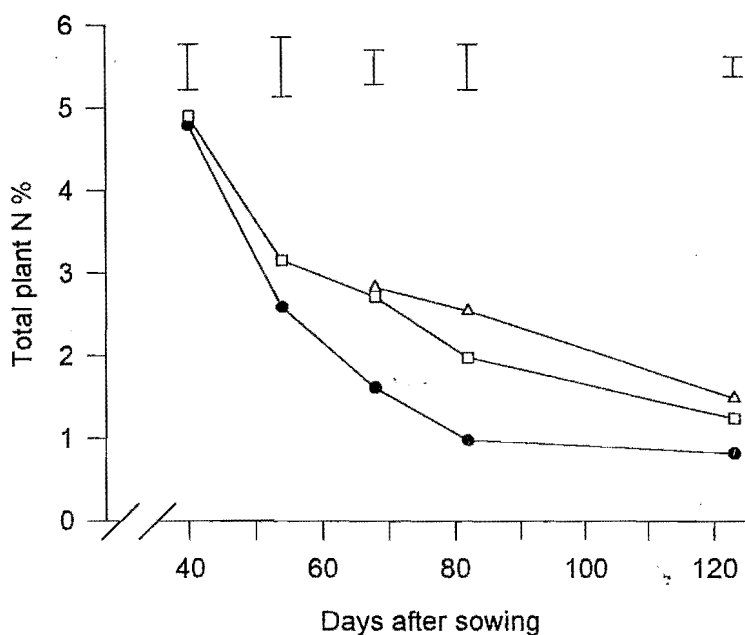
Figure 6.1   Pattern of total plant N % from 40 to 123 DAS
in barley grown with different N fertiliser treatments.
Treatments are in kg N ha^{-1} at nil (●), 50 (○), 100 (■), 150 (□),
150/50 (▲) and 150/100 (△). Error bars are LSD.
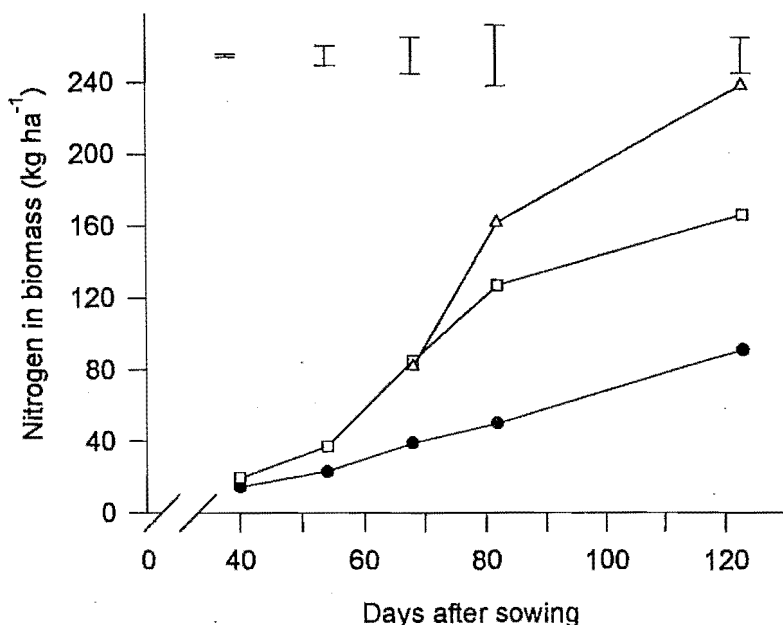
Figure 6.2   Pattern of total plant N (kg ha⁻¹) accumulation from 40
to 82 DAS in barley grown with different N fertiliser treatments.
Treatments are in kg N ha⁻¹ at nil (●), 50 (○), 100 (■), 150 (□),
150/50 (▲) and 150/100 (△). Error bars are LSD differences.

The N pool developed at anthesis showed significantly ($p < 0.05$) higher amounts of N ha⁻¹ in the high N treatments than in the nil and 50 kg N ha⁻¹ treatments (Table 6.4). The split N treatment of 150/100 had more than three times the amount of N ha⁻¹ than the nil N treatment. The overall trend was for increased amounts of N ha⁻¹ in the higher N treatments.

