THE EFFECT OF NITROGEN MANAGEMENT AND PADDOCK HISTORY ON GROWTH AND YIELD OF BARLEY (*Hordeum vulgare* L.)

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ABSTRACT

A field experiment was conducted during spring 1983/1984 at four adjacent sites on marginal the cropping soil Tokomaru silt loam to study the effect of nitrogen management and paddock history on growth and yield of barley (Hordeum vulgare L.) cv. Magnum. Six nitrogen treatments were tested in three replications in a randomised complete block design at each site. The treatments were no-N (control), 60 kg N/ha either applied at sowing, growth stage (G.S.) 3, G.S.6 or equally split between G.S.3 and G.S.6 and a higher rate based on soil test results (70-90 kg N/ha depending on site) applied at sowing. Site histories were immediately out of pasture and previously cropped with barley for 1, 2 and 3 years. Crop nitrogen status was monitored by nitrate sap test and plant analysis.

Control plot yield decreased almost linearly from 5.78t/ha directly out of pasture to 3.55 t/ha on the site previously cropped for three years. This indicated that regular cropping without fertiliser nitrogen on this soil could substantially reduce the yield of barley.

Application of nitrogen significantly increased yield over control at all sites. The response in the first year of cropping was probably because of the low accumulation of nitrogen during the pasture phase on this soil. Average yield of plots receiving nitrogen were similar for the first two year of cropping (7.09 and 6.86 t/ha respectively) but declined rapidly for the third and fourth year of cropping (5.90 and 5.94 t/ha respectively). Plots receiving the high nitrogen rate were also unable to maintained yield as cropping increased. The yield decline could have been caused by deteriorated soil physical conditions under continuous cropping. Maintaining adequate nitrogen toward later stages of growth by late or split application was found to be as effective as applying the higher nitrogen rate at sowing especially as soil fertility reduced.

Ear density was the main component affecting yield. Grain number/ear was also an important yield component for crop grown under lower fertility and was increased when nitrogen was applied at sites cropped for 3 and 4 years.

There was differences between predicted yield based on soil test results and actual yield of control plots across the sites. Sap nitrate concentration showed a good relationship with total nitrogen analysis. Both measurements of plant nitrogen at earlier stages of growth were related to the yield. Highest yield (7t/ha) was found to be associated with 4.5% total nitrogen and >6000ppm sap nitrate concentration at about G.S.3.

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1. INTRODUCTION

Application of fertilizer nitrogen to increase crop yield under intensive agriculture has been a common practice throughout the world. In New Zealand however, the use of nitrogen fertiliser is small compared to its use in Europe and North America (Walker and Ludecke, 1982). This is mainly because the New Zealand agricultural system has developed to almost complete dependence on biological nitrogen fixation by legume-based pasture. Crops are normally grown in rotation with fertility-buiding pasture and little intensive croppi̇̈ng has been practiced (Mcleod, 1968; Stephen, 1982).

Sears (1960) suggested that pasture should be cropped when soil fertility has built up to the stage of grass dominance. The length of the cropping period during which soil fertility and higher crop production can be maintained varies with pasture management and soils (Mcleod, 1968; Greenland, 1971). This situation coupled with the wide variation in climatic conditions across New Zealand complicate the prediction of crop fertiliser nitrogen requirement.

Most previous studies on nitrogen response and requirement of wheat and barley were conducted in the South Island. Little work has been conducted in the North Island particularly on marginal cropping soils. The general conclusion has been that nitrogen requirement of wheat and barley varies depending on paddock history and moisture availability before and during cropping season. For a reliable fertiliser recommendation, such studies should cover the wide range of climate, soils and cultural practices in New Zealand.

To obtain some informations on the influence of paddock history on the response of barley to nitrogen, a field experiment was conducted on a marginal cropping soil in North Island with the following objectives:

1. To study the influence of paddock history on the response of barley to nitrogen application.

2. To study the effect of nitrogen application time (later referred to as nitrogen management) on yield, yield components, growth and nitrogen status of barley.

3. To evaluate some possible methods of assessing nitrogen fertiliser requirements; sap and plant tests and soil tests.

2. LITERATURE REVIEW

2.1. EFFECT OF PASTURE AND CROP ON SOIL

The beneficial effect of pasture on soil is widely documented. The main contributions of pasture are an increase in organic matter and soil nitrogen levels and an enhancement of soil physical properties. All these factors are important for crop growth and production.

When pasture soils are brought under cultivation, the changes in soil organic matter, nitrogen and soil physical conditions are normally the reverse to that which occur under pasture.

2.1.1. Soil Organic Matter and Nitrogen

Soil nitrogen particularly in the surface layer, occurs largely in organic forms or in organic combination that are mainly associated with soil organic matter (Bremner, 1965; Allison, 1973; Stevenson, 1982b). Thus the the dynamics of nitrogen are related to that of organic matter.

Changes in the amount of nitrogen with time under any given agronomic practices are shown by the following equation (Bartholomew and Kirkham, 1960; Stevenson, 1982a):

$$N_t = A/k + (N_i - A/k)\ e^{-kt} \qquad \text{.....}\ (1)$$

Where:
A = Annual addition of nitrogen
k = nitrogen mineralisation constant
N_i = initial nitrogen
t = time
N_t = amount of nitrogen at time t

This equation indicates that the changes in the amount of nitrogen and organic matter are curvelinear with time. The rate is most rapid during first few years of pasture or cropping then proceeds more slowly toward a steady-state (Russell, 1962; Jackman, 1964a; Sears et al., 1965a; Carran, 1983).

Under pasture rate of nitrogen addition to the soil (A) is normally higher than rate of meneralisation (k) resulting in net increased in soil nitrogen levels, the reverse occurs under cropping (Greenland, 1971).

The accumulation of nitrogen under pasture is mainly from biological nitrogen fixation by the legume component that is mainly white clover (Trifolium repens L.). Input from other sources termed as 'background nitrogen' are only 15 - 20 kg N/ha/year (Sears et al., 1965a; Ball, 1982).

Jackman (1964a) showed that the rate and amount of accumulated soil organic matter and nitrogen under permanent pasture in some North Island soils varies with soil type. Half-lives (time required to accomplish 50% of the changes to steady-state) for accumulation of organic carbon and nitrogen in top 15 cm of Tokomaru soils were about 14 and 6 years respectively. The accumulation was mainly confined to the top 7.5 cm soil. At or near steady-state, this soil accumulated 11500 kg organic C/ha and 1200 kg organic N/ha in top 7.5 cm. This amount was the lowest amongst soils in his study.

Considering the low input of 'background nitrogen' and without external sources of nitrogen, the supply of nitrogen for non- leguminous crops such as wheat and barley solely depends on mineralisation of organic nitrogen that comes mainly from organic matter. Non-allophanic soils such as Tokomaru silt loam has a higher mineralization constant 'k' (average 12.1) than the allophanic counterpart (average 4.6). This resulted in a higher rate of nitrogen mineralization and an earlier steady-state is reached (Jackman, 1964b).

Organic matter and nitrogen in most pasture or virgin soils decrease when it brought to cropping (Williams and Lipsett, 1961;

Sears et al., 1965b; Williams, 1973; Carran, 1983). The decrease in nitrogen is maily due to the absence of nitrogen fixation, lower addition of organic matter and removal of nitrogen normally as grain (Stevenson, 1982a). Beside that, soil cultivation and fallowing between crop seasons that promote nitrogen mineralization (Jackman, 1960; Williams and Lipsett, 1961; Black, 1968; Halford, 1981) enhanced the losses of nitrogen. Leaching of nitrogen was reported to be higher under crop than under pasture (Harmsen and Kolenbrander, 1965; Cooke, 1967; Goh, 1982). Losses of nitrogen through direct volatilization of nitrogen compounds from the crop was also suggested (Quin, 1982).

The effect of cropping on soil nitrogen however may vary between soils. Stephen et al. (1973) obtained no yield decline in their four years continuous wheat cropping representing fourth to seventh crops. According to Steele and Cooper (1980), some North Island soils can be continously cropped for 11 years without showing nitrogen response, while other soils responded to nitrogen fertilisers even in their first year out of pasture.

2.1.2. Soil Physical Conditions

Works on the effect of pasture or cropping on soil physical properties in New Zealand is scarce (Cossens, 1984). This is possibly because any effect of pasture or cropping on soil physical conditions is overshadowed by their overwhelming effect on nitrogen.

It has long been recognised that the physical conditions of soil is at its best in the year or so after long term pasture. According to Jacks (1946) the increase in soil fertility under pasture is attributed more to the improvement of physical rather than chemical constituents of the soil.

Physical changes that occur under pasture are mainly related to soil structure; this include an overall increase in soil porosity, increase in aggregate stability and increase in water retention and consequently available moisture (Greenland, 1971; Dermott, 1972; Corbin and Pratley, 1980). All these factors are important for root growth, soil aeration, movement of water and availability of nutrients to the plant.

The improvement of soil physical conditions is associated with the nature of grass roots, increased soil fauna, addition of organic matter and absence of land cultivation under pasture (Jacks, 1946; Greenland, 1971; Dermott, 1972).

As soon as pasture soils are cultivated, the desirable soil physical properties begin to deteriorate (Low, 1955; 1972). The deterioration is mainly due to rapid losses of organic matter. There are indication of world wide problems of soil degradation due to intensive cropping (Greenland, 1981).

Soils with high contents of fine sand or silt in the surface horizon are most prone to structural instability (Greenland, 1971; Batey, 1972; Cowie, 1978). Several workers have indicated the importance of organic matter in stabilising soil structure on these types of soil. Decreased soil aggregate stability, increased bulk density and a much weaker structure have been reported under intensive cropping (Williams, 1971; Low, 1972; Martell and MacKenzie, 1980; Unger, 1982). Under intensive cropping, this type of soil has a tendency to develop a structure that unsuitable for plant growth (Clarke et al., 1967; Walker and Ludecke, 1982).

Although most studies in Europe, North America and Australia show that the effects of pasture on subsequent crops are not due to their influence on soil physical conditions, an exception have been noted on a few soils with high silt and fine sand content (Cooke, 1967; Greenland, 1971). Locally, Sears et al. (1965b) have indicated that deteriorated soil structure under continuous cropping on Manawatu and Kairanga silt loams decreased crops yield. The period of changes before soil physical conditions could reach steady-state under continuous cropping may vary between soils. Cotching et al. (1979) found that on Horotiu silt silt loam, the changes almost complete after three years but on Puniu silty clay loam it continued for a longer period, after six years the soil was considered to be in poor physical condition.

2.2. YIELD AND YIELD COMPONENTS

Grain yield of barley is the product of three components; number of ears per unit area (ear density), number of grains per ear and mean grain weight with the following relationship:

$$\text{Yield/ha} = \text{Ear/ha} \times \text{grain number/ear} \times \text{grain weight} \quad \ldots.(2)$$

This equation can be rewritten as:

$$\text{Grain Yield/ha} = \text{Grains/ha} \times \text{mean grain weight.}$$

This relationship shows that yield could be increased by increasing one or all of the components. However this very difficult to achieved because of the interaction between the components, where large increases in one component is accompanied by decrease of others. For example, application of nitrogen or increases in sowing rate that increased ear density can result in fewer grain number/ear and smaller grain size (Thorne, 1966; Drewitt and Rickard, 1973; Feyter and Cossens, 1977; Scott, 1978). Therefore the final grain yield depends on the results of the yield components interaction.

Under most circumstances, ear density and number of grains per ear (or grain density) are the two most important components contributing to yield (Scott et al., 1973; Gallagher et al., 1975; Hampton et al., 1981; Withers and Pringle, 1981).

Increase in ear density generally increase grain yield until an optimun level where yield becomes constant or tends to decrease due to reduction of other components. There was no report available regarding the optimum ear density for barley. However studies in South Island showed that barley could supports more than 1000 ears/m^2 that yielded about 10t/ha (Risk et al., 1984). For wheat yield up to 6 t/ha, the optimum ear density ranged from 600 to 800 ears/m2 (Scott et al., 1973; 1977; Scott, 1978; Hampton et al., 1981), beyond that, grain number/ear and grain weight decreased (Dougherty et al., 1974; Scott, 1978; Hampton et al., 1981).

2.3. DEVELOPMENT OF YIELD COMPONENTS

Early stages of cereal growth are important in determining the yield levels. This is because at or before anthesis, potential ear density and grain number per ear are determined (Heslop-Harrison, 1969; Kirby, 1973) and possibly also the potential size grain size (Porter et al., 1950, Scott et al., 1983).

2.3.1. Tillering and Ear Density

Donald (1968) proposed that a crop with a single culm is an ideal characteristic for higher yielding cereals. However, tillering ability is still considered necessary (Kirby and Farris, 1972; Evans et al., 1975; Yoshida, 1981). This as an assurance for adequate ear density under adverse conditions such as poor germination, pest and disease that may occur during crop growth. Beside that, photosynthetic area of tillers (that is greater than that of the mainstem) is responsible for significant light interception (Gallagher et al., 1983).

Ear density depends on sowing rate, number of tillers produced and proportion of those tillers that survive and bear an ear at maturity.

Under field conditions, beside the mainstem, only about four or five tiller buds successfully grow to form tillers (Cannell, 1969; Kirby, 1973; Fraser and Dougherty, 1977). Tiller density generally increases rapidly to a maximum at about stem elongation period, then declines to an almost stabilised number at heading (Thorne, 1962; Cannell, 1969; Gallagher et al., 1976).

Nitrogen is one of the factors that influence the rate of tiller production, maximum tiller density and reduction of tiller after the maximum. Early and high nitrogen application is reported to increase the rate of tiller production and the maximum tiller number achieved (Aspinall, 1961; Thorne, 1962; Cannell, 1969).

Reduction of tiller number after the maximum is due to cessation of tiller production and death of tillers. Gallagher et al. (1976) recorded a maximum of 1500 stems/m^2 from an initial of 450 plants/m^2, but only 925 ears/m^2 survived to maturity. In wheat, tiller mortalities of 40% are common and even as high as 60% (Langer, 1965; Scott et al., 1973; Dougherty and Langer, 1974; Fraser and Dougherty, 1977). Generally the earliest formed tillers have a higher probability of surviving and producing ears (Thorne, 1962; Bunting and Drennan, 1966; Cannell, 1969).

Production of tillers that are destined to die is considered a significant wastage of resources (e.g. water, light and mineral nutrients). Although some materials might be retranslocated to the fertile shoots (Palfi and Dezsi, 1960; Rawson and Donald, 1969), the tillers may compete for assimilate needed for ear development, enhanced moisture deficit and retain some immobile nutrients (Rawson and Hosfra, 1969; Kirby and Jones, 1977; Moorby and Besford, 1983). An increase in grain number/ear and grain weight of the mainstem was reported when a proportion of tillers were removed (Jones and Kirby, 1977).

The competition between and within tillers has been suggested as the reason for the death of tillers (Aspinall, 1961; Bunting and Drennan, 1969; Gallagher et al., 1976). Early nitrogen application that promotes high tiller production may increase the competition at later stages of growth and result in high tiller mortality. Kirby (1967) indicated that in two-row types of barley, the maximum number of tillers is inversely related to the final ear density. Aspinall (1961) reports no tiller reduction occurs under continous supply of nitrogen even after ear emergence. Therefore adequate nitrogen supply after the maximum tillering period is important for tiller survivals.

Application of nitrogen during tillering improved tiller survival and increased ear density (Fraser and Dougherty, 1977; Hanson et al., 1983; Withers and Palenski, 1984). Application of nitrogen after tillering period however can reduce yield although tiller survival improved (Millner, 1983; Easson, 1984). This was associated with a reduction of grain number/ear.

Different orders of tillers contribute differently to yield. The earliest formed tillers contribute more to the yield and their contribution relative to mainstem increased with nitrogen application (Thorne, 1962; Cannell, 1969; Langer, 1980).

Thus, the maximum tiller number produced and tiller survival are important in determining ear density at harvest. Early nitrogen application may increase tiller production and a subsequent application up to the period of maximum tillering may improve tiller survival. Later nitrogen application may reduce yield due to the reduction of other yield components. This however will vary between sites and seasons.

2.3.2. Grain Number/Ear

Number of grain/ear is limited by the number of spikelets formed on the ear. Normally a proportion of the spikelets form grain, others degenerate or become infertile spikelets.

Spikelet initiation on the mainstem occur as early as G.S.2, when the crop is at about 2 or 3 leaf stage (Kirby, 1973; Gallagher and Biscoe, 1978; Kirby and Appleyard, 1981). Initiation of tiller spikelets begins slightly later. The period however varies with cultivars and temperature as shown in wheat by Halse and Weir (1974).

Kirby (1973) recorded maximum spikelet primodia as high as 51 on Proctor barley but at ear emergence only 29 spikelets remained. The maximum and final spikelet numbers were higher on main-stem than on tillers (Gallagher et al., 1976).

The number of spikelets formed is influenced by the duration of ear development. The longer the duration the more spikelets can be developed (Evans et al., 1975). Nitrogen application can increase the duration of spikelet development and number of spikelets formed (Single, 1964; Campbell and Davidson, 1979; Frank and Bauer, 1982). Langer and Liew (1973) found that spikelet number depended on nitrogen status of the crop between double ridge stage and spikelet initiation.

2.3.3. Grain Size

Grain size or grain weight is considered the most stable component of grain yield (Fischer and Kohn, 1966; Gallagher et al., 1975; Scott, 1978). It is genetically controlled and characteristic of a cultivar (Holliday and Willey, 1969; Scott, 1978).

It was widely accepted that under most circumstances, the grains are filled almost entirely from photosynthesis after anthesis and little contribution comes from reserve assimilates (Thorne, 1974; Biscoe et al., 1977; Evans et al., 1975). Under unfavourable conditions during grain growth, contribution of pre-anthesis reserve assimilates could increase that contribute a significant amount to the grain weight (Gallagher et al., 1975; Scott and Dennis-Jones, 1976). Even under conditions normally encountered in United Kingdom, Daniel et al. (1982) have shown the positive role of reserve assimilate for grain growth and yield production. Therefore amount and persistence of photosynthetic area after anthesis as well as pre-anthesis dry matter production are important for grain growth.

