The potential of tagasaste (*Chamaecytisus palmensis*) in maintaining fertility in a sustainable cropping system

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I dedicate this page to my wife; Olivia for her love, patience and support and to my parents; Nyarko and Oyikyi for their guidance and prayers.

ABSTRACT

Abstract of a thesis submitted in fulfilment of the requirements
for the degree of MAgrSc

THE POTENTIAL OF TAGASASTE (*Chamaecytisus palmensis*) IN MAINTAINING FERTILITY IN A SUSTAINABLE CROPPING SYSTEM

The effects of incorporating tagasaste (*Chamaecytisus palmensis*) dry matter (DM) on the growth and yield of maize (*Zea mays* L.) was studied in two field experiments in Canterbury, New Zealand. In the first experiment (1997-98), tagasaste DM was incorporated at four rates (0, 5, 10 and 15 t DM/ha) and maize was sown four (7 November) and eight (5 December) weeks after tagasaste incorporation. In the second experiment (1998-99), 0 and 10 t DM/ha of tagasaste and 200 kg N/ha were soil incorporated and maize was sown four weeks after tagasaste incorporation (2 November) with no, or with full irrigation.

In 1997-98, the incorporation of 15 t DM/ha of tagasaste increased maize DM yield from 19,700 to 25,400 kg/ha and grain yield by 33 %. This was equivalent to maize production from the plots which received 200 kg N/ha. The November sown crop produced 42 % higher grain yield than the December sown crop. However, the DM yield did not differ with sowing date. Incorporating 15 t DM/ha increased both the weighted mean average growth rate and maximum crop growth rate by 26 % but had no effect on the duration of exponential growth. Leaf area duration increased at 15 t DM/ha of tagasaste but sowing date had no effect. Maize sown in November intercepted about 17 % more photosynthetically active radiation (PAR) but had a lower radiation use efficiency (RUE), than the December sown crop. Tagasaste incorporation at 15 t DM/ha increased RUE by 24 % from 2.59 to 3.22 g DM/MJ PAR.

Incorporating at least 10 t DM/ha of tagasaste reduced soil bulk density and increased total soil nitrogen but had no influence on the soil C:N ratio or pH in both seasons. In 1998-99, application of 200 kg N/ha reduced the soil pH. Volumetric soil water content at grain filling for the unirrigated plots was approximately 66 % of the irrigated plots.

Dry matter yield increased by 5,200 kg/ha with irrigation in 1998-99. Irrigation did not increase grain yield but, it did increase mean grain weight by 21 %. Irrigation increased DM yield by increasing intercepted PAR from 730 to 860 MJ/m^2. There was a positive and linear relationship between DM accumulation and intercepted PAR and between DM and grain yield. There was a significant interaction between incorporation of tagasaste or 200 kg N/ha and irrigation for DM production. In irrigated plots, the DM yield from the 200 kg N/ha plots at 27,000 kg/ha was about 14 % higher than the yield from plots where tagasaste had been incorporated. These plots produced 3,200 kg more DM/ha than the control plots. However, in the unirrigated plots, DM yields were similar in the 10 t DM/ha and 200 kg N/ha plots. Both treatments gave higher DM yield than the control. Incorporation of either 10 t DM/ha or 200 kg N/ha increased the DM and grain yield by increasing RUE. The results show that tagasaste incorporation can improve soil fertility and increase maize yield provided sowing date coincides with periods of adequate soil moisture.

Additional key words: *maize, radiation use efficiency, yield, irrigation, sowing date, nitrogen.*

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LIST OF ABBREVIATIONS

θ	Volumetric soil moisture content
ANOVA	Analysis of variance
CAN	Calcium ammonium nitrate
CEC	Cation exchange capacity
C_m	Maximum crop growth rate
cv	Cultivar
CV	Coefficient of variation
DAS	Days after sowing
DM	Dry matter
DUR	Duration of exponential growth
F_i	Proportion of radiation intercepted
FW	Fresh weight
HI	Harvest index
LAD	Leaf area duration
LAI	Leaf area index
LTM	Long term mean
MLP	Maximum Likelihood Program
PAR	Photosynthetically active radiation
r	Correlation coefficient
r^2	Coefficient of determination
RUE	Radiation use efficiency
S_a	Absorbed solar radiation
SEM	Standard error of mean
S_i	Incident solar radiation
TDR	Time domain reflectometry
T_i	Fraction of radiation transmitted through the canopy
WMAGR	Weighted mean absolute growth rate

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CHAPTER ONE

General Introduction

1.1 Justification

A major problem facing crop production in many countries is low soil fertility. This is partly due to leaching, erosion or poor farming practices such slash and burn. In the tropics, nitrogen (N) deficiency limits crop yields more than by available water. However, in the absence of adequate rainfall or irrigation, N application has only a marginal effect on maize production as a significant interaction has been reported between N and irrigation (Sridhar *et al.,* 1991; Liang *et al.,* 1992).