Partitioning the N in plant components over the whole crop at anthesis showed that awns + rachis, stem and leaves all contained differing levels of N between treatments ($p < 0.05$) (Table 6.4). Stem N ranged from 24 kg N ha⁻¹ to 97 in the nil N and 150/100 kg N ha⁻¹ treatments respectively. Leaves ranged from 19 kg N ha⁻¹ in the nil N treatment up to 55 kg in the 150/100 kg N ha⁻¹ treatment.

Over the period of grain-filling, there was an increase of total N ha⁻¹ in biomass between each of the treatments (Table 6.5). The increase was due mainly to N components of grain and screenings. For example, at anthesis, the nil N treatment totalled 49 kg N ha⁻¹, but at

final harvest had a total of 91. In this treatment, leaves lost N (dead material), stem N ha^{-1} remained the same at 23 kg N ha^{-1}, but grain and screenings assimilated 62 kg ha^{-1}. In the 150 kg N ha^{-1}, total kg N ha^{-1} increased by 39, the increase due mainly to grain and screenings (115 kg N ha^{-1}).

In all plant components making up the total N at final harvest, all responded to N treatments ($p < 0.05$) (Table 6.5). Screenings ranged from 1 kg N ha^{-1} in the nil N treatment up to 21 kg in the 150/100 kg N ha^{-1} treatment. Awns + rachis, stem and leaves, all increased the amount of N ha^{-1} as the application of N treatments increased.

The changes in total kg N ha^{-1} between anthesis and final harvest were not significant ($p < 0.309$) for N treatments (Table 6.6). However, the amount of N assimilated in grain + screenings was greater than the net increase in total N between anthesis and final harvest. Therefore, relocation of N biomass exclusive of grain and screenings occurred in all treatments (Table 6.6). Differences between N treatments ($p < 0.023$) were significant. The 150 kg N ha^{-1} treatment relocated 87 kg N ha^{-1} to the grain + screenings between anthesis and final harvest. All other treatments were less than this with the nil N treatment relocating only 21 kg N ha^{-1}. The differences between N treatments was only significant when comparing nil and 150 kg N ha^{-1} treatments.

Nitrogen harvest index (NHI), a measure of the efficiency of N relocated within the plant, was similar in the single N application treatments, with a mean of 74 (Table 6.7). The NHI was reduced ($p < 0.001$) in the split N treatments showing that low N treatments relocated more N from biomass to grain. Splitting N (150/50 and 150/100 kg N ha^{-1} treatments) decreased the amount of N relocated, ie, more N was left in the biomass and not relocated to the grains.

Table 6.4   Total amount of nitrogen and proportion of nitrogen of plant components (kg ha⁻¹)·at anthesis in barley grown with different N fertiliser treatments

Treatment (kg N ha^{-1})	Total anthesis		Awns + rachis		Stem		Leaves	
0	49	d	6	b	24	d	19	e
50	79	cd	7	ab	45	cd	27	de
100	95	c	7	ab	56	bc	32	cd
150	127	b	9	ab	76	ab	42	bc
150/50*	140	b	10	a	86	a	44	ab
150/100*	162	a	10	a	97	a	55	a
SEM	6.8		0.7		5.4		2.5	

Note. * = treatments where second application of N fertiliser was applied at 56 DAS.

Table 6.5   Total amount of nitrogen and nitrogen in plant components (kg ha⁻¹) at final harvest in barley grown with different nitrogen fertiliser treatments

Treatment (kg N ha^{-1})	Total nitrogen final		Screenings		Grain		Awn + rachis		Dead	Stem	
0	91	e	1	c	62	c	2	b	3	23	c
50	127	d	3	c	91	b	3	ab	2	28	c
100	138	cd	4	c	102	ab	2	b	2	28	c
150	166	bc	11	b	115	a	3	ab	2	34	c
150/50*	196	b	16	ab	109	ab	4	a	3	64	b
150/100*	238	a	21	a	118	a	4	a	4	91	a
SEM	7.4		1.5		5.0		0.2		0.4 (ns)	5.4	

Note. * = treatments where second application of N fertiliser was applied at 56 DAS.