2.4. GROWTH IN RELATION TO YIELD

Grain yield related to the total dry matter at maturity by 'harvest index' (Donald, 1962; Donald and Hamblin, 1976):

$$Y_e = HI \times Y_b \qquad .... (3)$$

Where: Y_e = grain yield
HI = harvest index
Y_b = total accumulated dry matter

This relationship indicates that yield could be increased either by increasing the total dry matter or harvest index. Dyson (1977) found that grain yield was more closely related to total dry weight at ear emergence than the increase in weight after that. Threfore pre-ear emergence dry matter accumalation is important for grain yield.

More than 90% of crop dry weight is the product of photosynthesis (Biscoe and Gallagher, 1978; Moorby and Besford, 1983). Mineral nutrients themselves contribute very little to the dry weight compared to their effects on photosynthetic system of the plant (Moorby and Besford, 1983).

In wheat and barley, even though all green organs including the ear inflorescence are capable of photosynthesis (Thorne, 1974; Biscoe and Gallagher, 1978), only total leaf area or leaf area per unit ground cover (Leaf Area Index, LAI) is widely used as the indicator of crop photosynthetic capacity. This because of the difficulty in measuring the area of other organs.

Total leaf area depends on rate of leaf expansion and leaf senescence. The canopy develops in a sigmoid pattern to a maximum then decreases due to increased rate of leaf senescence (Evans and Wardlaw, 1976). Dry matter production increases with leaf area until an optimum LAI is reached, when the foliage becomes sufficiently dense to cause mutual shading that decreases dry matter production per unit leaf area (Stoy, 1969; Puckridge, 1971; Yoshida, 1972). Yoshida (1972) indicated that total accummulated dry matter at final harvest has a close relationship with the maximum LAI.

Even though haigh LAI is important for dry matter production, its value in relation to the optimum LAI and period of ear formation are critical for grain yield. Scott et al. (1973) reported that supra-optimal LAI at high plant density during early ear development drasically reduced grain number/ear due to limited supply of assimilate. The high ear density produced unable to compensate for the lower grain weight/ear results in lower grain yield.

Nitrogen is one of the factors that influences leaf production and leaf senescence. Higher LAI of wheat and barley following nitrogen application or under high nitrogen supply is widely documented (e.g. Watson et al., 1958; Scott et al., 1977; Gregory et al., 1981). Nitrogen increased leaf area by increasing the rate of leaf expansion on a shoot (Biscoe and Gallagher, 1978), total number of leaves by increasing tiller production (Ishizuka, 1969; Biscoe and Gallagher, 1968) and by delaying leaf senescence (Gregory et al., 1981).

2.5. NITROGEN NUTRITION OF BARLEY

In this section only a general overview of nitrogen nutrition is discussed. Detailed aspects of nitrogen nutrition for non-leguminuous crop has been recently reviewed Hocking et al. (1984a; 1984b).

2.5.1. Nitrogen Uptake and Translocation

Rate of nitrogen uptake is rapid during active vegetative growth (Olson and Kurtz, 1982). The rate is influenced by availability of nitrogen and soil moisture which depends on root density and exploitable soil volume (Davidson et al., 1978; Huffaker and Rains, 1978; Hocking et al., 1984a). Total uptake rate was similar to dry matter accumulation and was maximum at about heading (Barley and Naidu, 1964; Storier, 1975).

Ammonium and nitrate are equally available to the plants, however the main form taken up depends on the relative amount present in soil. In most soils, ammonium is rapidly nitrified by soil microbials and plants obtain most nitrogen in the form of nitrate.

Nitrate absorbed by the root may go to one of three possible pathways; reduced and synthesized into amino acid by root tissue, accumulated in root storage sites, or transported to the shoot via the xylem to be reduced or stored in the upper plant parts (Huffaker and Rains, 1978; Oaks, 1979; Schrader and Thomas, 1981).

The major site of nitrate reduction varies between plant species, nitrogen supply and plant age. Barley and wheat are in the intermediate group where the roots reduces a considerable proportion of nitrate (Miflin, 1970; Pate, 1973; Lewis et al., 1982). As high as 60% and 40% of incoming nitrate can be reduced in root of barley and wheat respectively (Miflin, 1970; Ashley et al., 1975; Austin et al., 1977). Under high nitrogen supply, leaves are favoured as the major site of reduction (Wallace and Pate, 1967; Pate, 1973; Huffaker and Rains, 1978). Work on spring wheat (Kirkham and Miflin (1979) indicated that potential for root nitrate reduction increased at low nitrogen levels and as plant progressed toward maturity .

Amount of nitrate present in stem sap therefore depends on the amount of nitrate reduced in the shoot relative to the root, nitrogen supply and age of plant. Measurement of plant nitrate concentration can give a good indication of crop nitrogen status and reflects soil nitrate availability (Fernandez, 1972; Papastylianou and Puckridge, 1983; Withers and Palenski, 1984).

2.5.2. Nitrogen Concentration and Distribution

Nitrogen concentration in the plant varies between organs and stages of development. The concentration is higher in shoots than in roots (Hocking *et al.*, 1984a) and more nitrogen is distributed in leaf than in stem (Suzuki and Mcleod, 1977). The shoot nitrogen in wheat and barley decreases with plant age (Smith, 1962; Waldren and Flowerday, 1979; O'Neill *et al.*, 1983).

Reduction in plant nitrogen concentration with growth is normally termed the 'dilution effect' that due to decline in nitrogen supply in absolute sense or relative to the increase in structural material and non-growing tissues (Campbell *et al.*, 1977; Bouma, 1983).

Redistribution of nitrogen continously occurs in crop plants, either from older leaves to younger ones, or from stems and leaves to storage organs. At later stages of growth, nitrogen from vegetative parts is mostly retranslocated to the grains (Hewitt, 1970; Gregory *et al.*, 1981). Under inadequate nitrogen supply, excessive redistribution of nitrogen to the developing grain may promote premature leaf senescence that can reduce photosynthetic capacity of the crop and curtail the grain filling process (Gregory *et al.*, 1981).

Although sterile tillers exported most of their nitrogen to fertile ones, these tillers are considered of little or no value to the crop nitrogen economy (Rawson and Donald, 1969). This is because its comprise only 5% or less of the total nitrogen and during their development consumed photosynthate and other less mobile nutrients (Bouma, 1983).

2.6. RESPONSE OF BARLEY TO NITROGEN

Nitrogen requirement of barley is similar to that of wheat. An amount between 20 - 25 kg N is required per tonne of grain yield (Millner, 1983). In term of fertiliser application however, a higher amount than that may be required as losses of nitrogen may occur and efficiency of nitrogen decreases with increasing level of available nitrogen. For irrigated wheat, Quin et al. (1982) reported an efficiency about 40 kg N/tonne of yield increase. Therefore on low fertility soils or under intensive cropping, the use of nitrogen fertiliser is necessary for higher production.

The response of wheat and barley to nitrogen fertiliser however, is inconsistent. It is influenced by many factors that operate before and during the cropping period and that vary between seasons and localities. Review of early work (Stephen, 1980; 1982) show yield responses ranging from economic yield increases to depression.

Two main factors widely reported to affect nitrogen responses are soil nitrogen status and soil moisture during growth. The response of wheat and barley to fertiliser nitrogen occurs most frequently following cereals and less frequently after pasture or forage crops (Hudson and Woodcock, 1934; Lynch, 1959; Drewitt, 1979; Drewitt and Smart, 1981).

Grain yield of wheat decreased under continuous cropping and subsequently the response to applied nitrogen increased (Mcleod, 1974; Greenwood and Mcleod, 1980).

Grain yield depression with nitrogen application occurs under rainfed as well as irrigated conditions. Some depressions under rainfed conditions have been explained by the "haying off" effect, where the application of nitrogen promotes vegetative growth, increases evapotranspiration losses and induces a condition of moisture deficit later in the growing season (Fischer and Kohn, 1966; Dann, 1969; Dougherty, 1973; Dougherty et al., 1975). The yield losses were due to high tiller mortality resulting in lower ear density and also lower grain number/ear and grain weight. Under irrigated conditions, excessive vegetative growth and delayed reproductive development creates an intense competition for carbohydrate between developing ear and vegetative parts resulting in low grain set (Dougherty and Langer, 1974).

Nitrogen application may also increases crop lodging and incidence of diseases that can results in lower grain yield.

2.7. ASSESSMENT OF NITROGEN FERTILISER REQUIREMENT

There are two categories of assessment related to the nitrogen fertiliser requirement of cereals in New Zealand; first a general assessment that used to determine which paddock that likely responsive to nitrogen application, and second is a more specific assessment that try to predict the amount of nitrogen required for maximum yield. Goh (1983) has critically reviewed the assessment methods and its application in New Zealand cropping.

Most assessment methods directly or indirectly measure the amount of available and/or potentially available nitrogen before or during crop growth. The methods used in New Zealand can be grouped into three broad categories; paddock history and winter rainfall, soil tests and plant analysis.

2.7.1. Paddock History and Winter Rainfall

This method is based on the general principle that soil available nitrogen is higher after good pasture and subsequently reduces with increasing years of cropping and that heavy winter rainfall decreases the amount of available nitrate.

Nitrogen fertiliser is not recommended for the first crop following pasture or other restorative crops. For subsequent crops, crop performance and availability of water will determine the need for fertiliser nitrogen (Mcleod, 1962; Unwin and Cornforth, 1980; Malcolm, 1983).

Feyter *et al.* (1977) developed a relationship between winter rainfall and nitrogen response of spring sown wheat in Southland and Otago. The test of this relationships however was successful only for the second crop after pasture (Feyter and Cossen, 1977) and it is not widely used.

Latest fertiliser recommendation for wheat and barley in New Zealand by Greenwood *et al.* (1982) included both of the above parameters plus the assurance of moisture availability during the cropping season as the basis for determining the nitrogen that should be applied.

The difficulties in fertiliser recommendation based on paddock history alone have been widely reported (Douglas, 1968; Walker, 1969; Quin *et al.*, 1982; Goh, 1983). The use of this method in U.K. (MAFF, 1967; Batey, 1976) is also reported to have variable success (Needham and Boyd, 1976; Tinker, 1979; Gales, 1983). This method does not take account of the variability in the amount of accumulated nitrogen during pasture phase, subsequent depletion by the crops and losses of nitrogen between paddock and locality (Ludecke, 1974; Feyter and Cossen, 1977; Steele and Cooper, 1980).

2.7.2. Soil Tests

Measurement of nitrate or total mineral nitrogen levels of field soils before or at planting have been used in estimation of cereals nitrogen fertiliser requirement in Canada (Soper and Huang, 1963; Soper et al., 1971; Nuttal et al., 1971) and West Germany (Jungk and Wehrmann, 1978; Becker and Aufhammer, 1982).

Locally, Ludecke (1974) and Walker and Ludecke (1982) have established the relationship between soil nitrate levels during late-winter / early-spring and grain yield response of wheat to nitrogen. Likely yield responses could be expected if nitrate nitrogen in the top 60 cm soil is less than 60 kg N/ha. A similar level was reported for barley by Dilz (1981) in Netherland. This criteria was used by Stephen (1982) as the basis of nitrogen fertiliser recommendation for cereals in New Zealand.

The 'deep nitrate' test however did not take account of the amount of mineralised nitrogen and losses that could possibly occur during the cropping period. Hart et al. (1979) showed that more than 200 - 300 kg N/ha was available in top 80 cm soil in Canterbury during the wheat growing season. Quin and Drewitt (1979) found 2 - 4 times more nitrogen in crop than that was indicated by the 'deep nitrate' test at planting.

A latest method developed by Quin et al. (1982) incoporated both initial and potential available nitrogen as detrmined by an 'incubation test' of field soil. This method involved estimation of zero-nitrogen yield and try to predict the amount of nitrogen required for an expected yield. It was suggested to be equally suitable for autumn, winter and spring-sown wheat and barley with little or no modification. This method was established on soil without moisture stress and should not be used indiscriminatetely on non-irrigated crops (Goh, 1983).

2.7.3. Plant Analysis

The use of plant analysis is based on the concept that plant nutrient concentration is related to the growth of the plant. Within certain limits, increase in soil nutrients result in increase of plant nutrient status, growth and yield (Smith, 1962; Ulrich and Hills, 1967; Jungk and Wehrmann, 1978)

Although the use of plant analysis for predicting nitrogen fertiliser requirment in annual crops is very limited in New Zealand (Goh, 1983), it has a role in monitoring nitrogen status (Cornforth, 1982; Bouma, 1983). If the analysis can be made early enough, it can provide an indication of nitrogen sufficiency.

Plant analysis for nitrogen can be divided into two groups; total nitrogen and inorganic nitrogen. Total nitrogen in plant tissues varies between organs and stages of development (section 2.6.2). Therefore for diagnostic purposes, the tissues and stages of development must be clearly identified. The procedure for analysis and interpretation of the results and problems related to plant analysis has been widely discussed (Aldrich, 1967; Ulrich and Hills, 1967; Jones, 1967; Jungk and Wehrmann, 1978).

Work in New Zealand on the relationship between total nitrogen concentration, growth and yield of barley or wheat is scarce. Cornforth (1982) has listed a standard concentration of nitrogen and other nutrients for wheat, oats and barley. Optimum nitrogen concentration in above-ground plant parts at heading is between 2.1 -3.0% for crop grown under favourable conditions. Diagnostic at this stage of growth could be too late for any corrective measures of current crop and possibly too early for next crop. In United Kingdom, Crooke (1977) indicated that nitrogen concentration at six-leaf stage of barley is optimum at 4.5%. O'Neill et al. (1983) obtained the highest correlation between yield and nitrogen concentration at 4 to 5 week after emergence (mid-tillering to mid-stem elongation).

Nitrate concentration is a common form of inorganic nitrogen used to monitor nitrogen status of the plant. Measurement of sap nitrate has been shown to be a good indicator of growth and yield of cereals. Withers (1982) reported a good relationship between grain yield and sap nitrate concentration of barley as measured by nitrate test strip at growth stage 6. A later study by Withers and Palenski (1984) showed that wheat growth rate reduced when sap nitrate levels fell below 5000 ppm before tillering (G.S. 5) and after that stage, a level about 1000 ppm was considered critical. The sap nitrate concentration reflected various nitrogen managements imposed. Prasad and Spiers (1982) reported a linear relationship between sap nitrate concentration measured by the nitrate test strip and by auto analyser method.

Therefore, although plant analysis is limited for prediction of nitrogen requirement, its measurement either by total analysis or by simple sap nitrate test could indicate possible nitrogen deficiency and additional nitrogen that may needed if the measurement were made early enough.

3. MATERIALS AND METHODS

3.1. EXPERIMENTAL SITE

The experimental area was located at the Pasture and Crop Research Unit, Massey University, Palmerston North. The soil is Tokomaru silt loam whic is mainly used either for dairying or fattening lambs and is considered marginal for cropping due to drainage problems (Cowie, 1978).

Ryegrass and white clover was established from old pasture in 1977. In 1980, part of the area was divided into three blocks for a long-term barley experiment. Cropping was started in that year in one of the sections and in subsequent years new section were cropped in each block. Adequate phosphorus and potassium fertilizers was applied to the crop every year and no nitrogen was used. During winter, the cropped areas were sown with either turnip or annual rye grass which were grazed in situ with sheep.

This experiment was conducted during spring 1983 on one of the blocks which consisted of four adjacent sections differing in the number of years cropped (Table 1).

Prior to land preparation, the top 15cm of soil was sampled from 20 random points in each site. The samples from each site were bulked and immediately send to Winchmore Irrigation Research Centre for determination of mineral nitrogen (NH_4-N + NO_3-N) by the method of Quin et al. (1982). The results of the soil test are presented in Table 1.

Table 1: Site history and soil test results.

Site		History	Mineral Nitrogen (ppm) Initial nitrogen (IN)	Increase after incubation (Δ N)
Site1	-	Immediately after pasture	8.6	47.4
Site2	-	1 year cropped with barley	6.2	45.3
Site3	-	2 years cropped with barley	5.5	45.0
Site4	-	3 years cropped with barley	6.3	41.2

3.2. CLIMATOLOGICAL DATA

Climatological data for the experimental area were taken from DSIR meteorological station that was situated about one kilometer from the site.

3.3. EXPERIMENTAL METHOD

3.3.1. Design

Four identical experiments were conducted, one at each site. The design was a randomised complete block (RCBD) with three replications within each site. The plots measured 2.25m x 15m.

3.3.2. Treatment

The six treatments are shown in Table 2. Growth stage (G.S.) is based on Feekes' scale as described by Large (1954). Treatments CONT, 60B, 60E, 60L and 60SP are common to all sites. The 60 kg N/ha rate was based on the optimum rate obtained by Withers (1982) on a similar soil type.

For treatment SOILT, the rate of nitrogen fertilizer was calculated by the method of Quin et al. (1982). Control plot grain yield was estimated by the following equation:

$$Yo = 1 + 0.0417\,(IN + 2\,\Delta N) \qquad \ldots.(4)$$

Where: Yo = estimated yield on control plot (t/ha)

IN = initial nitrogen concentration (ppm)

ΔN = changes in nitrogen concentration between the initial nitrogen concentration and final nitrogen after 7 days incubation at $37^{o}C$ (ppm).