In countries where over-population has put pressure on land, fallow periods are often short and fertilisers are usually used to increase crop yield. The continuous cropping of cereals such as maize requires regular application of fertilisers to sustain yield. High fertiliser cost, spreading salinity, continuing soil acidification, declining soil fertility and declining soil structure due to constant application of inorganic fertiliser on soil fertility have raised much concern. In recent years attention has been focused on sustainable cropping systems involving legumes as alternative sources of soil N. Research has shown that incorporation of legumes increased soil fertility and improved the productivity of succeeding crops such as maize (*Zea mays* L.) (Dalland *et al.,* 1993) and Italian ryegrass (*Lolium multiflorum*) (McKenzie and Hill, 1984). This technology has raised farmers' interest because it makes savings in the cost of N fertiliser and reduces production costs. Barreto (1994) reported N fertiliser substitution value of 158 kg N/ha for tree legume *Canavalia ensiformis* when the residues were incorporated into the soil. In New Zealand, most soil N comes from organic N via biological N fixation by clovers (Walker, 1995). Other tree legumes which have been reported to improve soil N include *Leucaena leucocephala* and *Gliricidia sepium.* In the absence of such tree legumes in New Zealand, incorporation of tagasaste (*Chamaecytisus palmensis*) may have similar effects on the soil.

Tagasaste has a long tap root, nodulates freely and fixes atmospheric N in association with rhizobium bacteria *Lotus pedunculatus.* Nitrogen fixation, by tagasaste of 19.4 g N/m^2

has been reported (Gebru, 1989) which is similar to that fixed by white clover (*Trifolium repens*) (18.7 g N/m^2). Tagasaste can grow on relatively poor soils where most plants cannot thrive. Moreover, it is drought tolerant and this is usually ascribed to the deep penetrating tap root which can obtain moisture and nutrients from relatively deep in the soil. The low C:N ratio of tagasaste foliage indicates that its incorporation will improve soil N and increase yields of non leguminous crops such as maize.

Maize belongs to the family Gramineae, within the tribe triticeae. In terms of production throughout the world, it is at present the third most important grain crop. In New Zealand, maize is the third most important cereal after barley (*Hordeum vulgare*) and wheat (*Triticum aestivum*) in terms of area sown (18,559 hectares) with 209,710 t of grain produced in 1996 (Agriculture Statistics, 1996). Most of the grain (70 %) is used for feeding pigs and poultry (Hardacre *et al.,* 1991) while forage maize is used for the production of silage for ruminant feeding, particularly cattle. In Ghana, maize is a staple diet and is used to prepare dishes such as *banku, kenkey* and porridge. Industrial uses include preparation of cornflakes and flour.

A study in Canterbury, New Zealand, to assess maize yield responses to time of sowing by Johnstone and Wilson (1991) showed that October sown crops yielded 19 % more grain than November sown crops. Early sowing in Canterbury is important as, at least with early maturing cultivars, early sowing can help to ensure the crop matures before the onset of early frost (Wilson *et al.,* 1991). Additionally, sowing date may influence the breakdown of incorporated organic N which could influence its effects on a succeeding crop. To avoid frosty weather and ensure good plant population at establishment, Wilson *et al.* (1991) recommended that sowing should not commence before 15 October in Canterbury.

Previous research on tagasaste has mostly centred on the feeding quality of the plant as a supplementary feed for livestock. In New Zealand, the effects of organic matter incorporation on subsequent maize production have not been extensively investigated. Moreover, there is little literature on the interaction between organic matter incorporation and irrigation on crop yield. The aims of this study were to assess the effects of incorporated tagasaste residues, sowing date and irrigation on the DM and grain yield of maize and to assess the effects of the incorporation on the soil fertility.

1.2 Hypothesis:

Incorporation of tagasaste biomass may lead to improved soil structure and increased soil N levels which benefits a succeeding crop and saves on fertiliser application.

1.3 Objectives:

I. Assess the effects of tagasaste residues and fertiliser on soil N, organic carbon, pH, bulk density and volumetric soil moisture content.