Table 6.6   Change in nitrogen (kg ha⁻¹) between anthesis and final harvest, total N in grain + screenings and the amount of nitrogen relocated to grains during grain filling in barley grown with different nitrogen fertiliser treatments

Treatment (kg N ha^{-1})	Increase from anthesis to final harvest	Grain + screenings		Change of nitrogen (exclusive of grain + screenings)	
0	42	63	d	-21	b
50	48	94	c	-46	ab
100	43	106	bc	-63	ab
150	39	126	ab	-87	a
150/50*	56	125	ab	-69	a
150/100*	76	139	a	-63	ab
SEM	11.6 (ns)	4.7		10.6	

Note. * = treatments where second application of N fertiliser was applied at 56 DAS.

Table 6.7   Nitrogen harvest index (NHI) of barley grown with different nitrogen fertiliser treatments

Treatment	Nitrogen Harvest Index (NHI)	
0	69	ab
50	74	a
100	77	a
150	76	a
150/50*	64	bc
150/100*	58	c
SEM	2.2	

Note. * = treatments where second application of N fertiliser was applied at 56 DAS.

6.4 Discussion

Grain yield is the result of the amount of biomass relocated or assimilated during grain filling (Gallagher *et al.* 1975; Blacklow & Incoll 1981; de Ruiter & Brooking 1996). The effect of nitrogen treatments showed current biomass assimilation post-anthesis rather than from remobilisation had the greatest influence on grain yield. This agrees with Austin *et al.* (1977) who showed only about 7 % of biomass accumulated by anthesis was relocated to grains.

For all treatments there was an increase in biomass accumulated after anthesis (Table 6.1; 6.3). Most of the biomass produced post anthesis was partitioned into grain although there was a difference in the way crops responded to nitrogen treatments. In the 150 kg N ha^{-1} treatment most of the biomass was accounted for by grain growth but in the 150/100 kg N ha^{-1} treatment, 66 % of the biomass change was attributed to grain growth.

The lack of remobilisation of biomass reserves from the accumulated reserves at anthesis was expected because the crop was not water stressed (Chapter Three). Therefore, grain mass increase was primarily from current photosynthesis rather than assimilate remobilisation. Because the grains were filled mainly by current photosynthesis, all crops produced grain N % levels suitable for malting, ie. less than 2.0 % (Austin *et al.* 1977; de

Ruiter & Haslemore 1996) and the assimilates diluted N in the grain accumulated by remobilisation (Table 6.6).

Leaves were 12 (nil N) to 17 % (150/100 treatment) of the total weight at anthesis (Table 6.1). However, at maturity differences were no longer significant (Table 6.2). Austin *et al.* (1977) concluded that leaves act as a temporary store for assimilates until the grain requires assimilates. Therefore, green leaves are important in the process of assimilate accumulation in grain by acting as a storage organ and for synthesis of new material. The current study demonstrates the important photosynthesis role leaves play in ensuring grain filling. To maintain grain quality and yield, maintenance of green leaf area (de Ruiter & Brooking 1996) for photosynthesis is required, and this is demonstrated in the current study by their importance as contributors to grain-filling. However, the high N treatments had significantly more grains to fill than the low N plots, and because not all grains were filled to the maximum, the high N treatment resulted in an unacceptable level of screenings.

Therefore, late N application was effective in maintaining biomass growth for a longer duration during grain-filling, assuming that the rate of filling was constant in all treatments. This was not the situation in these crops (Table 4.1). An alternative implication is that the late N application prolonged leaf area duration and therefore more current assimilate was available for grain and stem growth (Table 6.2).

Biomass increases between anthesis and final harvest ranged from 6020 to 9670 kg ha^{-1} overall crops (Table 6.3). However, when a split application of N fertiliser was applied screenings increased. Screenings were greatest (820 kg ha^{-1}) in the high N treatments (Table 6.2). Although the high N treatments accumulated the greatest biomass (Table 6.1), grain filling was incomplete. The level of stem weight would suggest that there was adequate biomass for complete fill, but the screening level was high (Table 6.2). An explanation for the increased screenings may be in the development of the N reserves pool rather than biomass because the amount of N in tissue influences the distribution of assimilates between the various organs of the plant (van Keulen & Seligman 1987).

Alternatively, the influence of nitrogen on grain filling was related to the production of assimilates. In the nil N treatment, grains were filled, and then stem weight increased.