Table 2: List of treatments

Treatment	Description	Code
1	- Control (no nitrogen)	CONT
2	- 60 kg N/ha applied at sowing	60B
3	- 60 kg N/ha applied at early tillering (G.S.3)	60E
4	- 60 kg N/ha applied at late tillering (G.S.6)	60L
5	- Soil test rate applied at sowing (See Section 3.3.2)	SOILT
6	- 60 kg N/ha equally split between early (G.S.3) and late tillering (G.S.6)	60SP

The amount of nitrogen fertiliser required for each sites (Table 3) was calculated for expected yield potential (Yp) of 7 t/ha and 40 kg N/tonne of yield responses by the following equation:

Nitrogen required (kg/ha) = (Yp - Yo) x 40 ....(5)

Where: Yp = estimated yield potential (t/ha)

Yo = estimated yield on control plot (equation 1)

40 = nitrogen required per tonne of yield response.

Nitrogen was applied as urea (46 %N). For the application at sowing, the fertiliser was broadcast and raked-in. For other application times, it was broadcast on the surface. At all sites, an amount of 300 kg/ha 30% potassic superphosphate was applied and incoporated with the final cultivation.

3.3.3. Crop Establishment and Maintainance

One week after land preparation, barley (*Hordeum vulgare* L.) cultivar 'Magnum' was sown on 19th Oct. 1983 in 15cm row spacing at 100 kg seed/ha.

Two weeks after sowing, crop establishment counts were taken from three areas of 0.1 m^2 on each plot.

One month after planting, crop was treated with mixture of 4 l/ha of 'Salvo' (210 g/l mecoprop, 233 g/l dichloroprop, 107 g/l MCPA, 17 g/l dicamba) for weed control and 50 ml/ha of Tilt (250 g/l propiconazole) as fungicide. No insecticide was applied and none of the crops were irrigated.

Toward maturity, birds were effectively controlled by hanging black polythene strips across and surrounding the experimental areas.

Table 3: Estimated yield on control plot (no nitrogen) and calculated rate of nitrogen application for treatment SOILT.

Site	Estimated grain yield on control plot (Yo) (t/ha)	Calculated rate of Nitrogen fertiliser (kg N/ha)
Site1	5.31	70
Site2	5.04	80
Site3	4.98	80
Site4	4.70	90

3.3.4. Samplings and Measurements

Each plot was divided into two sections, one-half for destructive samplings during vegetative growth and the other for final harvest of grain.

Five above-ground samplings were done at 31 (harvest 1), 47 (harvest 2), 54 (harvest 3), 80 (harvest 4) and 117 days after sowing (DAS) at about G.S.3, G.S.6, G.S.8, G.S.10.2 and maturity respectively.

At each sampling, three randomly placed quadrats of 0.1 m^2 were taken from each plot. Three rows surrounding the plot were treated as borders.

The plot samples were bulked and subsamples were taken for the following measurements whenever applicable:

1. Tiller number
2. Leaf area
3. Plant dry weight
4. Fertile and sterile tillers
5. Ear number.

Tillers were divided into dead and living tillers and counted separately. The dead tillers were characterised by absence, yellowing or death of the youngest leaf. At harvests 2 and 3 the green tillers were divided into several sizes based on their fresh weight. For harvest 2, three sizes were used; very small tillers (VST): < 0.5 g, small tillers (ST): $0.5 - < 1.0$ g and medium tillers (MT): > 1.0 g. For harvest 3, five sizes were used with addition of; medium tillers (MT): $1.0 - < 1.5$ g, large tillers (LT): $1.5 - < 2.0$ g and very large tillers (VLT): > 2.0 g. At harvest 4, the tillers were partitioned into fertile and non-fertile based on the presence of an ear.

The living tillers were partitioned into 'leaf' and 'stem' fractions. The 'leaf' fraction consisted of all fully expanded green lamina removed at the junction with leaf sheath. The 'stem' fraction consisted of all the remaining material. Area of green leaves were measured by Li-Cor area meter model LI-3100.

After drying at 82°C for 24 hours, the separate fractions were weighed.

3.3.5. Final Harvest and Yield Components Analyses.

For final grain yield measurement, an area of 1.3m x 5m was harvested by plot harvester. Grain moisture content was determined and the yield adjusted to 14 % moisture content.

Crop harvest index (HI) was calculated by the following equation (Donald and Hamblin, 1976):

$$\text{Harvest index} = \frac{\text{Grain yield/m}^2}{\text{Total above-ground dry matter/m}^2}$$

Ear density was determined by counting the number of ears present in three 0.1 m^2 samples per plot. Grain number/ear for each plot was determined by sampling about 100 ears which were hand threshed, the total number of grains were counted and divided by the actual number of ears.

Grain weight was measured by counting and weighing four lots of 300 seeds. This weight was adjusted to 14 % moisture and presented as 1000-grain weight.

3.4. PLANT ANALYSIS

3.4.1. Herbage Nitrogen Analysis.

Separate nitrogen analysis was done for leaf, stem, and whole tillers for harvests 2, 3 and 4. For harvests 1 and 4 only whole tiller and ear-bearing tillers respectively were analysed. Three replicate samples were analysed from each plot.

Nitrogen was analysed by semi-micro kjeldahl method. An amount of 0.25 g of oven dried ground plant material was digested with 5 ml N-free sulphuric acid with Kjeltab tablet as catalyst. Titration was done by Kjeltec Auto 1030 Analyzer.

3.4.2. Sap Nitrate Test.

Sap nitrate concentration was measured using Merckquant nitrate test strip throughout vegetative growth until no nitrate was detected. The test method was similar to that described by Withers (1982). Six plants were sampled at random from each plot. The white tiller base was sampled by cutting with scissors and a drop of sap was squeezed onto the test paper. The time taken for the colour to change to 500 ppm standard or the maximum colour if less than 500 ppm were noted. The time was then converted to nitrate concentration (ppm) by a standard calibration curve.

3.5. ANALYSIS OF RESULTS

Statistical analyses were carried out using Genstat (Alvey *et al.*, 1980, 1982) and SPSS (Nie *et al.*, 1975) programs. Test for homogeneity of variance between the sites (Snedecor and Cochran, 1967) give a significant differences on most sets of data, therefore only analysis of variance within the sites were carried out.

All sets of data gave no skewness as tested by Genstat (Alvey *et al.*, 1982), therefore no data was transformed.

About one month after sowing, a reduced performance of plants were noticed on both headland plots at sites 1 - 3 where soil compaction due to turning of tractors appeared to be a problem. Initially plot position was tried as a covariate but later it was found that initial plant counts were closely related to the plant performance and this was used as a concomitant variable to adjust all the results in the analysis of variance (Snedecor and Cochran, 1967). Comparison between treatment means was done by least significant difference method at 5 % level.

When measuring the relationships between pairs of variables involving only one pair of variables, simple correlation and regression were used. However, when there were more than one pair of variables, partial correlation and multiple regression were used. Partial correlations were calculated as describe by Steele and Torrie (1980) and Nie _et al_. (1975). First order partial correlation coefficients were calculated between pairs of variables while holding the effect of third variable constant. Second order partial correlation coefficients were calculated between pairs of variables with the effect of a third and fourth variable held constant.

4. RESULTS

4.1. CLIMATE

Climatological data of the experimental area which cover the previous winter and during the crop season are shown in Table 4.

The experimental area experienced relatively drier weather than normal before and during the cropping season. Total winter rainfall (June - August) prior to cropping was only 193 mm compared to the long term average of 275 mm. During the cropping period (October - Febuary) the area received a total of 305 mm rainfall, which was about 100 mm less than average.

There was an increasingly negative water balance during the cropping period, however no visual sign of crop water stress was observed. Sunshine hours were also below the average until toward the end of cropping season. Air temperature was generally about normal.

4.2. CROP ESTABLISHMENT

Mean plant density counted two weeks after sowing at site 1 to site 4 was 393, 388, 375 and 377 plant/m^2 respectively. At all sites, there were no significant differences between treatments. So that nitrogen application at sowing (60B and SOILT) had no effect on initial plant establishment.

There were no serious infestation of pests, weeds and diseases and no lodging occur on any plot. Birds were effectively controlled.

Table 4: Total monthly rainfal, water balance, sunshine hours, mean monthly temperature and their respective long term average (in brackets) before and during the experimental period*.

year	month	rainfall (mm)	water balance (mm)+	sunshine hours	temperature (^oC)
1983	June	93 (97)	+66 (+73)	84 (94)	8.9 (8.6)
	July	35 (89)	+14 (+64)	79 (104)	7.7 (8.0)
	Aug.	64 (89)	+25 (+47)	90 (122)	9.7 (9.0)
	Sept.	117 (75)	+47 (+10)	104 (133)	11.4 (10.6)
	Oct.	57 (88)	-24 (-10)	86 (158)	13.5 (12.4)
	Nov.	54 (78)	-47 (-51)	149 (177)	13.8 (14.2)
	Dec.	68 (94)	-82 (-60)	184 (193)	15.5 (16.1)
1984	Jan.	35 (79)	-136 (-89)	210 (209)	16.2 (17.3)
	Feb.	91 (67)	-42 (-76)	195 (186)	17.1 (17.6)

(DSIR, Palmerston North)

* Planting date: 19th Oct.1983

+ (rainfall - potential evapotranspiration)

4.3. GRAIN YIELD

Mean grain yield over all treatments were highest on the first crop after pasture (site 1) and decreased with increasing year of cropping (Table 5). Yield of control plots decreased at a steady rate of about 0.74 t/ha/year of cropping (Figure 1).

Nitrogen application at all sites significantly increased grain yield over the control with a tendency for increased nitrogen response as years in cropping increased. Average yield of nitrogen-treated plots were similar for the first two years of cropping at sites 1 and 2 (7.06 and 6.86 t/ha respectively) then dropped sharply for the third year (site 3), which were similar to the fourth year at site 4 (5.90 and 5.94 t/ha respectively) (Figure 1).

Different nitrogen management showed various responses at sites 2 - 4. Except at site 1, nitrogen application at early tillering (60E) tended to give the lowest yield of all the nitrogen treatments and this was significant at site 3.

Treatments involving late application (60L and 60SP) and the higher application rate (SOILT) applied at sowing did not differ from each other. These treatments consistently gave yields higher than early application particularly at sites 3 and 4. At site 4, split nitrogen application (60SP) between early (G.S.3) and late tillering (G.S.6) yielded significantly higher than the early applications at the same rate (60B and 60E).

Efficiency of nitrogen application (kg grain/kg N applied) gave no consistent trend across the sites (Table 6). Generally, late and split application of 60 kg N/ha tended to give the highest efficiency.

Table 5: Effect of nitrogen treatments on grain yield.

	Grain yield (t/ha)			
Treatment	Site 1	Site 2	Site 3	Site 4
CONT.	5.78 a	4.84 a	4.31 a	3.55 a
60B	6.89 b	6.95 bc	5.87 c	5.60 b
60E	7.32 b	6.02 b	5.21 b	5.52 b
60L	6.93 b	7.54 c	6.23 d	5.93 bc
SOILT	6.70 b	6.74 bc	6.09 cd	6.09 bc
60SP	7.50 b	7.03 bc	6.12 cd	6.55 c
Mean	6.85	6.52	5.64	5.54
C.V.(%)	7.1	9.1	3.3	7.9

The number within column followed by same letter is not significantly different by LSD test at 5% .

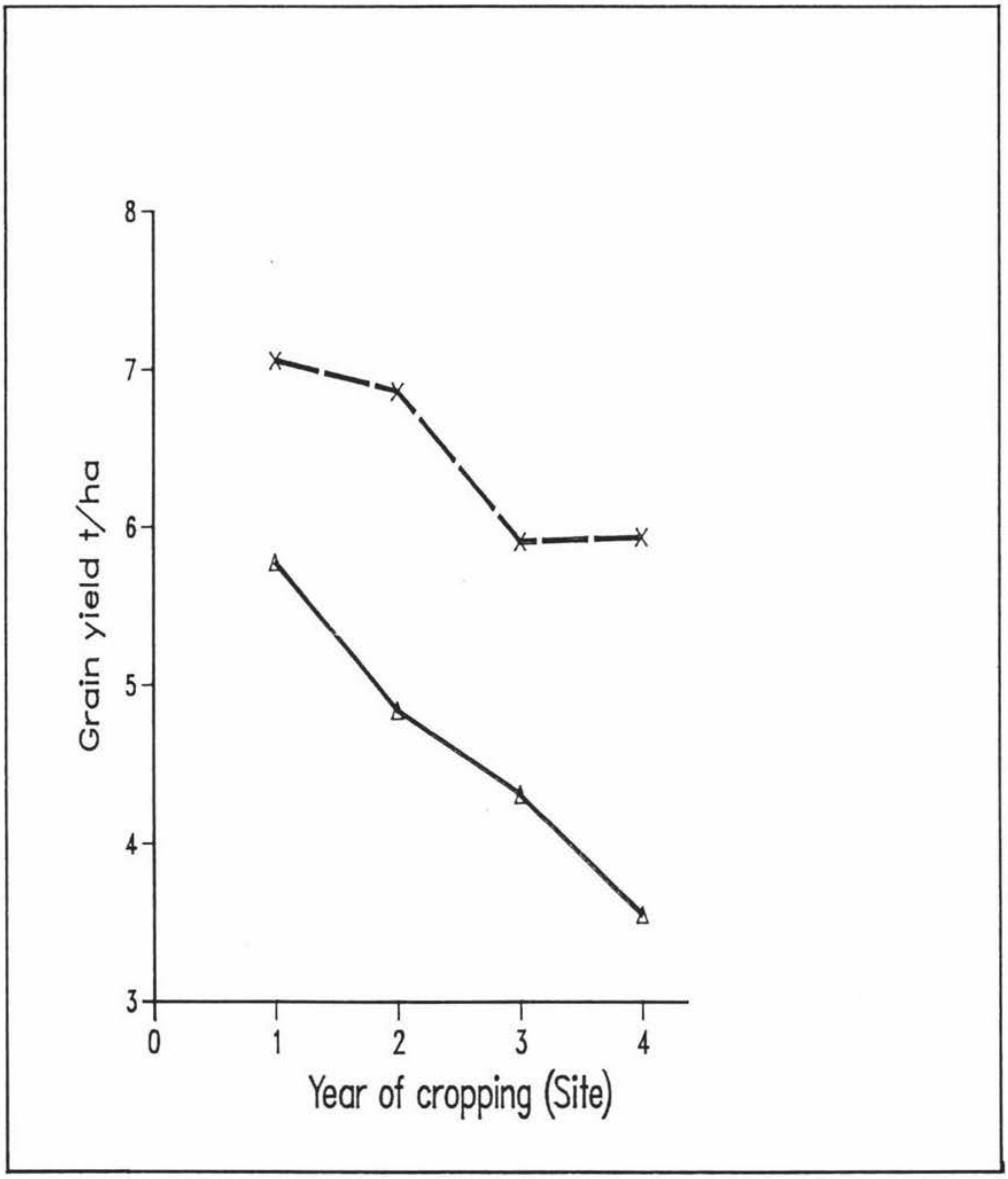

Figure 1: Average grain response to nitrogen application (**X**) and control plot yield (Δ) across the sites differing in year of cropping.

Table 6: Nitrogen fertilizer efficiency under different nitrogen treatments.

Nitrogen treatment	N fertiliser efficiency (kg grain/kg N)				
	Site 1	Site 2	Site 3	Site 4	mean
CONT.	-	-	-	-	-
60B	18.5	35.2	26.0	34.2	28.5
60E	25.7	19.7	15.0	32.8	23.3
60L	19.2	45.0	32.0	39.6	40.0
SOILT	13.1	23.8	22.3	28.2	21.9
60SP	28.7	36.5	30.2	50.0	36.4
Mean	21.0	32.0	25.0	37.0	

4.4. YIELD COMPONENTS

Ear density on control plots and average over all treatments were highest at site 1 and then decreased with increasing number of previous crops to site 4 (Table 7).

Nitrogen application gave a significant increase only at sites 1 and 4. For sites 1 - 3, SOILT tended to have the highest ear density. At site 4, late or split application of 60 kg N/ha (60L and 60SP) tended to be more beneficial for this component.

There were very little differences in grain number/ear between the sites. Except at site 2, application of nitrogen significantly increased grain number/ear. Split application of nitrogen (60SP) tended to give highest grains/ear at sites 1, 3 and 4 and this was significantly higher than control at sites 1 and 4.

Average grain weight was lowest at site 1 and was almost the same at other sites. At site 2 nitrogen application significantly reduced grain weight compared with the control. Nitrogen management had no effect on grain weight.

4.5. RELATIONSHIP BETWEEN YIELD AND YIELD COMPONENTS

Partial correlation between yield and yield components of pooled data and at each site are shown in Table 8.

At all sites grain yields were positively correlated with ear density. At sites 3 and 4 yield also correlated with grain number/ear. There were no significant correlation between grain weight and yield.

Regression of pooled data between yield and the yield components are shown in Figure 2. Overall results showed that yield linearly increased with increasing ear density and grain number/ear to a maximum at about 7 t/ha at about 950 ears/m^2 and

Table 7: Effect of nitrogen managements on yield components at final harvest.

Site	N-trmt	Ear Density (number/m2)	Grain/ear	1000 grain weight (g)
Site 1	CONT.	818 a	17.92 a	43.99 a
	60B	1022 b	19.97 b	41.90 a
	60E	1013 b	19.90 b	42.08 a
	60L	965 b	19.77 b	41.80 a
	SOILT	908 ab	21.02 bc	42.66 a
	60SP	996 b	21.54 c	41.71 a
	Mean	954	19.99	42.36
	C.V.(%)	6.5	3.8	2.6
Site 2	CONT.	751 a	15.30 a	45.71 a
	60B	868 a	18.35 a	43.77 b
	60E	863 a	18.94 a	44.42 b
	60L	908 a	17.84 a	44.24 b
	SOILT	914 a	18.29 a	43.81 b
	60SP	894 a	18.14 a	44.08 b
	Mean	867	17.81	44.34
	C.V.(%)	9.4	6.6	1.2
Site 3	CONT.	696 a	16.61 a	45.56 a
	60B	834 a	19.25 bc	44.44 a
	60E	788 a	19.52 b	44.57 a
	60L	874 a	18.61 bc	44.35 a
	SOILT	902 a	17.39 ac	43.86 a
	60SP	881 a	20.46 b	45.36 a
	Mean	829	18.64	44.69
	C.V.(%)	9.4	5.5	2.6
Site 4	CONT.	667 a	15.86 a	44.69 a
	60B	773 ab	17.99 b	44.43 a
	60E	757 ab	17.84 b	45.50 a
	60L	898 c	18.20 b	43.74 a
	SOILT	810 bc	19.00 bc	43.76 a
	60SP	858 bc	20.14 c	44.78 a
	Mean	794	18.17	44.32
	C.V.(%)	7.5	3.6	2.0

At each site, the number within column followed by same letter is not significantly different by LSD test at 5% .