II. Examine total dry matter (DM) and grain yield of maize after incorporation of varying amounts of tagasaste.

III. Assess the effects of time of incorporation and sowing date on the growth and yield of maize.

IV. Assess the effect of fertiliser and tagasaste incorporation on grain and DM yield of maize under two different soil moisture regimes.

CHAPTER TWO

Literature Review

2.1 Introduction

The potential of tree legumes such as *Gliricidia sepium* and *Leucaena leucocephala* in maintaining soil fertility and sustaining crop production have been reported by several researchers (Sraha, 1994; Yamoah, 1997). In New Zealand, research has shown that incorporation of legumes such as lupins (*Lupinus angustifolius*) and white clover in rotations increased soil nitrogen (N) percentage and increased the yield of succeeding non-legume crops (Janson, 1984; McKenzie and Hill, 1984; Ganeshan, 1998).

Tagasaste is a tree legume which produces large amounts of biomass annually. The N concentration of the leaves is high, especially newly emerged leaves (Borens, 1986). Although the decomposition constant of tagasaste foliage has not yet been reported, the low C:N ratio (14) indicates that incorporation of the residues will not cause much immobilisation of soil N by micro-organisms decomposing the material. This may reduce the need to apply synthetic N fertiliser as has been reported in studies involving tree legumes such as *L. leucocephala* (Mureithi *et al.,* 1995) and *Mucuna pruriens* (Ile *et al.,* 1996).

Previous research on tagasaste has mostly centred on the feeding quality of the plant as a supplementary feed for livestock. However, no experiments have attempted to assess the potential of tagasaste prunings in maintaining soil fertility and improving crop yield. The aims of this study were to assess the effects of tagasaste foliage incorporation, sowing date and irrigation on the growth and grain yield of maize.

2.2 Tagasaste

2.2.1 Description

Tagasaste (also known as tree lucerne) is an evergreen tree-legume which produces a mass of white flowers in the early spring. It originated in the Canary Islands of the Atlantic ocean. It belongs to the family leguminosae, sub-family papilionoideae, and the genus Chamaecytisus. In the southern hemisphere, the plant grows in the latitudinal range 30^o-45^o S. In New Zealand, it is distributed throughout the North Island from sea level to 750 m and is widely distributed throughout low altitude coastal regions of the south Island up to 600 m (Davies, 1982; Webb, 1982).

Tagasaste can be propagated by seed which usually is inoculated with the *Rhizobium* of *Lotus pedunculatus*. If undisturbed by grazing or cutting, it can grow to a height of 5 m (Voon, 1986). It nodulates freely and can fix atmospheric N in association with the *Rhizobium* bacteria of *Lotus pedunculatus* (Snook, 1986) it thus enriches the soil and can help reduce the amount of fertiliser N applied (Thomas, 1988). Gebru (1989) recorded N fixation of 19.4 g N/m^2 by tagasaste which was similar to that fixed by white clover (18.7 g N/m^2). This enables the plant to grow on relatively poor soils where most plants cannot thrive. It is drought tolerant and this is attributed to the deep penetrating tap root which obtains moisture and nutrients from relatively great depths in the soil. The plant can grow in a wide range of soils, loams, limestone and laterite (Snook, 1986). However, it prefers well-drained sandy soils with a pH of 5.0-6.2 (Dann and Trimmer, 1986). It is susceptible to water logging and can be affected by diseases and pests such as root rot bacteria (*Phytophthora spp.*) and silver leaf fungus (*Chondostereum purpureum*) reported by Radcliffe (1985).

2.2.2 Uses

Tagasaste is a multipurpose tree species that can be used to improve agroforestry systems in New Zealand. The plant nodulates freely and fixes atmospheric N. The deep root system makes it an efficient species in terms of recycling nutrients that have leached beyond the root zone of crops. Litter falling from the tree enriches the soil with large quantities of N and other essential minerals absorbed by the tree from considerable depths. Recently, more emphasis is being placed on its deep rooting ability to conserve both soil and water. Soil conservation authorities in New Zealand have long recognised the useful characteristics of tagasaste for stabilising steep rocky dry slopes, where most other species have difficulty surviving (Saunders, 1980).

Tagasaste produces rich nectar which serves as feed for bees. It is good forage for ruminant livestock and pigs because the foliage is palatable, nutritious and highly digestible. The digestibility of tagasaste has been studied in several sheep feeding trials (Ulyatt *et al.,* 1980; Voon, 1986). Ulyatt *et al.* (1980) reported a DM digestibility value of 77 % which is similar to the digestibility values (80 %) for ryegrass and white clover. The crude protein (CP) content of tagasaste hay is 200 g CP/kg of DM (Ulyatt *et al.,* 1980). This exceeds the 70 g CP/kg of DM required by a ruminant animal for maintenance (Poppi, 1982). Unlike *Leucaena* which may be toxic due to the presence of mimosine, there are no reported cases of toxicity in animals grazing tagasaste. According to Borens (1986) and Poppi (1982) wethers consuming a sole diet of the tagasaste leaves for 4 and 9 weeks respectively, showed no signs of ill health.