The increased stem weight was due to assimilates being stored after grains were filled. In the 150 kg N ha^{-1} treatment, current assimilation at anthesis was directed into grains, and into the stem, where at the onset of leaf senescence, reserves were relocated to the grains. In the 150/100 kg N ha^{-1} treatment, most of the assimilation was directed to growth of the large number of tillers (Chapter Three), and there was no assimilate reserve available for grain filling. At the end of the grain filling period, the lack of reserves to be remobilised into grains was low, indicating a sink problem, and resulted in large screenings levels in the high N treatments (Table 6.2).

The biomass N pools varied significantly between the three measured treatments. At 40 DAS the high (> 4.0) total % N in the plants was due mainly to leaves that contained a high % N (> 5.9) (Chapter Five). However, the total plant % N in the nil N treatment was 0.98 % at anthesis, this being lower than expected (de Ruiter & Brooking 1996) compared with the two high N treatments at 1.98 and 2.55 % N in the 150 and 150/100 kg N ha^{-1} treatments. If the % N was diluted by the additional biomass accumulated, then the high N treatments should have had a total % N similar to the nil N treatment. This did not occur. The implication is that in the 150 and 150/100 kg N ha^{-1} treatments, the large amounts of biomass assimilated at anthesis (Chapter Four) was not diluted as much as the lower N treatments. There is also likely to be a greater amount of N in the high N treatments not directly associated with growth or storage but rather is mobile (de Ruiter & Haslemore 1996). Thus, the high N treatments had developed a N pool that had more N available for relocation during the grain filling phase of growth.

At anthesis, plant N % levels were similar to those reported by de Ruiter & Brooking (1994). Crops with higher N pool are less likely to take up N after anthesis, and there is an increased likelihood of sustained relocation to the grain. The data in this study supports this hypothesis. The N pool at anthesis in the nil treatment was about 0.98 % N, and this pool relocated the least amount of N to the grain from biomass (Table 6.6). The 150 kg N ha^{-1} treatment had an N concentration of about 1.98 %, and relocated 87 kg N ha^{-1} to the grain. However, the 150/100 kg N ha^{-1} treatment relocated less than 63 kg N ha^{-1} and had the greatest N concentration at anthesis (2.55 %).

Nitrogen treatments that had 2.0 % total plant N at anthesis, also had the highest grain yield and acceptable grain quality. When total plant N exceed 2.0 %, the proportion of screenings increased. Splitting the applications of N fertiliser increased plant N % levels, but decreased the portion of N relocated to the grain. Furthermore, the amount of N accumulated at anthesis was directly proportional to grain yield response. For example, the 150 kg N ha^{-1} treatment had assimilated 76 % of the total amount of N at anthesis, all other treatments had acquired less than this, the values being lower than those reported by de Ruiter & Brooking (1994) at 87 %. However, post-anthesis N uptake is detrimental to grain N % (de Ruiter & Brooking 1994), as was the case in the current study. For example, in the 150/100 N treatment, 68 % of total N uptake had occurred by anthesis and that crop had a grain N % of 1.83 (Chapter Three), compared with the 150 kg N treatment where 77 % of total N was taken up by anthesis and grain N decreased to 1.64 %.

With single applications of N, there appeared to be an increase in total N in the above ground biomass at final harvest than the amount applied as split treatments. For example, in the 50 kg N ha^{-1} treatment there was 127 kg N ha^{-1} in the biomass compared with 196 kg N ha^{-1} in the 150/50 kg N ha^{-1} treatment and these results are comparable to de Ruiter & Brooking (1994). This demonstrates that the single applications of N were more efficiently utilised than split applications, a result also shown by the NHI in Table 6.7.

A possible explanation for the decreased amount of N relocated from split applications is that the plants lose the capacity to relocate N if the second application is too late ie. roots must actively take up N but root growth and function were not studied. For example, the 150/100 N treatment accumulated an additional 76 kg N ha^{-1} between anthesis and final harvest for a total uptake of 238 kg N ha^{-1} but relocated only 63 kg N ha^{-1}. Thus, one possible explanation may be related to the ability of the crops to take up and store N in relation to biomass accumulation.