Table 8: Partial correlation between grain yield and yield components.

Site	Ear density	Grains/ear	1000-grain
Overall	0.584 **	0.260 *	-0.117ns
Site 1	0.456 *	0.333 ns	0.110 ns
Site 2	0.563 *	0.008 ns	- 0.414 ns
Site 3	0.766 **	0.426 *	- 0.032 ns
Site 4	0.433 **	0.730 **	- 0.378 ns

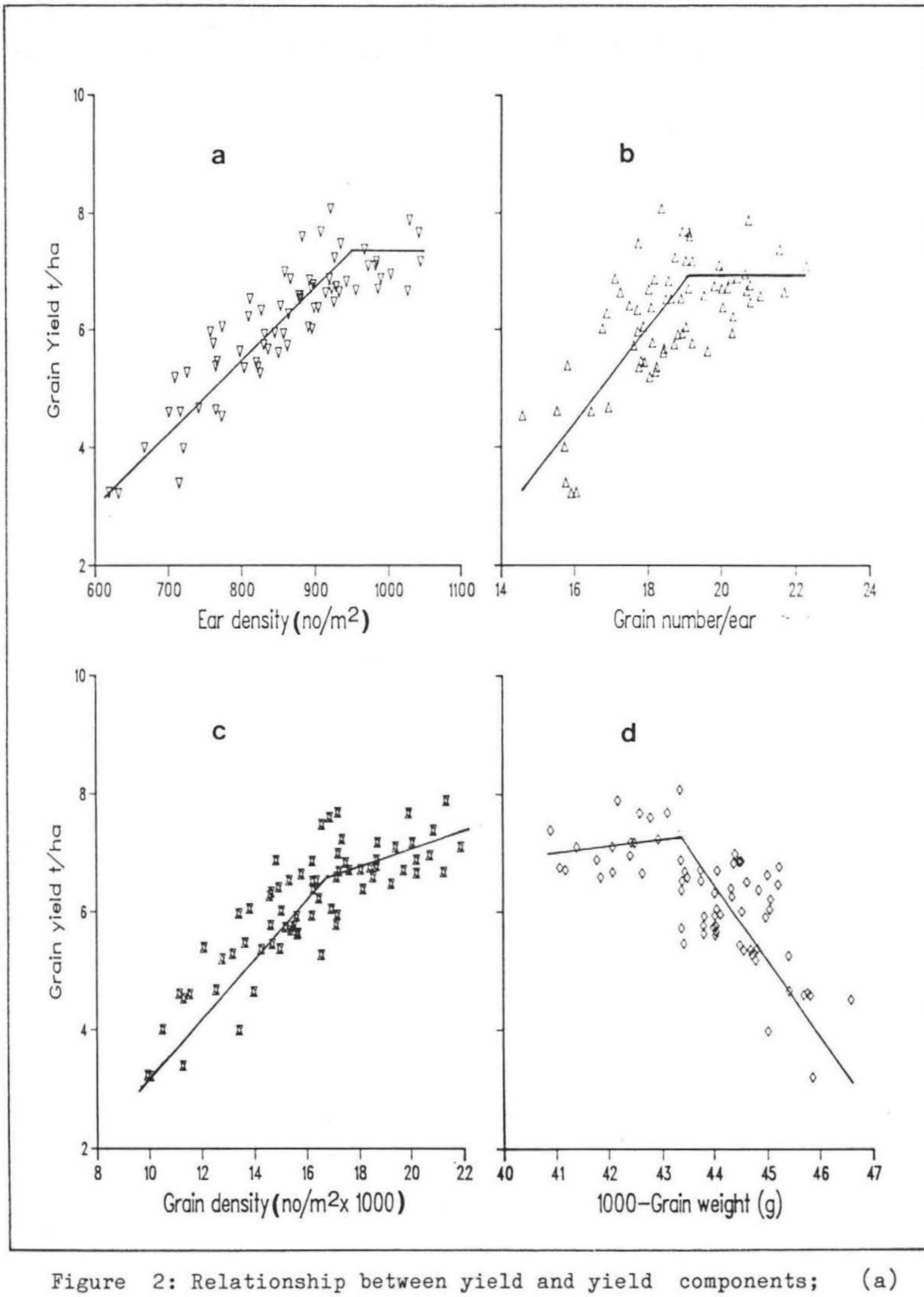

Figure 2: Relationship between yield and yield components; (a) ear density, (b) grain number/ear, (c) grain density and (d) 1000-grain weight. (All lines fitted by eye).

19 grains/ear. Combination of both components as grain density (grain number/m^2) similarly shown the positive relationship with yield. Grain weight is optimum at about 40mg, below which yield declined.

4.6. YIELD COMPONENTS INTERACTION

Analyses of yield components interaction by partial correlation at various sites are shown in Figure 3.

Grain number/ear showed a positive interaction with ear density at all sites and significantly correlated at sites 2 - 4. Grain weight however was negatively or non-significantly correlated with other components.

4.7. TILLERING AND EAR DENSITY

4.7.1. Tiller Production

At all sites, total tillers rapidly increased to a maximum at about 50 DAS then declined to an almost stabilised number at 80 DAS (Figure 4).

Cropping history mainly affected the rate and duration of tiller production. On first and second crops, tiller density rapidly increased after 31 DAS (harvest 1) but on third and fourth crops tiller production had almost ceased by that period, especially on plots which received nitrogen after sowing (60E, 60L and 60SP) or when applied at low rate at sowing (60B). Rate of tiller reduction after the maximum tended to decrease with increasing years of cropping.

Nitrogen application at sowing (60B and SOILT) boosted earlier tiller production and produced significantly higher maximum tiller density than control. Effectiveness of nitrogen application after sowing to increase number decreased from site 1 to site 4.

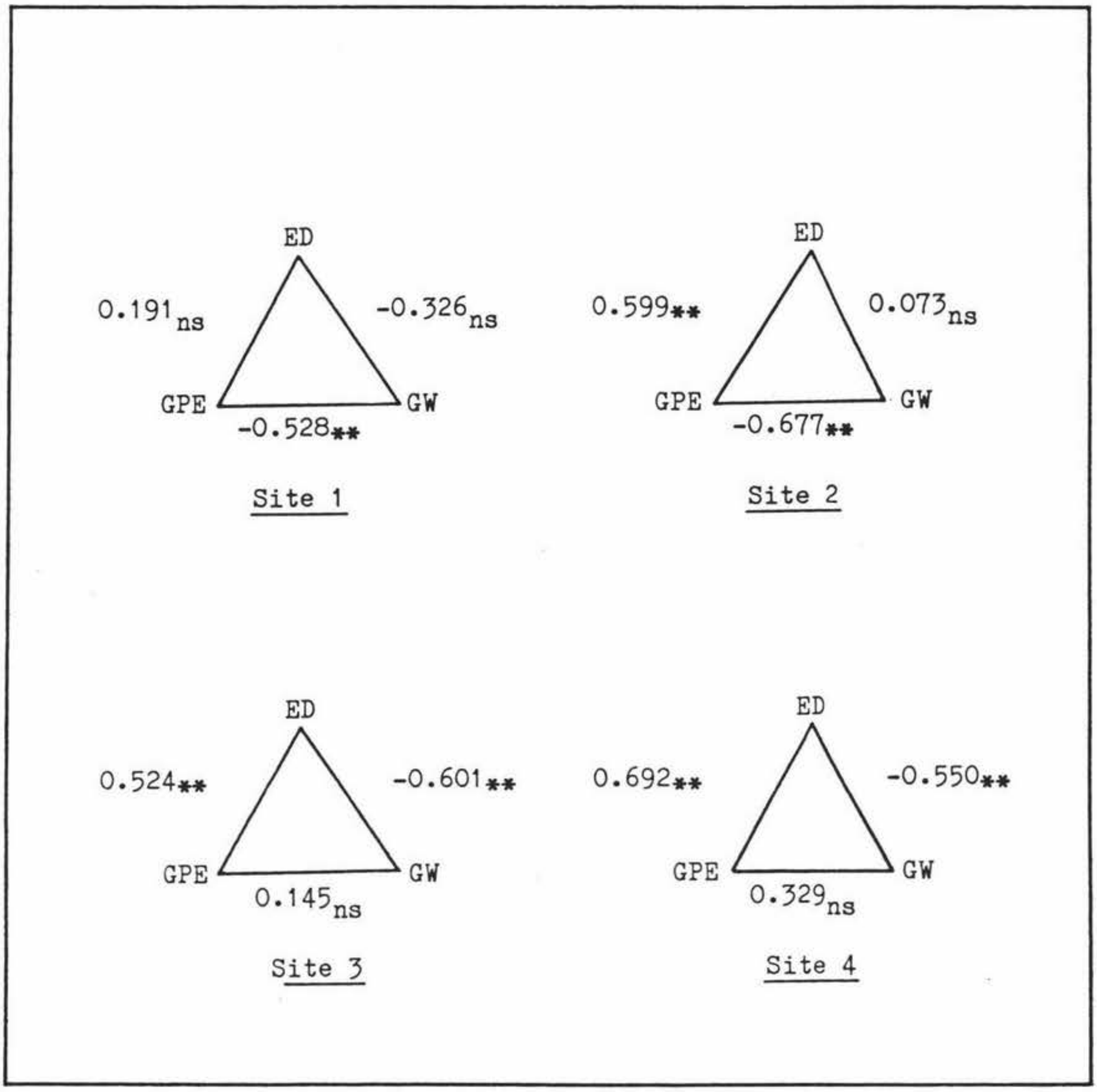

Figure 3: Partial correlations between yield and yield components at each site. ED: ear density, GPE: grain number/ear, GW: 1000-grain weight.

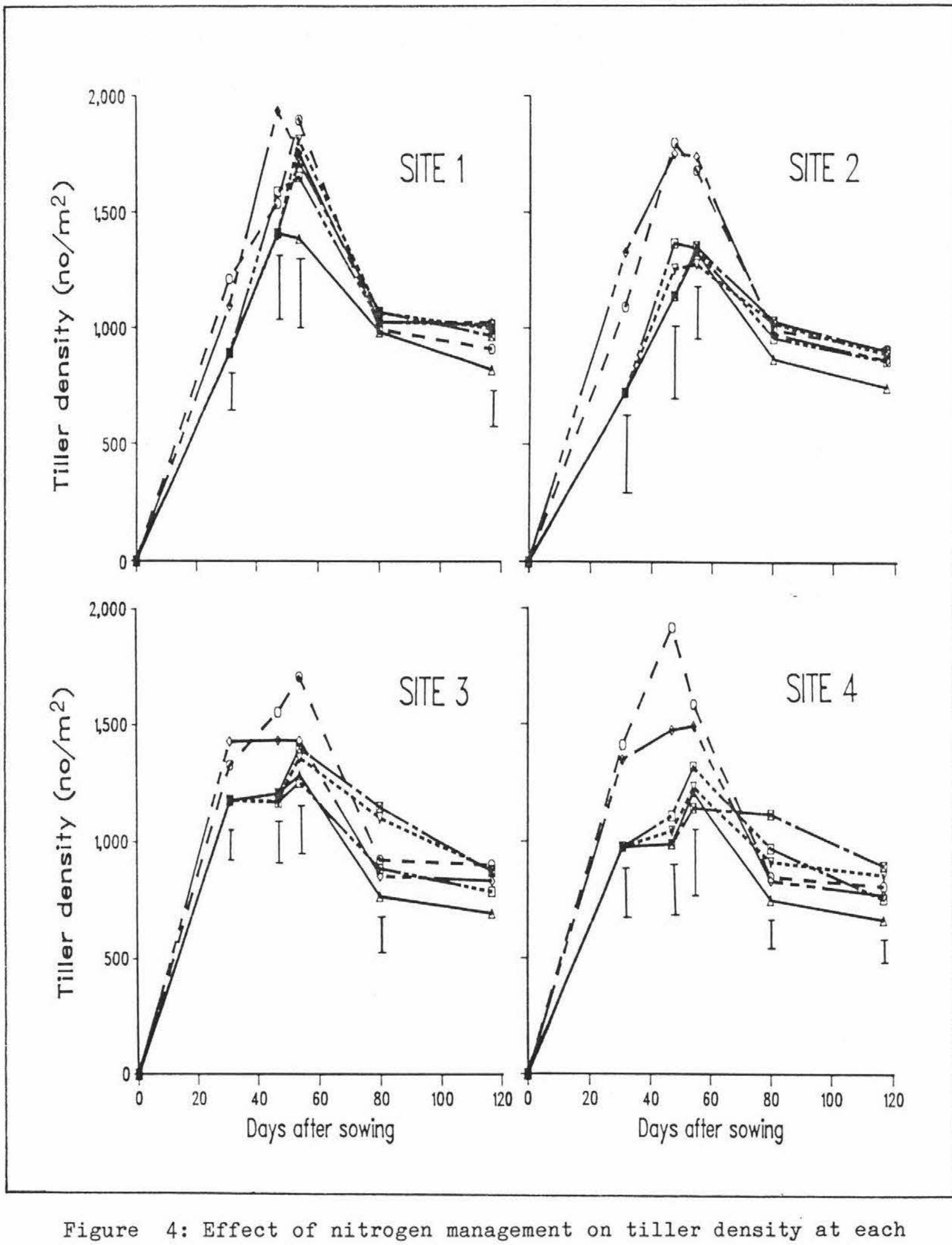

Figure 4: Effect of nitrogen management on tiller density at each site. (△——△) CONT, (◇– – –◇) 60B, (□——····□) 60E, (⊠————·⊠) 60L, (○– – –○) SOILT, (▽········▽) 60SP. (Vertical bars: LSD 5%).

Partitioning of tillers into various sizes according to fresh weight at harvests 2 and 3 showed that the largest tillers were highest at site 1 and decreased to site 4 (Figure 5). At both harvests at site 2 - 4 almost half of the tillers comprised of small tillers (<1.0 g at harvest 2 and <2.0 g at harvest 3).

The effects of nitrogen treatments on the number of largest tillers at harvests 2 and 3 are shown in Table 9. Except at site 1, nitrogen application at sowing (60B and SOILT) increased the number of the largest tillers. Application of nitrogen after sowing gave no significant effect on the number of largest tillers.

4.7.2. Tiller survival

Tiller survival is defined as the number of ears as a proportion of the maximum tiller number.

The number of dead tillers were highest in the first crop (site 1) and decreased with increasing years of cropping toward site 4 (Table 10). At site 1, nitrogen application gave no significant effect on tiller death eventhough in tended to increase. At other sites nitrogen application at sowing (60B and SOILT) that promoted tiller production subsequently results in higher amount of tiller death compared to other treatments.

Average tiller survival over all treatments tended to increase from site 1 to site 4 (Table 11). Application of nitrogen at sowing (60B and SOILT) generally gave the lowest tiller survival at all sites. Nitrogen application after sowing (60E, 60L and 60SP) increased tiller survival and the effectiveness of these treatments particularly treatments 60L and 60SP in maintaining high tiller survival increased with increasing years of cropping to site 4.

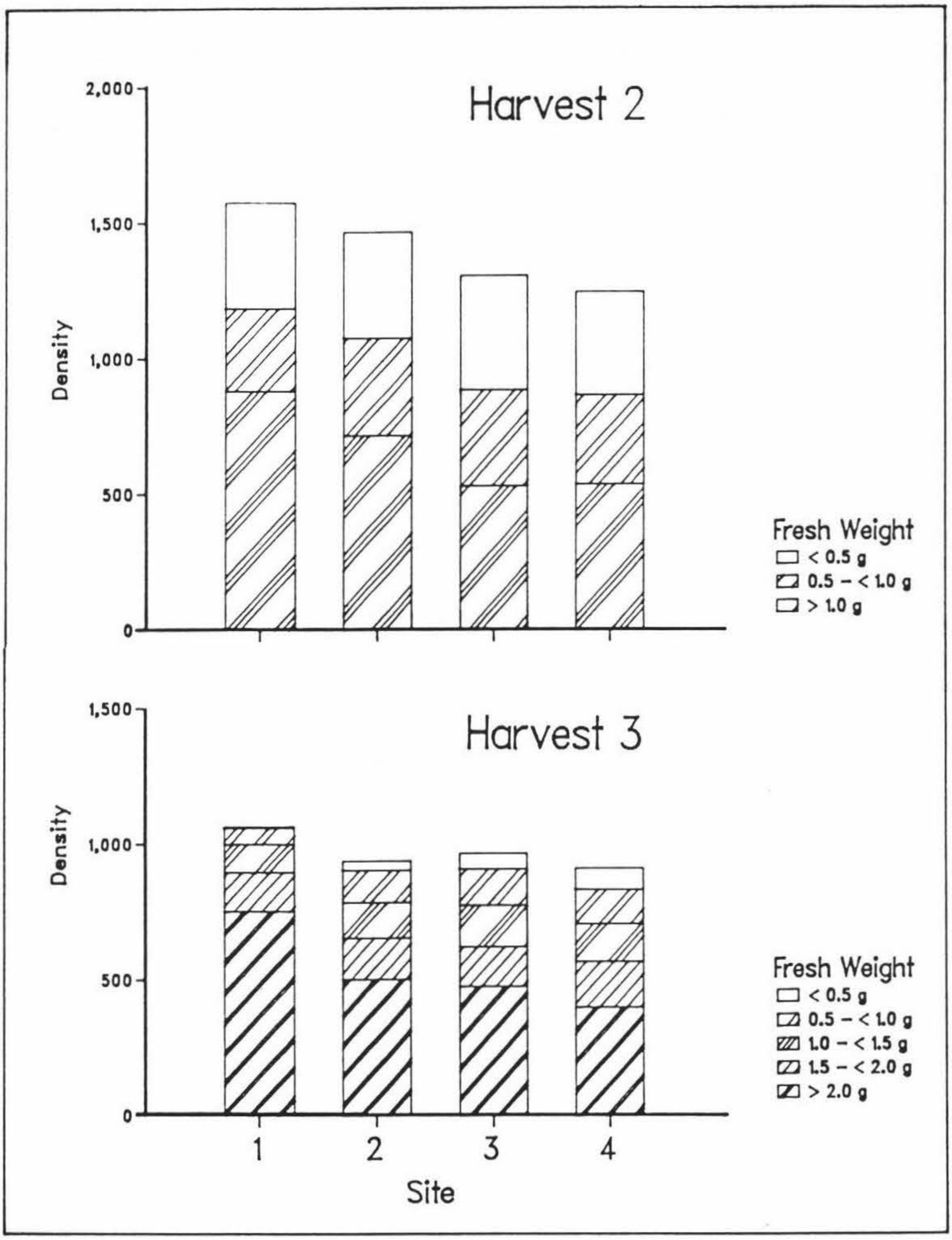

Figure 5: Average tiller size at harvest 2 (G.S.6) and harvest 3 (G.S.8) across the sites.