In Chapter Four, biomass accumulation rates at anthesis of 225 kg N ha^{-1} d^{-1} in the nil N treatment were reported compared with 275 in the 150 kg N ha^{-1} and 310 in the 150/100 kg N ha^{-1} treatment. There was a 50 % difference in the daily amount of biomass accumulated between the nil and 150/100 kg N ha^{-1} treatments. However, the amount of N ha^{-1} in the treatments at anthesis was much greater, 49 in the nil N treatment compared with 162 in

the 150/100 kg N ha^{-1} treatment. Thus, the high N treatment did not assimilate sufficient biomass to dilute the additional N in the above ground biomass. The nil and 150 kg N ha^{-1} treatments assimilated biomass at a rate that was sufficient for the maximum biomass accumulation rate and not for luxury consumption of N (de Ruiter & Brooking 1996). Therefore, acceptable grain quality was achieved provided the amount of nitrogen in the plant was sufficient for the peak biomass accumulation but not for luxury uptake, a critical nitrogen % at anthesis of about 2.0 %.

The total kg ha^{-1} of N increased with increased biomass. There was significantly less N in the low N treatments compared with the high N treatments (Table 6.5). van Keulen & Seligman (1987), commented that N shortage in vegetative tissue influences distribution of assimilates between various organs. The increased amounts of N in the high N treatments did influence the distribution of assimilates. If the distribution of assimilates was assisted by the increased amount of N, then more biomass should have been allocated to the grains with the extra available N. However, not all grains were filled in the split N treatments as indicated by the higher levels of screenings. Therefore, large amounts of plant N as indicated by the high N fertilisation may not necessarily assist in achieving increased grain yields with suitable quality grain. Other effects such as the partitioning of assimilation (biomass and nitrogen) interact to regulate the development of grain size and nitrogen distribution patterns.

Relocation of N to the grain was significantly different over all treatments in contrast with the biomass relocation. The highest (87 kg N ha^{-1}) amount of N was relocated in the 150 kg N ha^{-1} treatment (Table 6.6). The green leaf weight contribution (14 - 18 %) to grain weight was significant, as well as the amount of N in the leaves (range 19 to 55 kg N ha^{-1}). Leaves are important sources of N for relocation to the grain, but are more important for their photoassimilation contribution. In the current study, the loss of leaf weight (Table 6.1; 6.2) showed that leaf weight contribution to grains was greater than 50 %. The pattern of N relocation was more responsive to N treatments than biomass relocation. Therefore it could be assumed that additional applications of N late in crop growth (before anthesis when N uptake is more rapid) will present problems for maintenance of acceptable grain N %. In conclusion, late applications of easily mobile N may increase the grain N % above

the 2.0% threshold set as acceptable for quality, but this was not demonstrated in the current experiment.

NHI decreased in treatments with split N application. In these treatments, the plants were unable to fully utilise the additional N but responded by producing more biomass. These results were higher than reported results of de Ruiter and Brooking (1996). As the split N application decreased the NHI, it is proposed that increasing the amount of applied N decreases the capacity of the plant to remobilise N (Table 6.6). This matches with the decreased amounts of biomass relocated to the grain. In reality, the high N plots should have yielded the most, but they did not (Chapter Three). Therefore, the lack of remobilisation of N to the grain in the high N treatments (Table 6.6) affected biomass relocation which in turn increased the screenings. Austin *et al.* (1977) stated that plants that can remobilise the most biomass usually have the greatest yield.

6.5 Conclusion

Increasing N fertiliser as a single application increased grain yield, and the increase in biomass between anthesis and final harvest was due almost entirely to grain filling through current assimilation. Where high N applications were made, plants continued to assimilate biomass rather than accumulate reserves for grain-filling. However, splitting N fertiliser decreased the quality of yield through increased screenings, the increased screenings resulting from the lack of the ability of the plant to remobilise stem biomass assimilates due to excessive N plant concentration allowing continued growth.

Splitting N fertiliser allowed the plant to continue to assimilate biomass. The large amounts of biomass assimilated at peak growth rates at anthesis were stored in the stem in the low N treatments, but used for growth in the high N treatments to maintain tiller numbers (Chapter Three). After the crop began to senesce, the high N treatments were unable to source assimilate from the higher biomass accumulation rates (Chapter Four) to the grain.

A new finding that crops that have a N pool at anthesis with total plant N composition at or less than 2.0 % are able to relocate biomass efficiently and at rates that will ensure maximum grain yield and quality. This appears to be more important than the total amount of biomass accumulated over the growth of the crop.