Table 9: Effect of nitrogen managenent on number of largest largest tillers at harvest 2 (> 1 g fresh wt.) and harvest 3 (> 2 g fresh wt.).

Site	Treatment	Harvest 2 (G.S.6)	Harvest 3 (G.S.8)
Site 1	CONT.	709 a	544 a
	60B	1124 a	756 a
	60E	922 a	774 a
	60L	-	780 a
	SOILT	865 a	884 a
	60SP	786 a	785 a
	Mean	881	754
	C.V.(%)	18	16
Site 2	CONT.	513 a	329 a
	60B	923 b	637 a
	60E	618 a	525 a
	60L	-	544 a
	SOILT	905 b	583 a
	60SP	620 a	400 a
	Mean	716	503
	C.V.(%)	20	25
Site 3	CONT.	408 a	335 a
	60B	671 b	535 c
	60E	420 a	431 ab
	60L	-	414 ab
	SOILT	735 b	668 d
	60SP	424 a	471 bc
	Mean	532	476
	C.V.(%)	16	11
Site 4	CONT.	393 a	204 a
	60B	681 b	557 b
	60E	438 a	332 a
	60L	-	346 a
	SOILT	783 b	557 b
	60SP	401 a	396 a
	Mean	539	399
	C.V.(%)	9	18

At each site, the number within column followed by same letter is not significantly different by LSD test at 5%.

Table 10: Effect of nitrogen management on number of dead tiller/m^2 at harvest 3 (80 DAS)

Treatment	Site 1	Site 2	Site 3	Site 4
CONT	469 a	461 a	442 ab	324 a
60B	736 a	724 b	537 bc	511 b
60E	594 a	426 a	287 a	377 a
60L	547 a	429 a	349 ab	302 a
SOILT	792 a	740 b	701 c	660 b
60SP	702 a	338 a	330 a	306 a
mean	640	570	441	413
C.V. (%)	18	12	21	16

The number within column followed by same letter is not significantly different by LSD test at 5% .

Table 11: Effect of nitrogen management on tiller survival (% of ear over the maximum tillers).

Treatment	tiller survival (%) Site 1	Site 2	Site 3	Site 4
CONT.	58 a	67 abc	57 a	68 b
60B	53 a	50 a	59 a	53 a
60E	65 bc	63 ab	68 bc	68 b
60L	63 abc	81 c	74 c	92 c
SOILT	62 ab	51 a	58 a	50 a
60SP	71 c	73 bc	75 c	82 c
Mean	62	64	65	69
C.V.(%)	9	15	7	11

The number within column followed by same letter is not significantly different by LSD test at 5% .

The overall relationship between tiller survival and maximum tillers (MT) was described by the following equation:

$$\text{Tiller survival (TS;\%)} = 15.326 + 65093MT^{-1} \qquad ....(6)$$

$$r^2 = 0.679^{**}$$

This relationship is shown in Figure 6. Tiller survival decreased with increasing maximum tiller number.

Introducing nitrogen uptake at various harvests and periods by multiple stepwise regression into the above equation (6) showed that nitrogen uptake before and after the period of maximum tillering substantially improved the relationships. The relationships are shown by equation 7 and 8:

$$TS = -9.988 + 81554MT^{-1} + 1.906NUP13 \qquad ....(7)$$
$$r^2 = 0.820^{**}$$

$$TS = -1.342 + 71050MT^{-1} + 1.545NUP13 + 0.802NUP24 \qquad ....(8)$$
$$r^2 = 0.856^{**}$$

Where:

NUP13 = Nitrogen uptake between harvest 1 and harvest 3 (G.S.3-G.S.8) (g/m^2).

NUP24 = Nitrogen uptake netween harvest 2 and harvest 4 (G.S.6-G.S.10.2) (g/m^2).

The relatioship showed that NUP13 contributes most to the tiller survival and further uptake (NUP24) improves the survival of tillers.

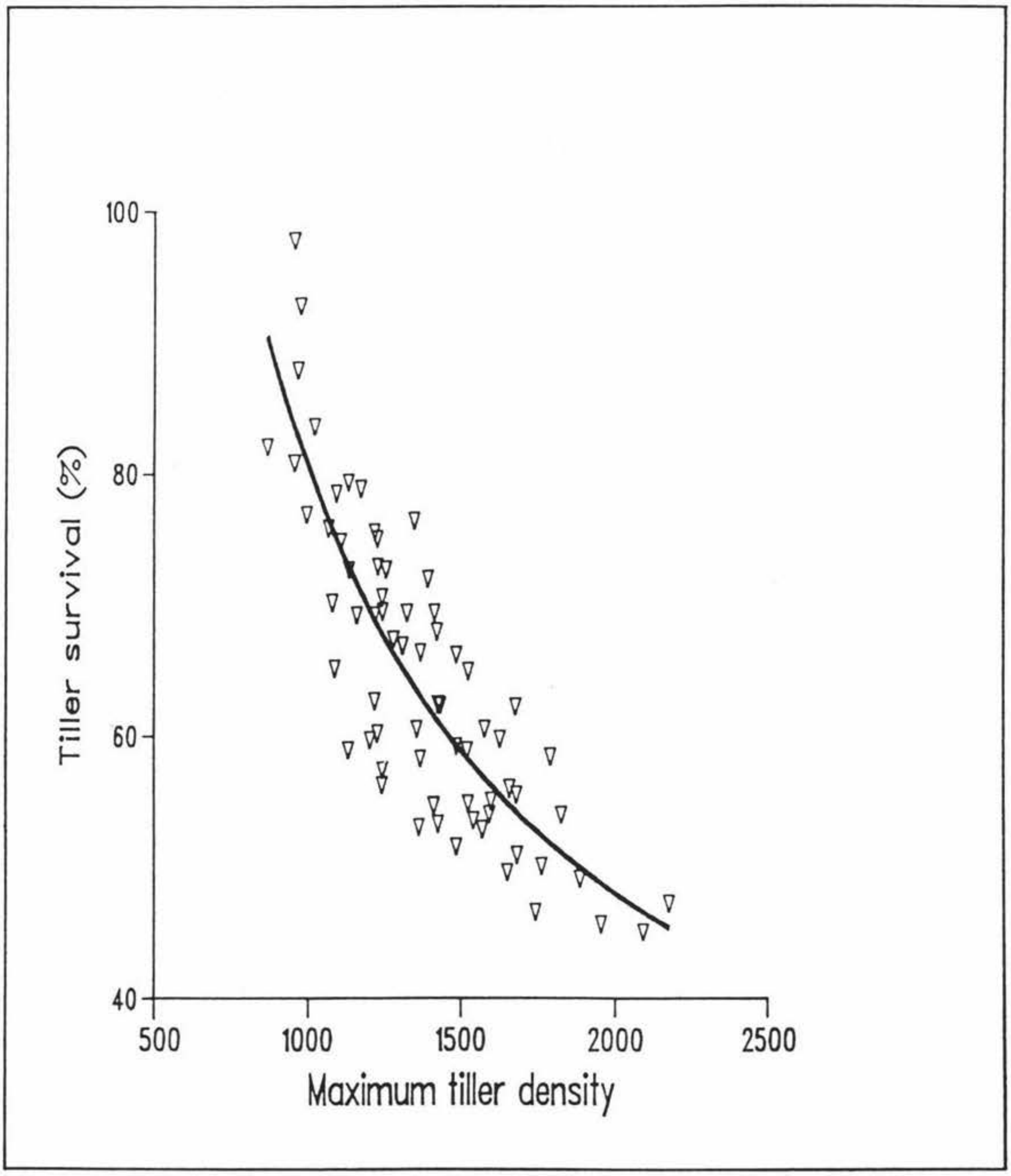

Figure 6: Overall relationship between tiller survival and maximum tiller density. Regression: $y = 15.33 + 65093x^{-1}$, $r^2=0.679^{**}$.

4.8. LEAF AREA, DRY MATTER PRODUCTION AND YIELD

4.8.1. Maximum Leaf Area Index (LAI)

The pattern of leaf area development was similar to the pattern of tillering. At all sites and all harvests, leaf area index were highly correlated with tiller density. The overall correlation coeficients for harvest 1, harvest 2, harvest 3 and harvest 4 were 0.939^{**}, 0.936^{**}, 0.896^{**} and 0.583^{**} respectively. Maximum LAI was achived at the same period of maximum tiller density (50DAS).

The effect of nitrogen treatments on maximum LAI at various sites are shown in Table 12. On all treatments the maximum was highest at site 1 and decreased to site 4. Nitrogen application at sowing (60B and SOILT) significantly increased the maximum LAI over the control at all sites. The effect of other treatments on maximum LAI tended to decrease with increasing years of cropping.

4.8.2. Total Dry Matter

Total dry matter (TDM) accumulation occured in the normal sigmoid pattern (Figure 7). After an initial slow growth, dry matter rapidly increased until about 80 DAS with differences in TDM at that stage being largely reflected in final TDM. Control plots had generally lower TDM than nitrogen-treated plots.

At sites 1 and 2, nitrogen significantly increased leaf dry weight relative to it effect on stem. At sites 3 and 4, nitrogen increased both leaf and stem particularly toward later stages of growth (Data not shown). Total dry matter and its components at harvest 4 (80 DAS) are shown in Table 13. The effect of nitrogen application in increasing stem, ear and total dry weight increased from site 1 to site 4.

Table 12: Effect of nitrogen management on maximum Leaf Area Index.

Treatment	maximum leaf area index			
	Site 1	Site 2	Site 3	Site 4
CONT.	3.51 a	2.49 a	2.36 a	1.99 a
60B	6.22 b	4.92 bc	3.78 d	3.76 c
60E	5.03 b	3.74 b	2.74 ab	2.62 b
60L	5.06 b	3.20 a	3.13 bc	2.30 ab
SOILT	6.02 b	5.06 c	4.63 c	4.18 c
60SP	5.33 b	3.17 a	3.66 cd	2.57 ab
Mean	5.19	3.76	3.38	2.90
C.V.(%)	16	15	9	10

The number within column followed by same letter is not significantly different by LSD test at 5% .

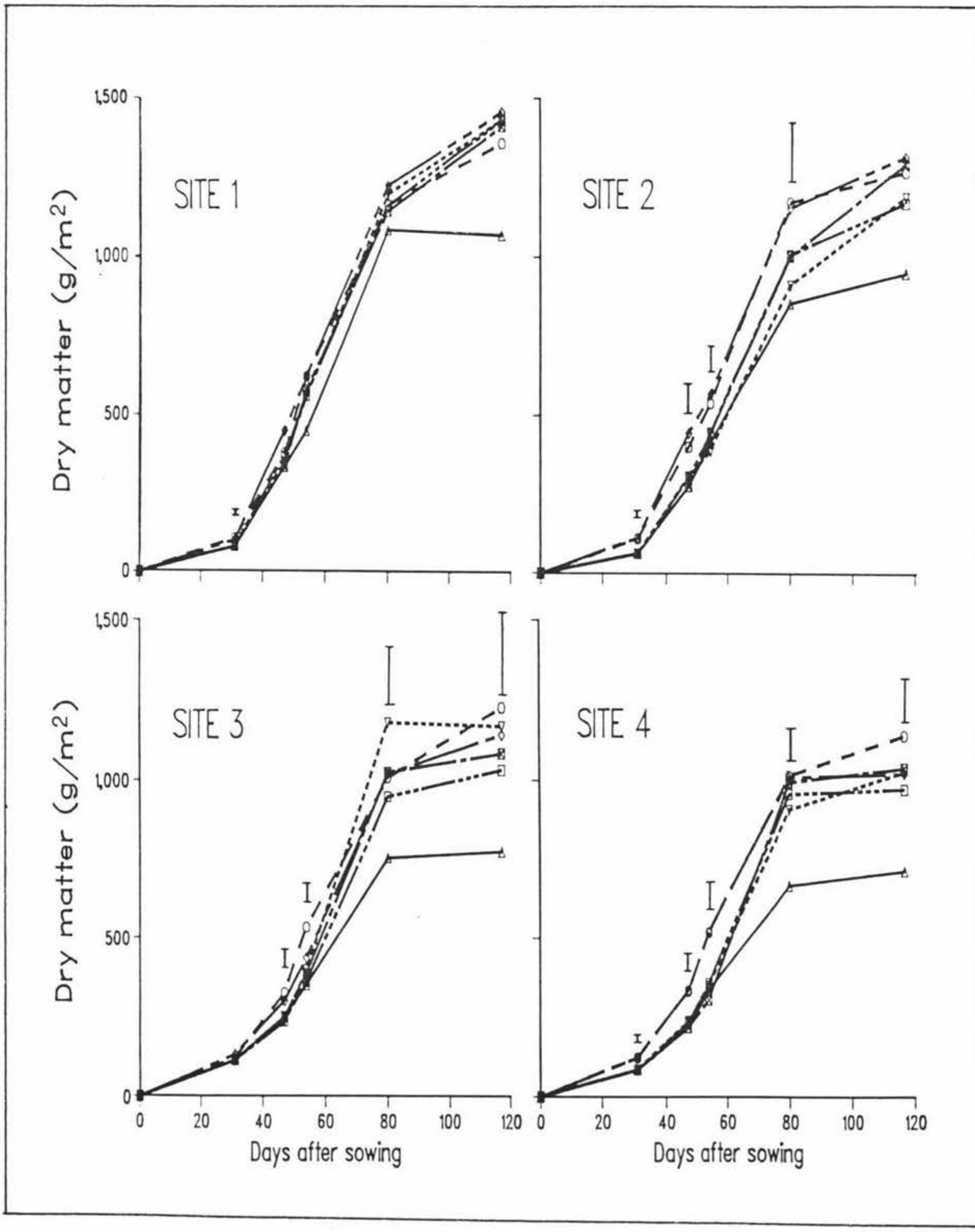

Figure 7: Effect of nitrogen management on total dry matter accumulation at each site. (△——△) CONT, (◇– – –◇) 60B, (□—···□) 60E, (⊠——-⊠) 60L, (○– – –○) SOILT, (▽·······▽) 60SP. (Vertical bars: LSD 5%)

Table 13: Effect of nitrogen management on components of dry matter (g/m2) at harvest 4 (G.S.10.2).

Site	treatment	dry matter components leaf	stem	ear	total
Site 1	CONT.	56 a	570 a	278 a	904 a
	60B	82 b	624 a	309 ab	1015 a
	60E	78 b	590 a	329 b	997 a
	60L	76 b	567 a	354 b	997 a
	SOILT	87 b	586 a	294 a	967 a
	60SP	85 b	597 a	366 b	1048 a
	Mean	77	589	322	988
	C.V.(%)	19	9	9	9
Site 2	CONT.	38 a	449 a	241 a	728 a
	60B	60 b	580 a	342 b	982 b
	60E	50 b	493 a	332 b	875 ab
	60L	58 b	479 a	349 b	886 ab
	SOILT	65 b	584 a	339 b	988 b
	60SP	53 b	456 a	292 ab	801 a
	Mean	54	507	316	877
	C.V.(%)	21	12	10	10
Site 3	CONT.	34 a	368 a	248 a	650 a
	60B	52 b	518 bc	286 b	856 b
	60E	50 ab	450 ab	344 d	844 b
	60L	60 b	491 bc	372 e	923 bc
	SOILT	49 ab	476 b	313 c	838 b
	60SP	64 b	593 c	378 e	1035 c
	Mean	52	483	324	858
	C.V.(%)	16	11	11	9
Site 4	CONT.	28 a	317 a	238 a	583 a
	60B	40 bc	487 c	342 b	869 b
	60E	35 ab	419 b	389 bc	843 b
	60L	46 c	445 bc	401 c	892 b
	SOILT	43 bc	469 bc	371 b	883 b
	60SP	35 ab	408 b	377 bc	820 b
	Mean	38	424	353	815
	C.V.(%)	12	8	8	8

At each site, the number within column followed by same letter is not significantly different by LSD test at 5% .

4.8.3. Dead Material

Death of plant parts did not occur until after harvest 1 (G.S.3). The amount of dead material at harvests 2, 3 and 4 are shown in Table 14. Highest amount of dead material was recorded at harvest 4 (G.S.10.2). Nitrogen application had no significant effect on death of plant parts at harvest 2 (G.S.6). Thereafter, nitrogen application at sowing (60B and SOILT) increased the amount of dead material. Other nitrogen treatments generally had no significant effect on death of plants.

4.8.4. Relationship Between Maximum LAI, TDM and Yield

Examination of the overall relationship between maximum LAI and grain yield showed that yield increased with increasing maximum LAI to about 7 t/ha at LAI value of 5 (Figure 8). The higher LAI value was only obtained on nitrogen-treated plot on paddock out of pasture (site 1) (Table 12).

Nitrogen application at all sites give no significant effect on harvest index (HI). The average HI was similar for site 1 to site 4 (0.51, 0.53, 0.53, 0.56 respectively).

Correlation between yield and total dry matter at harvest 4, final harvest and the dry matter increased after harvest 4 are shown in Table 15. At all sites, grain yields were significantly correlated with all the above dry matter parameters.

Multiple stepwise regression of pooled data between yield and total dry matter at harvest 4 and subsequent dry matter increases to maturity shown by the following equations:

$$\text{Yield} = 0.712 + 0.0061\text{DM4} \qquad r^2 = 0.622^{**} \qquad \ldots\ldots (9)$$

$$\text{Yield} = 0.638 + 0.0235\text{DM4} + 0.0025\text{DM45} \qquad r^2 = 0.740^{**} \qquad \ldots\ldots (10)$$

Table 14: Effect of nitrogen managements on the amount of plant dead materials (g/m^2).

Site	N-trmt	Harvest 2 (G.S.6)	Harvest 3 (G.S.8)	Harvest 4 (G.S.10.2)
Site 1	CONT.	22 a	81 ab	179 b
	60B	29 b	131 c	208 c
	60E	20 a	90 ab	163 a
	60L	-	72 a	146 a
	SOILT	22 a	110 bc	196 bc
	60SP	19 a	80 ab	149 a
	Mean	22.4	94.0	173.5
	C.V.(%)	12.0	20.3	8.6
Site 2	CONT.	27 a	81 b	130 a
	60B	26 a	124 c	174 bc
	60E	21 a	56 ab	134 ab
	60L	-	55 ab	118 a
	SOILT	30 a	122 c	188 c
	60SP	25 a	46 a	114 a
	Mean	25.8	80.7	143.0
	C.V.(%)	20.4	18.0	18.4
Site 3	CONT.	28 a	59 bc	102 a
	60B	20 a	69 c	163 b
	60E	19 a	33 a	103 a
	60L	-	39 ab	101 a
	SOILT	26 a	99 c	171 b
	60SP	19 a	34 a	143 ab
	Mean	22.4	55.5	130.5
	C.V.(%)	22.1	22.2	19.1
Site 4	CONT.	26 a	53 ab	81 a
	60B	36 a	81 b	139 c
	60E	17 a	38 a	111 abc
	60L	-	32 a	100 ab
	SOILT	34 a	133 c	129 bc
	60SP	24 a	32 a	86 a
	Mean	27.4	61.5	107.7
	C.V.(%)	28.4	34.8	17.5

At each site, the number within column followed by same letter is not significantly different by LSD test at 5% .

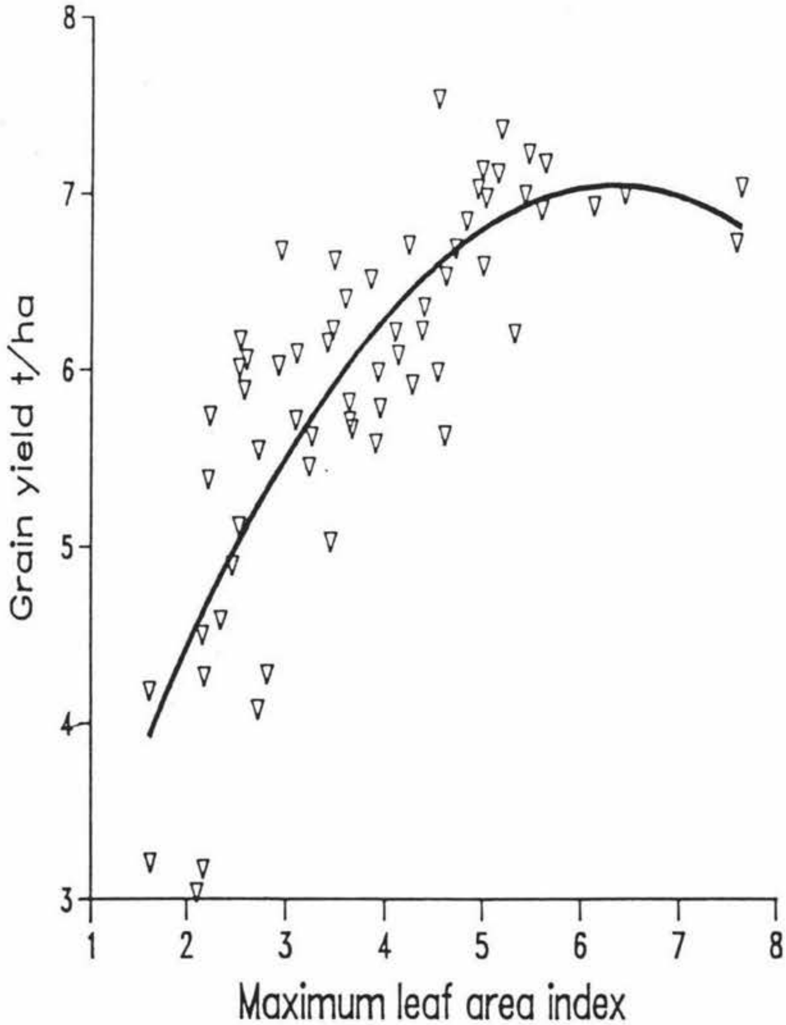

Figure 8: Overall relationship between grain yield and maximum leaf area index. Regression: $y = 1.453 + 1.767x - 0.140x^2$, $r^2=0.671^{**}$.

Table 15: Partial correlations coefficients between grain yield and total dry matter at harvest 4, dry matter increase after harvest 4 and simple correlation between yield and dry matter at final harvest.

Site	Partial correlation		simple correlation
	harvest 4	increase after harvest 4	final harvest
Site 1	0.449 *	0.733 **	0.720 **
Site 2	0.751 **	0.660 **	0.794 **
Site 3	0.806 **	0.661 **	0.824 **
Site 4	0.838 **	0.531 *	0.804 **

$$\text{Yield} = -6.816 + 0.0235DM_4 + 0.0022DM45 - 0.000011DM4^2 \quad \ldots\ldots (11)$$

$$r^2 = 0.806^{**}$$

where: DM4 = dry matter at harvest 4 (g/m^2)
DM45 = dry matter increased after harvest 4 (g/m^2)

This relationships indicated that the amount accumulated dry matter at harvest 4 (ear emergence) is important for grain yield, further increase in dry matter to maturity increased improve the yield. However very high dry matter at ear emergence may decrease the yield.

4.9. NITROGEN CONCENTRATION AND UPTAKE

4.9.1. Nitrogen Concentration (% dry matter)

Nitrogen concentration decreased as growth progressed (Table 16). Nitrogen application after sowing however generally increased the concentration compared to the control plots.

All nitrogen treated plots generally increased N concentration over the control until Harvest 3 (G.S.8). At harvest 4 (G.S.10.2), late nitrogen application (60L and 60SP) maintained significantly higher concentration over the control at all sites. The effectiveness of early nitrogen application (60B, 60E and SOILT) to maintain higher nitrogen concentration tended to decrease as cropping increased toward site 4.

Increasing rate of nitrogen application (SOILT) from site 1 to site 4 gave no obvious differences in tiller nitrogen concentration across the sites at all harvests.

4.9.2. Nitrogen Uptake

The pattern of total nitrogen uptake up to harvest 4 (80 DAS) are shown in Figure 9.

Table 16: Effect of nitrogen treatments on tiller nitrogen concentration (% dry matter).

Site	treatment	harvest 1	harvest 2	Harvest 3	Harvest 4
Site 1	CONT.	3.13 a	2.02 a	1.60 a	0.60 a
	60B	4.39 b	2.68 b	2.22 b	0.88 b
	60E	-	2.46 b	2.31 b	0.85 b
	60L	-	-	2.49 b	1.05 c
	SOILT	4.25 b	2.56 b	2.25 b	0.95 bc
	60SP	-	2.35 ab	2.31 b	1.09 c
	Mean	3.92	2.41	2.20	0.90
	C.V.(%)	7	9	10	10
Site 2	CONT.	2.81 a	1.66 a	1.37 a	0.60 a
	60B	4.49 b	2.50 b	2.05 b	0.71 ab
	60E	-	2.17 b	2.17 b	0.84 b
	60L	-	-	2.14 b	1.09 c
	SOILT	4.39 b	2.53 c	2.31 b	0.78 ab
	60SP	-	2.14 b	2.21 b	1.11 c
	Mean	3.90	2.20	2.04	0.86
	C.V.(%)	10	7	10	14
Site 3	CONT.	3.13 a	1.77 a	1.58 a	0.62 a
	60B	3.80 b	2.54 c	2.08 b	0.75 ab
	60E	-	2.35 bc	2.31 bc	0.83 b
	60L	-	-	2.36 bc	1.29 c
	SOILT	4.23 b	2.79 c	2.52 c	0.93 b
	60SP	-	1.94 ab	2.50 c	0.91 b
	Mean	3.72	2.28	2.23	0.89
	C.V.(%)	5	9	9	12
Site 4	CONT.	2.50 a	1.69 a	1.36 a	0.70 a
	60B	3.78 b	2.27 bc	1.81 b	0.74 a
	60E	-	2.16 bc	2.27 c	0.80 a
	60L	-	-	2.72 d	1.10 b
	SOILT	4.27 b	2.49 c	2.27 c	0.72 a
	60SP	-	1.87 ab	2.36 c	0.83 b
	Mean	3.52	2.10	2.13	0.82
	C.V.(%)	8	11	10	11

At each site, the number within column followed by same letter is not significantly different by LSD test at 5% .

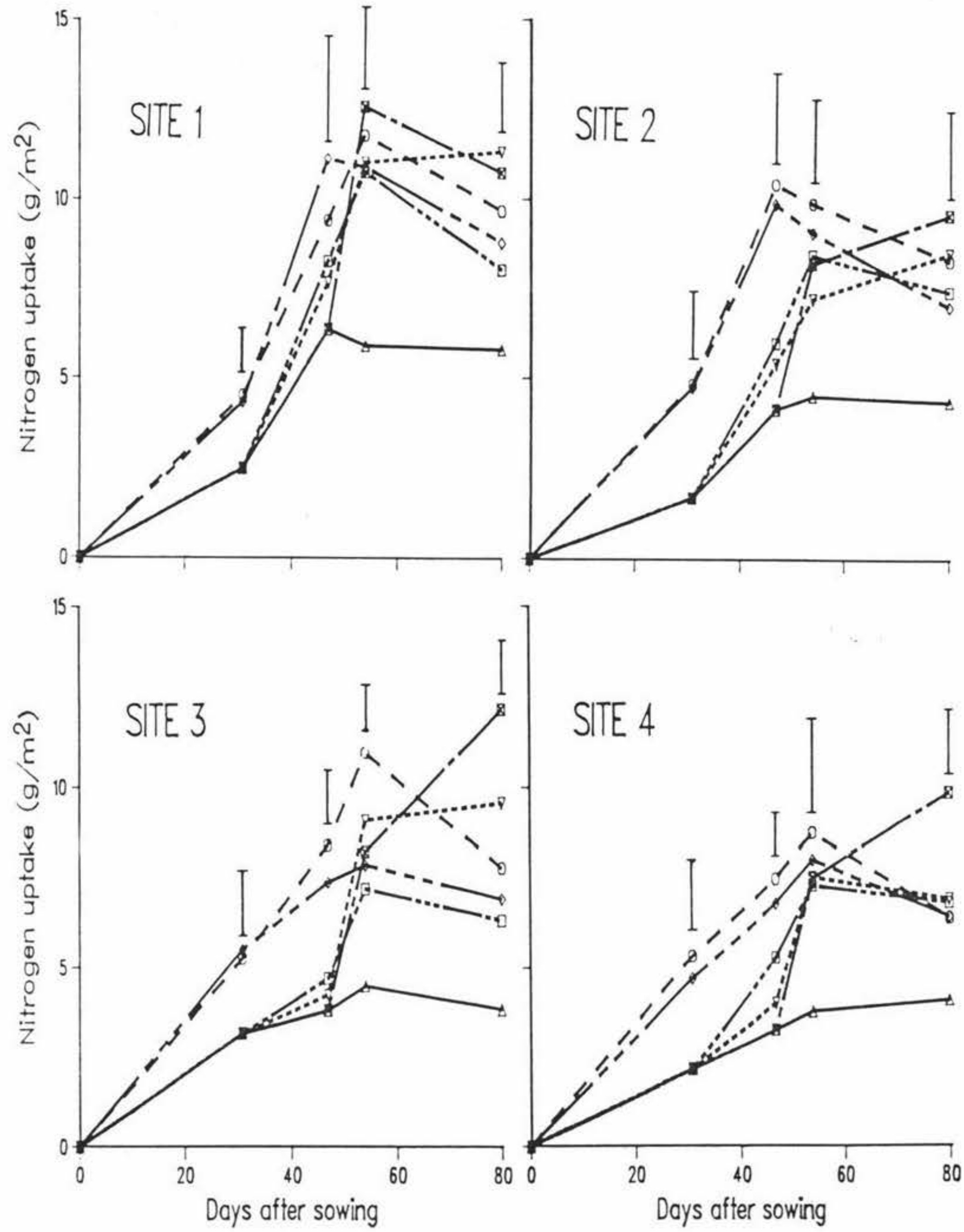

Figure 9: Effect of nitrogen management on total nitrogen uptake at each site. (△——△) CONT, (◇- - -◇) 60B, (□—··□) 60E, (⊠——·⊠) 60L, (○- - -○) SOILT, (▽·······▽) 60SP. (Vertical bars: LSD 5%)

At all sites, application of nitrogen at sowing (60B and SOILT) promoted nitrogen uptake at earlier stages of growth. At 54 DAS these treatments were generally not significantly different from plots that received nitrogen after sowing. The rate of uptake after the later application rapidly increased. Treatments involving late nitrogen application (60L and 60SP), particularly split application (60SP), tend to maintain high nitrogen uptake up to harvest 4 (80 DAS).

Section 4.7.2 indicated that nitrogen uptake between harvest 1 and 3 (NUP13) and between harvest 2 and 4 (NUP24) contributed to the survival of tillers. Examining nitrogen uptake within those period show that NUP13 was highest at site 1 and dropped sharply at site 2 with showed a smaller differences to sites 3 and 4. At sites 1 and 2, NUP13 on all nitrogen-treated plots were significantly higher than control. At site 3, only plants receiving late nitrogen application (60L and 60SP) and higher nitrogen rate (SOILT) had significantly higher uptake than control. At site 4, there was no significant differences between the treatments (Table 17).

Nitrogen uptake between harvest 2 and 4 (NUP24) (Table 18) was highest on plots receiving nitrogen after sowing (60E, 60L and 60SP) and significantly higher over other treatments at sites 2, 3 and 4. Uptake of nitrogen on plants that received nitrogen at sowing (60B and SOILT) tended to decrease by this period.

4.9.4. Sap Nitrate

At all sites on all related treatments, stem sap nitrate concentration showed an increase from 16 DAS to a maximum at 22 DAS, then steadily decreased and dropped rapidly after 37 DAS to a level that could not be detected by the test. The maximum level and period during which nitrate could be detected varied between sites and treatments (Figure 10).

Table 17: Effect of nitrogen treatments on total nitrogen uptake between harvest 1 (G.S. 3) and harvest 3 (G.S. 8)

	Total nitrogen uptake (g/m2)			
Treatment	Site 1	Site 2	Site 3	Site 4
CONT	4.58 a	3.93 a	2.22 a	2.30 a
60B	9.50 b	6.89 b	3.79 ab	4.73 a
60E	10.40 b	7.98 b	4.70 abc	5.92 a
60L	11.84 b	7.74 b	5.94 bcd	6.13 a
SOILT	9.78 b	7.66 b	8.22 d	6.50 a
60SP	10.42 b	6.60 b	6.75 cd	6.06 a
Mean	9.42	6.80	5.27	5.27
C.V. (%)	19	20	23	30

The number within column followed by same letter is not significantly different by LSD test at 5%.

Table 18: Effect of nitrogen treatments on total nitrogen uptake between harvest 2 (G.S. 6) and harvest 4 (G.S.10.2)

	Total nitrogen uptake (g/m2)			
Treatment	Site 1	Site 2	Site 3	Site 4
CONT	-0.14 a	0.53 abc	0.34 a	0.95 abc
60B	1.45 a	-2.26 a	-0.01 a	-0.13 ab
60E	0.94 a	2.12 bcd	2.42 a	2.04 bc
60L	5.34 a	6.22 d	9.02 b	7.24 d
SOILT	1.52 a	-1.27 ab	0.12 a	-0.97 a
60SP	4.93 a	3.73 cd	6.17 b	3.16 c
Mean	2.34	1.51	3.01	2.05
C.V. (%)	47	46	29	39

The number within column followed by same letter is not significantly different by LSD test at 5% .