CHAPTER SEVEN

General discussion, conclusions
and future research

7.1   General discussion

Nitrogen fertiliser up to 150 kg N ha^{-1} increased grain yield while maintaining grain quality. However, the timing and rate of the likely response of N fertiliser inputs were influenced by other agronomic practices such as water inputs, sowing rate and pest and disease control. The climatic conditions under which the crop is grown are also likely to influence yield and quality.

In all ranges of applied N fertiliser, quality was maintained below the 2.0 % grain N concentration but screenings were increased with increased applications of N. With the exception of the nil N treatment, grain yields were above 6000 kg ha^{-1}, higher than the 4500 New Zealand average (Anon 1997). In addition, these plots were hand harvested which over estimates yield.

In general, increased applications of N increased total biomass and because HI was relatively stable, the increased grain yields described by the functional crop growth approach were from the amount of PAR intercepted, and not the efficiency of conversion of PAR. Nitrogen fertiliser increased leaf area index (LAI) which was the major contributor to the increased amount of PAR intercepted (Q). The LAI was increased with additional N by more stems per unit area and an increase in the mean area of leaf lamina.

Because LAI was influenced by these two factors, the implication is that when establishing a malting barley crop, adequate N should be supplied to maintain survival of about 300 plants m^{-2}, slightly higher than Millner (1983) tiller survival and to ensure leaves reach their potential size.

Biomass accumulation was closely related to crop growth rate which was related to canopy development. Therefore, to gain the maximum biomass, canopy closure should occur as soon as possible after sowing. This suggestion agrees with Gallagher *et al.* (1983) who stated "Because growth is proportional to absorbed light, a heavy crop can only be grown if leaf area expansion is fast and full green cover is maintained for a long period. An appreciation of the environmental factors governing the expansion and longevity of the leaf surface is clearly needed. In barley, this depends on the expansion and senescence of leaves on individual tillers , and, necessarily, on the process of tillering itself."

Leaf response to available N gave some insight into the physiology of the responses to N fertiliser. In the current study, two main effects of N on leaves were shown to occur. The final area of a fully expanded leaf is mostly under genetic control (Ramos *et al.* 1995) but area can be reduced when N is limiting (Table 4.3). A reduced area of a leaf reduces the potential amount of PAR intercepted, and this is partly a reason for reduced biomass production.

In addition, a second major effect from the applied N fertiliser was the dynamic SLN levels. Specifically, SLN levels were similar at full leaf lamina emergence but decreased to below optimal levels (Grindlay 1997) for photosynthesis where N was limiting. This nitrogen was probably remobilised to new leaf tissue (van Keulan & Seligman 1987). Grindlay (1997) showed that a decrease in SLN level decreased the photosynthetic performance by decreasing leaf area resulting in less biomass accumulation.

For malting barley in Canterbury the data presented here show how leaves respond to different levels of available N. Leaves maintained a specific leaf weight regardless of N supply, increased individual lamina area in response to increased N supply, and maintained SLN levels over time as N availability was increased. A decrease in SLN suggests a decreased photosynthetic rate (Grindlay 1997) which may have been beginning to occur (Table 4.2), resulting in a decrease in biomass production. However, in all treatments, there was a high assimilate recovery rate from leaves (Chapter Six). Therefore, to obtain increased grain yields from increased biomass production, N availability to malting barley crops should be adequate to enable leaves to expand to their genetic potential, and to maintain a SLN level over time that is adequate for optimal photosynthesis.

The current study has shown that the amount of N in the stem and the number of grains to fill are of major importance to final grain yield and quality. For example, there were losses of N from the stem between anthesis and final harvest (Table 6.4 and 6.5), but there was a net increase in biomass. As with the leaf N levels, N is more mobile than biomass (de Ruiter & Haslemore 1996; Grindlay 1997). Biomass relocation was not significantly affected by N availability, but the amount of N relocated between anthesis and final harvest to grain was. Therefore, a conclusion can be drawn that managing the amount of total crop N for increased grain yield and quality through optimum levels (total plant N % 2.0 at anthesis) is better than managing for biomass production.

This study showed that the largest amount of N was relocated when a single application of N fertiliser was made, and that the treatment with most N relocated from the stem, gave the highest yield (7030 kg ha^{-1}) with acceptable quality (1.64 % N). Achieving high yields and acceptable quality was achieved with a single application of 150 kg N ha^{-1} N fertiliser at emergence which may have been, in part, because of N relocation from the stem.