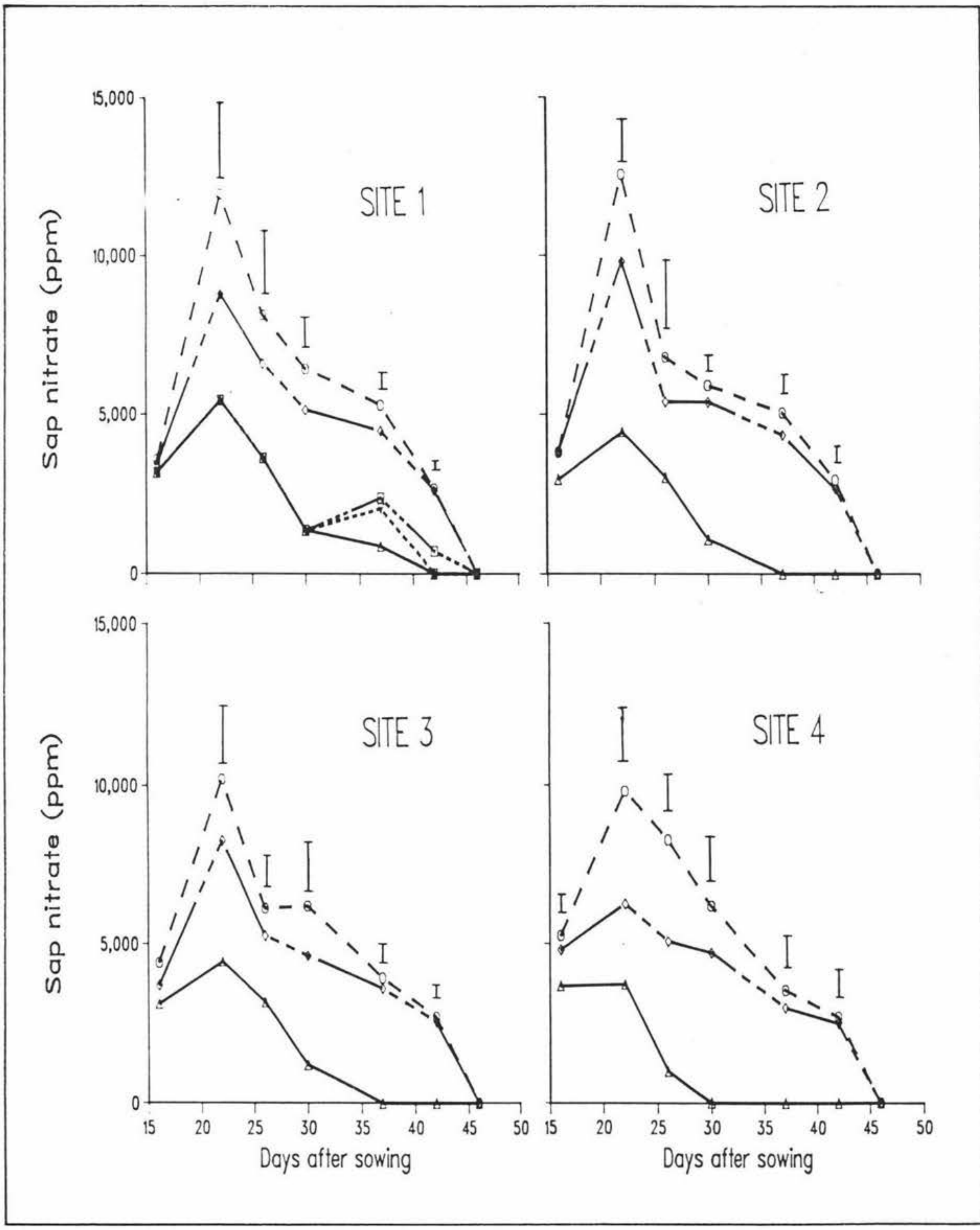

Figure 10: Effect of nitrogen management on sap nitrate concentration at various days after sowing at each site. (△——△) CONT, (◇- - -◇) 60B, (□——···□) 60E, (○- - -○) SOILT, (▽·······▽) 60SP. (Vertical bars: LSD 5%)

At all tests and all treatments, sap nitrate levels were generally higher at site 1 and decreased to site 4 except at 16 DAS, where plant at site 4 showed the highest concentration.

In control plots, maximum nitrate concentration was highest (5380 ppm) and was present for the longest duration (37 DAS) at site 1. At sites 2 and 3, peak nitrate levels were almost the same (4360 and 4440 ppm respectively) and nitrate was detected for the same period (30 DAS). At site 4, the maximum was only 3720 ppm and nitrate was present for the shortest period (26 DAS).

Application of nitrogen at sowing (60B and SOILT) significantly increased sap nitrate over the control at 22 to 44 DAS. The higher nitrogen rate (SOILT) generally give higher nitrate level than standard rate (60B). Nitrogen application after sowing failed to increase sap nitrate level over the control except at site 1, where nitrogen application at early tillering (60E and 60SP) increased sap nitrate at 37 DAS and this was maintained to 42 DAS for the 60E treatment.

4.9.5. Sap Nitrate and Tiller Nitrogen Concentration

Due to the limited sap test data available for the late nitrogen treatments (60E, 60L and 60SP), only CONTROL, and sowing nitrogen application treatments (60B and SOILT) are presented in this section.

Simple correlation of pooled data from all sites between sap nitrate and tiller nitrogen concentration are shown in Table 19. Sap nitrate concentration gave a good relationship with the tiller nitrogen concentration except for sap test at 16 DAS and nitrogen concentration at harvest 4 which gave a slightly lower coefficient value.

4.10. RELATIONSHIP BETWEEN NITROGEN TESTS AND YIELD

Nitrogen uptake and nitrogen concentration for the various harvests and were generally highly correlated with yield. Tiller

Table 19: Simple correlation coefficients between sap nitrate concentration (ppm) at various test dates (days after sowing, DAS) and tiller nitrogen concentration (% dry matter) at various harvests.

Sap test date	harvest 1 (G.S. 3)	harvest 2 (G.S. 6)	harvest 3 (G.S. 8)	harvest 4 (G.S. 10.2)
16 DAS	0.298 ns	0.435 **	0.439 **	0.283 ns
22 DAS	0.746 **	0.764 **	0.820 **	0.581 **
26 DAS	0.712 **	0.762 **	0.790 **	0.515 **
30 DAS	0.777 **	0.834 **	0.583 **	0.594 **
37 DAS	0.820 **	0.849 **	0.839 **	0.631 **
42 DAS	0.795 **	0.850 **	0.837 **	0.585 **

nitrogen concentration at harvest 1 ($r=0.901^{**}$) and leaf nitrogen at harvest 3 ($r=0.807^{**}$) gave the best relationship with grain yield (Figure 11). Grain yields were maximum (about 7 t/ha) at about 4.5% tiller nitrogen at harvest 1 and 3.7% leaf nitrogen at harvest 3.

The regression between maximum sap nitrate concentration and yield showed that grain yield rapidly increased with increasing sap nitrate until about 6000 ppm (Figure 12).

In control plots, the reduction in yield across the sites was similar to the pattern of maximum sap nitrate levels and total mineral nitrogen (Figure 13). Sap nitrate decreased from 5380 ppm at site 1 to 3720 ppm at site 4, while total mineral nitrogen from soil test decreased with much lower range; from 56 ppm at site 1 to 47.5 ppm at site 4.

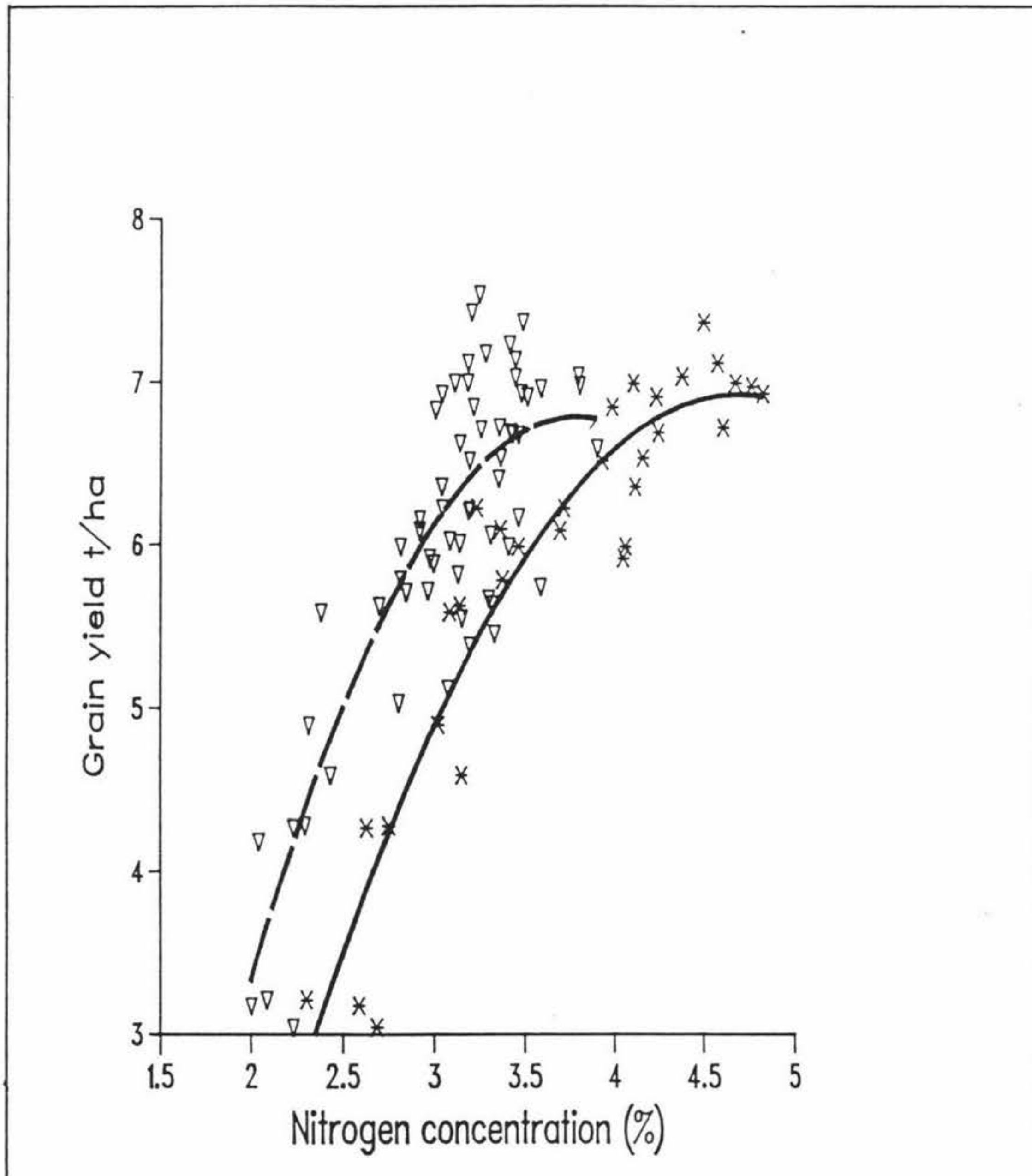

Figure 11: Overall relationship bewtween grain yield and nitrogen concentration (% dry matter). (a) Leaf nitrogen at harvest 3 (▽). Regression (— —): y = -8.69 + 8.17x - 1.079x^2, r^2=0.713**. (b) Tiller nitrogen at harvest 1 (✱). Regression (———): y = -8.80 + 6.71x - 0.716x^2, r^2=0.889**.

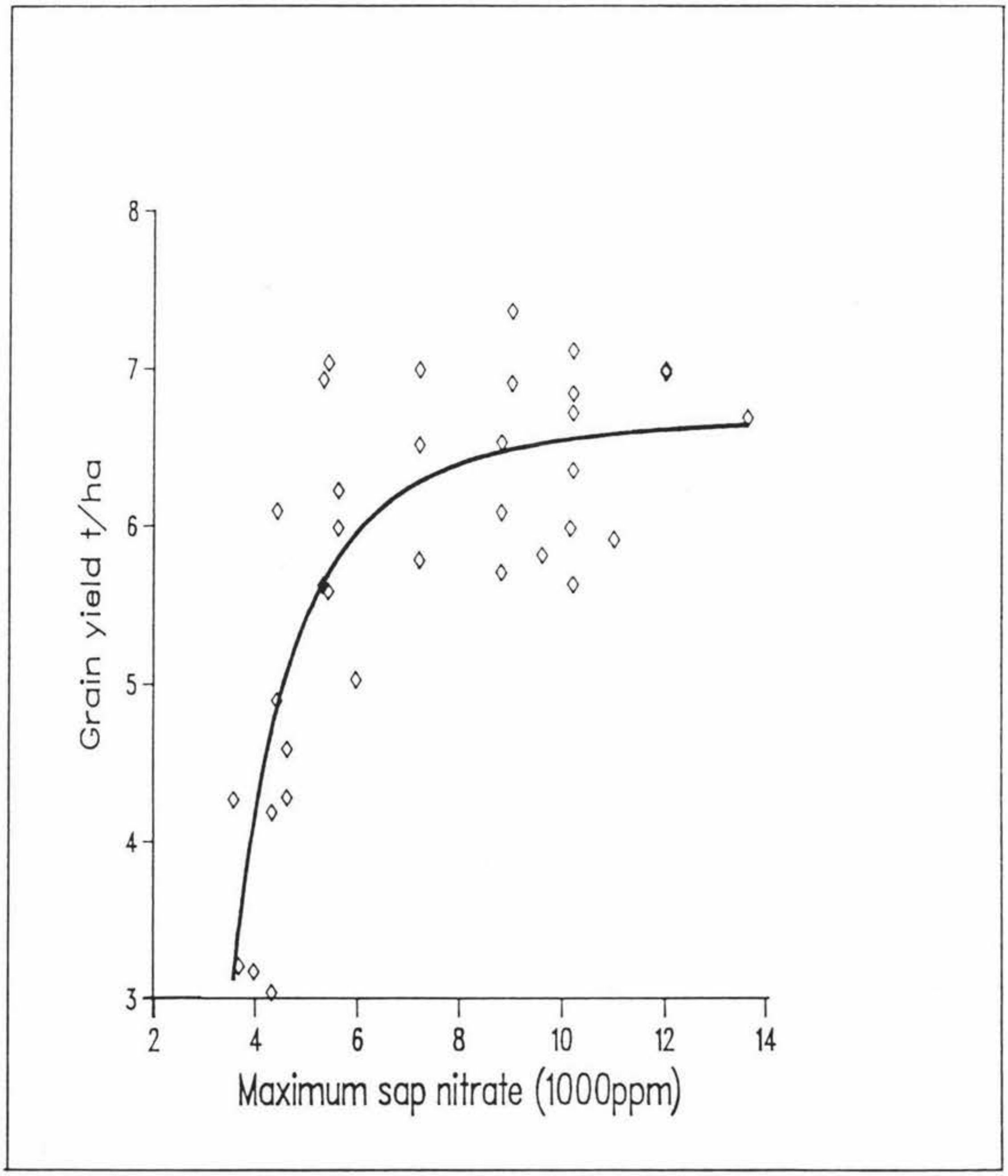

Figure 12: Overall relationship between grain yield and maximum sap nitrate concentration. Regression: $y = 7.062 - 44.65x^{-2}$, $r^2=0.620^{**}$.

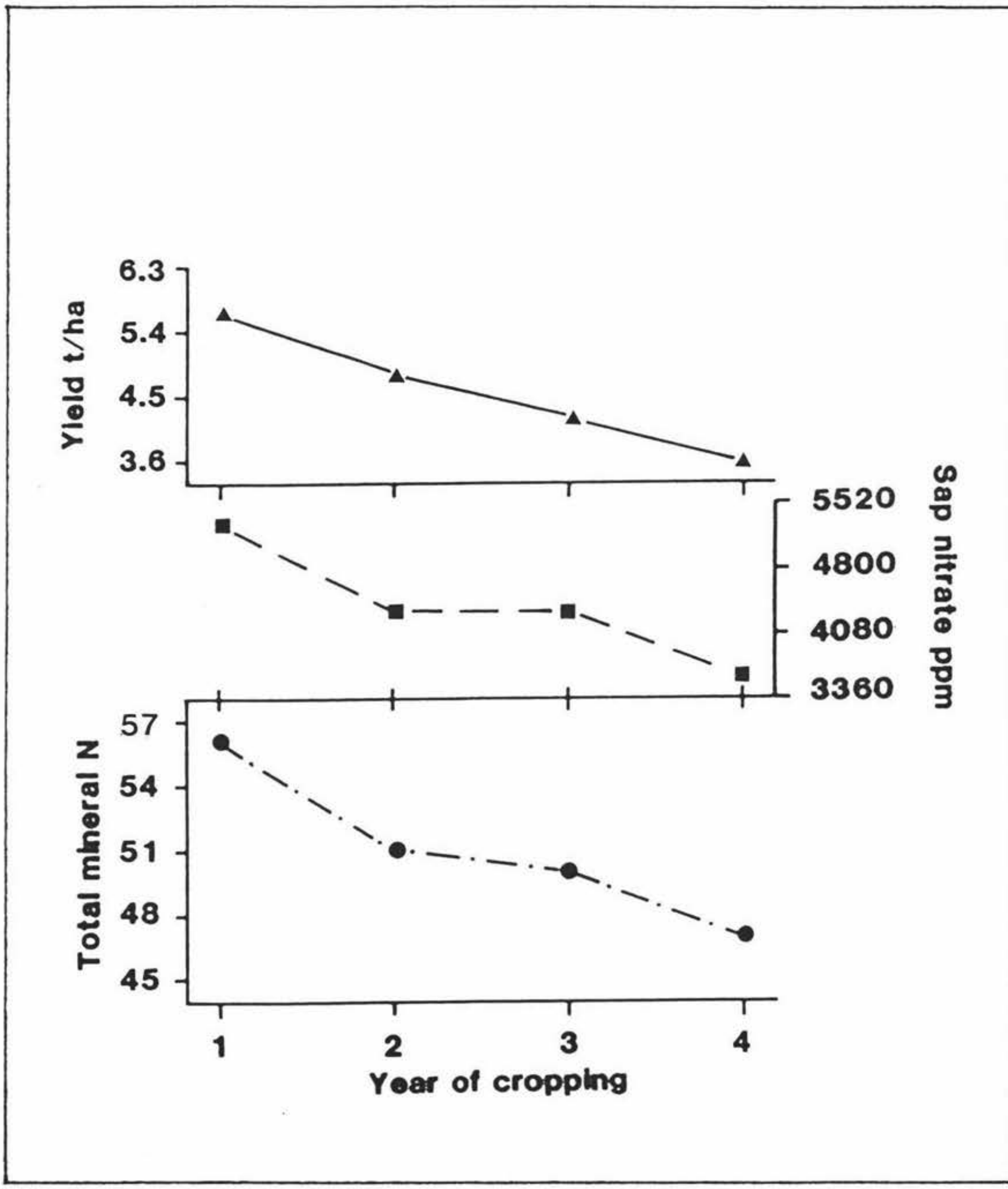

Figure 13: Grain yield (▲); maximum sap nitrate concentration (■) and total mineral nitrogen (●) of control plots.

5. DISCUSSION

5.1. GRAIN YIELD

Yield levels of up to 7.5t/ha were very satisfactory for this soil type, especially given the drier than normal rainfall over the growing season and were similar to the potential yield used to estimate the nitrogen rates from the soil test. The dry conditions therefore did not appear to significantly affect potential yield and the effects due to nitrogen were allowed to be expressed. However Risk et el. (1984) obtained yields of more than 8 t/ha from sites receiving adequate rainfall and which were cropped more than four years. Control and average yield decreased from the first year (site 1) to the fourth year of cropping (site 4). Yield at site 4 was higher than that obtained by Withers (1982) after five years cropping on the same soil type and higher than the 4t/ha suggested by Cowie (1978) for this soil type.

Continous cropping on this soil decreases the yield of barley. Rate of yield decrease on control plots, which represent the actual effect of previous cropping is more than double that reported by Greenwood and Mcleod (1980) for wheat six years in succession in the South Island. Stephen et al. (1973) however, obtained no wheat yield reduction in their four years experiment on Wingatui silt loam. The differences indicate the variation in soil productivity and capability to maintain crop yield under continuous cropping. Therefore extended periods of cropping on Tokomaru silt loam and similar soils need to be carefully considered.

All nitrogen treatments increased grain yield at all sites (Table 3). The response in the first year of cropping (site 1) was not expected as nitrogen fertilizer is not recommended on such paddocks (Greenwood et al. 1982). Response of spring-sown cereals to nitrogen is reported to increase with increasing amount of winter rainfall (Van Der Paauw, 1962; Feyter et al., 1977). In this experiment, the response is not likely to be related to those factors as the amount of rainfall before and during the cropping season was low (Table 2). The inherently low fertility of the soil itself is possibly the the main factor. The study by Jackman (1964a) showed that Tokomaru silt loam soil accumulates a low amount of nitrogen compared to other soils in the North Island even after a long established pasture. The soil test prior to planting on the paddock that has been under pasture for six years (site 1) showed only 47.4 ppm of potential mineralisable nitrogen (Table 1) compared to 61 ppm on Lismore soil after four years of pasture (Quin et al. 1982). Withers and Pringle (1981) reported a yield increase from additonal nitrogen fertiliser to that normally used by the farmers in this area. Thus the nitrogen requirement of manawatu terrace soils may have been underestimated.

Despite the increased nitrogen response at sites 3 and 4, nitrogen application was unable to maintain the yield to a level that was comparable to sites 1 and 2 (Figure 1). It is possible that inadequate nitrogen was used at the sites. However, the higher nitrogen rate applied according to soil test results (80 and 90 kg N/ha at sites 3 and 4 respectively) did not significantly increase yield over the standard treatment at 60 kg N/ha (60B) which would indicate that nitrogen was not the only limiting factor. It is possible that limitation in soil physical conditions which effect root and crop growth were reducing the yields at sites 3 and 4. A similar reason was suggested by Quin and Drewitt (1979) for the the lower wheat yield obtained by Drewitt and Rickard (1971, 1973) on a silt loam soil. Many workers have indicated the susceptibility of silty soils to structural breakdown under intensive cropping (Cooke, 1967; Greenland, 1971; Batey, 1972; Walker and Ludecke, 1982). According to Cowie (1978), Manawatu soils are readily broken down under continuous or intensive cropping so that the top soil becomes structureless and very compact. Therefore the effect of cropping on physical properties of this soil is worthy of further investigation.

Differences in the effect of the treatments from first crop (site 1) to fourth crop (site 4) indicate the role of nitrogen management varies between paddocks differing in cropping history.

On a fertile paddock such as at site 1, management of nitrogen fertiliser is less critical compared to less fertile ones such as at site 4. There are indications that treatments involving late nitrogen application (60L and 60SP) perform better and gave comparable yield to higher nitrogen rates appled at sowing (SOILT). At site 4, split application (60SP) yielded higher than early application at the same rate (60B and 60E). It appears that it is important to maintain high levels of plant nitrogen late in vegetative growth but as years of cropping increases, it becomes increasingly difficult to maintain nitrogen level toward later stages of growth. Thus on low fertility sites, split or late application may be more efficient than higher nitrogen rate applied at sowing. Similar result have been reported by Withers and Palenski (1984) on a similar soils in the same year.

5.2. YIELD AND YIELD COMPONENTS

The importance of ear density as the main contributor to yield is widely documented (e.g. Langer, 1980; Hampton, 1981; Withers and Pringle, 1981) and results were similar in this experiment. Yield increased with higher ear density to about 7 t/ha at about 950 ears/m^2 (Figure 2). Higher ear density than that had little effect on yield. In wheat, the optimum ear density reported varies with yield levels, cultivars and soil types. For yield up to 6 t/ha a range between 600 to 800 ears/m^2 was reported to be optimum (Scott et al. 1973; 1977; Scott, 1978; Hampton et al. 1981). However there is no similar information published for barley in New Zealand conditions. The reduction in yield from first crop (site 1) to fourth crop (site 4) was clearly influenced by a reduction in ear density.

Even though nitrogen management gave statistically significant effects only at sites 1 and 4, the application of nitrogen tended to increase ear density at all sites. The various nitrogen managements showed an interesting relationship with the dynamics of tiller production and subsequent ear density at final harvest. With the assumption that all the initial mainstems survived to maturity, at least one other tiller contributed to final ear density. Rate of tiller production and maximum tiller number were highest on the first crop (site 1) or with early nitrogen application and decreased with increasing years of cropping or with late nitrogen application (Figures 5, 6 and Table 8). This indicates that soil nitrogen levels at planting is an important factor influencing tiller production and tiller growth. However, adequate nitrogen supply throughout the growth period are important for survival of the tillers. Ear density at maturity is the balance between tiller production and subsequent tiller death after the maximum tillering period.

Competition for nutrients and light between and within tillers are responsible for tiller death after maximum tillering period or at higher density (Bunting and Drennan, 1969). In this experiment, nitrogen uptake before and after the maximum tillering period was found to be important for tiller survival (Equation 6). At all sites, the highest maximum tiller number was produced by early nitrogen application (60B and SOILT), but it was not an assurance for highest ear density as tiller death also increased resulting in lower tiller survival (Tables 10 and 11). The higher maximum tillers produced by these treatments probably increased the competition for depleted nitrogen and light toward later stages of growth. These treatments were unable to maintain high nitrogen uptake after the maximum tillering period (Table 18).

Even though all treatments on the fertile paddock at site 1, gave the highest maximum tillers compared to other sites, it was still able to produce the highest ear density. This was because the higher maximum tillers more than compensated for lower tiller survival. Presumably the soil could supply the nitrogen needed to maintain the tillers. Most tillers at this site were developed early in growth (Figure 5) and they had the highest probability of surviving and bearing an ear (Thorne, 1962; Bunting and Drennan, 1966; Cannell, 1969)

As soil fertility decreased to site 4, early nitrogen application was insufficient to enable the tiller to survive in contrast to late application (60L and 60SP). Even though they started with low tiller numbers, plants from treatments receiving late-applied nitrogen were more effective in maintaining high tiller survival that also resulted in high ear density. At site 4, application of 60 kg N/ha either at late tillering or splitting between early and late tillering was equally effective as applying 90 kg N/ha at sowing for increasing ear density. The late application was able to supply the nitrogen required after the maximum tillering period (Table 18) and at heading (harvest 4) it maintained significantly higher tiller nitrogen than earlier applications. Aspinall (1961) reported that no tiller reduction occurs even after ear emergence under continuous supply of nitrogen. Therefore late or split applications of nitrogen are effective in maintaining higher tiller survival particularly on low fertility paddocks.

At sites 3 and 4, grain yield was also positively correlated with grain number per ear (Table 8). Ear density and grain number/ear were significantly correlated at sites 2, 3 and 4.The positive relationship resulted in higher grain density. Grain yield continued to increase with increasing grain density until about 20,000 grains/m^2 (Figure 2c). Therefore on low fertility soil, when tiller production is inadequate for high ear density, crop management that can improve grain number/ear could be considered. The results showed that split nitrogen application that improved tiller survival was equally effective for increasing grain number/ear.

Interaction between grain weight and other components seemed to vary between sites. At sites 1 and 2 grain weight was negatively correlated with grain number/ear while at sites 3 and 4 it was negatively correlated with ear density. This may indicate that on the fertile sites the competition for grain growth was more within the plant while on low fertility sites it was higher between plants.

Even though there were interactions between grain weight and other components, there was no significant effect on grain yield at each site. This was because the increase in ear density and grain number/ear more than compensated for the reduction in grain weight.

The results indicate that there are two ways in which certain levels of ear density could be achieved; promoting higher tiller production by applying high nitrogen at sowing or by maintainance of a reasonable tiller density by split application of nitrogen. The former approach however may encourage excessive vegetative growth that could be detrimental to yield. Split or late nitrogen applications has the potential for increasing grain number/ear and also reducing leaching losses in areas of heavy rainfall or under irrigation. It could be more efficient particularly on low fertility paddocks.

5.3. RELATIONSHIP BETWEEN LEAF AREA, TOTAL DRY MATTER AND YIELD

Differences in leaf area index (LAI) between treatments and across the sites is mainly due to the differences in tiller density that control the number of leaves present (Biscoe and Gallagher, 1968). The period of maximum LAI coincided with the period of maximum tillering at about 4 weeks before heading (harvest 4). This was similar for wheat (Puckridge, 1971; Fischer, 1975). The period of grain growth is therefore during the declining stage of LAI which could effect the process of grain filling.

Grain yield increase with increasing maximum LAI until a value of about 5 (Figure 8). Above this value yield did not increase, therefore LAI of 5 appeared to be optimum. The reason that yield did not increase above LAI of 5 was that grain size was declining at relatively constant number of grains/ear. This optimum LAI value was only obtained on nitrogen-treated plots at site 1. In wheat, Scott et al. (1973) reported that a LAI about 4.5 was optimum and grain yield decreased obove this because of a reduction in grain number/ear with no effect on grain weight. If

LAI were to be increased significantly above 5 in our experiment, reduction in yield might therefore be expected.

The previous study by Dyson (1977) showed that grain yield was more closely related to accumulated dry matter at heading than the increase after that. In this experiment, both periods of dry matter accumulation were significantly correlated with yield (Table 15) but there were opposite trends in the significance of the correlation across the sites. At site 1 yield was more closely related to accumulated dry matter after heading while at site 4 it was more related to dry matter at heading. This indicates that the relationship between yield and period of dry matter accumulation may vary between paddocks differing in soil fertility. On fertile sites, dry matter at heading possibly sets the potential number of grains (Figure 2c) that determine the potential yield, further yield increase depended on the capacity of the crop to fill the grains which depended on dry matter potential after heading. On low fertility sites, optimum number of grain was not reached, therefore there was potential for more growth before heading. On fertile soils, dry matter production after heading is largely enviromentally controlled. On low fertility soils, promoting earlier dry matter production could be more beneficial and is more able to be controlled by management e.g. by nitrogen fertilization.

5.4. NITROGEN TESTS AND YIELD.

All timing of nitrogen applications increased tiller nitrogen concentration compared to control (no nitrogen). The decrease in concentration with growth reflected the decreasing soil nitrogen availability as well as the 'dilution effect' associated with the increase in structural material. Application of nitrogen after sowing increased the concentration over the control and this was maintained until heading. Therefore the nitrogen concentration in the plants could act as an indicator of soil nitrogen availability.

Tiller nitrogen concentration at harvest 1 (G.S.3) and leaf nitrogen at harvest 3 (G.S.8) showed a good relationship with yield but for diagnostic purposes, the earlier test is more useful. Batey (1982) indicated that wheat and barley can reflect nitrogen status of the soil in which it was grown as early as 3 to 5 weeks after emergence.

Maximum yield of 7t/ha coincided with 4.5% tiller nitrogen concentration. This concentration is similar to that reported by Crooke (1977) at six-leaf stage of barley for a wide range of U.K. cropping conditions. Ulrich and Hills (1967) defined critical nitrogen concentration as the concentration where yield is 10% below optimum. Based on this definition, the relationship showed that critical nitrogen concentration is about 3.7 % for barley at growth stage 3. Nitrogen concentration on control plots at all sites were below that level. This support previous indication (section 5.1) that the soil nitrogen status was the main factor influencing yield.

Tiller nitrogen concentration at heading (harvest 4) at all sites and on all treatments (Table 16) was below the optimum range listed by Cornforth (1982). The lower concentration perhaps indicates that insufficient nitrogen was applied. However the earlier examination of yield components indicated that higher yields were unlikely under the conditions prevailing.

Sap nitrate concentration varied according to sites and nitrogen treatments (Figure 13). The pattern of sap nitrate concentration measured by nitrate test strip throughout the test periods were similar to those of wheat (Withers and Palenski, 1984) and to laboratory nitrate analysis reported by Papastylianou and Puckridge (1981) on barley grown after various cultural treatments.

Although sap nitrate concentration may vary within a short period, it can represent the nitrogen status of the crop (Prasad and Spiers, 1982; Withers and Palenski, 1984). In this experiment, with a few exceptions, sap nitrate concentration were highly correlated with tiller nitrogen at all harvests (Table 19) and as has been shown earlier the sap nitrate concentration reflected soil nitrogen status and yield. These data therefore supports the idea of using the sap test to monitor crop nitrogen status (Withers, 1982; Withers and Palenski, 1984).

Overall relationship between grain yield and maximum sap nitrate across the site showed that yield increased rapidly with increasing sap nitrate up to 6000 ppm, thereafter it tends to level off (Figure 16). This supports previous suggestion that critical sap nitrate levels for growth as well as for yield is at about 5000 ppm (Withers and Palenski, 1984).

Reduction of sap nitrate with growth may indicate the decrease in soil nitrogen availability. This is shown by the increase in sap nitrate concentration following nitrogen application at tillering on high fertility paddock at site 1. Inability of late nitrogen application to increase sap nitrate levels on less fertile sites is possibly due to the increasing capacity of the root to reduce nitrate as soil nitrogen supply decreased and growth progressed (Kirkham and Miflin, 1979).

Although the pattern of the soil nitrogen tests across the sites were similar to sap nitrate tests in representing the yield of control plots (Figure 17), there was a great differences between the estimated yield based on soil test results (Table 3) and actual yield (Table 5). The rate of yield decrease from site 1 to site 4 is higher than the rate shown by the estimated yield. Yield at site 1 is higher and at other sites lower than that estimated. These differences could be due to several factors; the prediction method was used without modification and may be unsuitable for barley grown under the conditions of the experiment, soil mineral nitrogen may have been inaccurately estimated or involvement of other factors not related to nitrogen as previously discussed (Section 5.1). Since estimated yield of control (Yo) is one of the important parameters in the assessment for the amount of fertiliser needed, the use of the soil test procedure therefore needs further evaluation before it can used for wide a range of cropping conditions.

Sap nitrate and plant nitrogen concentration seem to be more sensitive to the apparent differences in nitrogen status and yield than the soil test. The reduction of 8.5 ppm in total available nitrogen from site 1 to site 4 estimated by soil test is relatively small compared with the reduction of about 1000 ppm in maximum sap nitrate and 2.23 t/ha control plot yield reduction. Detection of the small differences in the soil test value can be masked by error particularly during sampling and handling of the samples.

6. CONCLUSIONS

1. Cropping history influenced the yield of barley crops grown on Tokomaru silt loam soil. Yield without fertiliser nitrogen was highest on the site out out of pasture and decreased almost linearly (0.74t/ha/year) with each year of continuous cropping.

2. Nitrogen fertiliser at 60-90 kg/ha alleviates the decline in yield after the second crop but not completely. Factors other than nitrogen may be limiting the yield after the second year of cropping. Deterioration of soil physical conditions could be one of the reason but further work is required on this aspect.

3. Nitrogen fertiliser may be required on this soil type even when the crop is ploughed out of pasture.

4. Timing of nitrogen application became more critical as soil fertility reduced by continuous cropping. Under low fertility, late applications of nitrogen (about growth stage 5-6) may be more efficient than applications at sowing.

5. Late nitrogen application improved yield by increasing tiller survival resulting in higher ear density and also more grain number/ear under lower fertility.

6. Higher fertility sites achieved apparent optimum grain number/m^2 (grain density) with a tendency for grain weight to be low. At lower fertility, grain density was less than optimum so that nitrogen fertiliser nitrogen increased grain density by increasing both ear density and grain number/ear with little effect on grain weight.

7. At high fertility sites, total dry matter produced before ear emergence was sufficient to ensure adequate grain number for higher yields with increases in dry matter after ear emergence resulting in small differences in yield probably as a result of differences in grain size. On lower fertility, total dry matter was below the optimum at ear emergence so that increasing dry matter before ear emergence had a significant effect on yield.

8. Although the soil mineral nitrogen reflected yield variation across the sites, it was unable to represent the actual yield without fertiliser nitrogen particularly as soil fertility decreased. Soil test values showed only a small differences across the sites compared to the yield, therefore it not sensitive enough as a predictor and subjected to error. Further evaluation is needed for the use of the soil test method on this soil.

9. Plant nitrogen gave a good indicator of nitrogen status and yield. Sap nitrogen was closely related to total nitrogen levels.

10. Highest yield at about 7t/ha was associated with 4.5% nitrogen in tillers and >5500ppm sap nitrate concentration at about growth stage 3.

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