Another major conclusion is that as the amount of N made available to the crop increased, a larger N pool developed (Table 6.4). However, this large N pool was ineffective at generating high yields and quality. In conclusion, N fertiliser practises for maximum grain yield and quality should be at application levels in sufficient amounts to allow for just above non-limiting maximum biomass production but not in levels that allow elevated plant N %. This is possible provided timing of applications of N and irrigation are optimal (Thompson *et al.* 1974; Drewitt & Smart 1981; Carter & Fitzgerald 1987).

This study revealed that split N applications produced greater N pools and biomass production, which were not automatically translated into grain yield. There was obviously some factor contributing to interfering with grain filling in treatments where N is in excess of crop requirements. Perhaps if plants m^{-2} was constant along with stem numbers m^{-2}, then the results found here may have differed. An increased establishment in the number of plant m^{-2} would have resulted in mainly main stems and tiller one or two being sampled and the increased amounts of N may have generated higher yields while maintaining acceptable grain quality for malting.

However, this study has shown how dynamic crop growth is and has also highlighted the problem with single measures for predicting the strategic use of N fertiliser (de Ruiter & Haslemore 1996; Grindlay 1997), for example, yield components, or individual leaf N levels at emergence. In contrast, the single measure of plant N % at anthesis was closely related to the final yield. The approach of whole crop growth analysis provides opportunities to explain mechanisms associated with the complexities of malting barley grain yields and quality as shown in this study.

There are many interacting elements to crop yields and quality, and no one single parameter can be used to indicate results expected. For example, soil N test results were highly variable (Table 3.3), and although the trend seemed to show larger amounts of soil N as applications of fertiliser increased, there was a lack of large significant differences. This highlights the problems of associating one measurable parameter to a predicted final grain yield and quality, including the application and in turn the availability of N.

For malting barley, N availability affects grain yield and quality by initially creating a canopy that can efficiently intercept light. The following effect of the N is to allow the plant to create and partition biomass to grains. Excessive N creates continued growth and decreases the assimilate available for grain fill, whereas nil N decreases the number of grains to fill.

7.2   Main conclusion

Grain yields of more than 7000 kg ha^{-1} with acceptable quality are possible with the use of N inputs provided no other limitations occur. High yields with acceptable quality are likely to come from crops with increased biomass production and in crops where plant N % is around 2.0 at anthesis. Leaf area, weight and N concentration mechanisms are influenced by N availability. Leaves decrease area, and maintain a SLN level at emergence. As the leaf ages, SLN levels decline, but area remains reasonably constant.

In grain filling, crops should be managed with N fertiliser for maintained green leaf area so that grain filling is mainly by current biomass assimilation. This manner of grain filling dilutes the N portioned to the grain resulting in acceptable grain N quality. For predicting

grain yield and quality, measuring dynamic changes in growth and plant N concentrations have potential as indicators of the mechanisms in malting barley.

This study has:

Proven that grain yields of malting barley crops can be increased without detrimental effects on grain nitrogen content by applying N at crop emergence.

Shown that nitrogen fertiliser affects crop canopy characteristics by influencing the amount of PAR intercepted and partially the radiation use efficiency.

Revealed that the individual leaf size in malting barley is determined by available N and the mechanism for the area is the maintenance of specific leaf nitrogen concentration by adjustments to leaf size.

Quantified biomass and nitrogen relocation between anthesis and final harvest and shown that the nitrogen pool is more important than biomass for grain yield and quality because it affects biomass partitioning and accumulation of assimilates to the grain and that to maintain grain quality, grain filling from current photosynthates is preferred.

7.3   Recommendations for future research

Monitoring of soil N over whole crop growth to determine more accurately the quantities of N from soil reserves.

A more commercially real plant establishment rate and the use of only main stems for analysis of N and biomass partitioning.

More exacting measurements made at different heights through out the crop for light and leaf N levels.

Using labelled N to determine the distribution throughout the growth of the plant in a field grown malting barley experiment.

To identify the role of N in the way it effects the distribution of biomass; specifically, determine what mechanism in the stem of malting barley were affected by N that decreased the grain quality.

Measures of structural and non-structural assimilate relocation to determine assimilate losses in quantities and pattern.

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Personal Communications

de Ruiter, J. M. New Zealand Institute for Crop and Food Research, Lincoln.