Tagasaste is used for fencing paddocks; providing shade for grazing animals and also serves as a windbreak. It is a good source of fuelwood and can be used to suppress the growth of weed species such as gorse (*Ulex europeaus*) (Davies, 1982).

2.2.3 Dry matter production

Tagasaste DM yields of 11,200 kg/ha/yr have been reported in western Australia by Snook (1986) and of 12,000 kg/ha/yr in New Zealand by Poppi (1982). In the South Island of New Zealand, DM production of 7,000 kg/ha/yr with leaf and stem DM yields of 2,600 and 4,390 kg/ha respectively have been reported (Mcleod, 1982). The accumulation of DM by tagasaste is influenced by the weather. Lambert *et al.* (1989) obtained higher DM yield in summer than in winter.

2.2.4 Foliage Nitrogen

Legume species generally have a high foliar N concentration which is probably due to N fixation. Palm and Sanchez (1990) reported a N concentration of 3.94 % for *Leucaena* leaves which is similar to the 3.33 % reported by Fitzgerald (1982) for tagasaste. Research by

Fitzgerald (1982) and Snook (1986) has showed a higher nutrient content of tagasaste plants growing on fertilised plots than those grown on unfertilised plots. Table 2.1 gives the nutrient concentration (N, P and K) of tagasaste.

Table 2.1 Nutrient concentration (N, P, K) of tagasaste; Fitzgerald (1982).

Tagasaste leaves	Nitrogen (%)	Phosphorus (%)	Potassium (%)
Fertilised plots	3.74	0.22	1.64
Unfertilised plots	3.33	0.20	1.34

Leaf N percentage may also increase with N application (Fitzgerald, 1982; Snook, 1986). A foliar N concentration of 3.10 % from trees on unfertilised plots was reported by Snook (1986). However, on plots fertilised with superphosphate, he recorded leaf N concentrations of 3.20 and 4.48 % in summer and winter respectively.

Chemical analyses at several growth stages of tagasaste showed a general decline in the concentration of foliage nitrogen with maturity (Borens 1986). Borens (1986) reported 4.2 % N for newly emerged leaves and 2.7 % N for six months old leaves. Higher N percentages have been reported in the leaves (3.3 %) than in the stems (1.6 %) by Radcliffe (1985). The season of cutting also influences foliar N concentration. Research has shown that winter cuttings have higher N concentration than summer cuttings (Snook, 1986; Gebru, 1989). Gebru (1989) reported foliar N percentages of 3.62 % and 2.35 % in May (winter) and in January (summer) respectively.

2.2.5 Decomposition of organic materials

When plant materials are added to the soil, a complex chain of events is initiated which has a considerable effect on the properties and fertility of the soil. Soil organisms such as mesofauna (eg earthworms) and micro-organisms (eg bacteria) breakdown the organic compounds. Aerobic organisms as a result of this breakdown release carbon dioxide (CO_2) while anaerobic organisms release methane (CH_4) or ethylene (C_2H_4). Harper and Lynch (1981) reported that substances released through the anaerobic fermentation can interfere with germination and seedling growth as they are toxic to seedlings. The rate of decomposition depends on ambient environmental conditions (eg moisture, temperature and soil acidity) and the type of organic materials added to the soil. Fresh leafy materials contain a relatively high proportion of simple carbohydrates and proteins and are readily decomposed. On the other hand, old woody tissues contain a higher proportion of cellulose and lignin and other materials resistant to decomposition, for example fats and waxes.

Of the climatic factors, temperature and rainfall are of major importance. Warm and wet periods enhance decomposition rate (Pandey and Singh, 1982) while cold temperatures and drought slow down the rate. The substrate quality depends on the carbon to nitrogen ratio (C:N), polyphenol and the lignin content of the organic material (Tian *et al.,* 1992; Sraha, 1994). High polyphenol and high lignin percentages have been found to retard the decomposition rate of organic materials (Sivapalan *et al.,* 1985; Tian *et al.,* 1992). Extensive research has shown that species with a high N concentration decompose at a faster rate than those with low N contents (Pandey and Singh, 1982; Sraha, 1994). The optimal C:N ratio for rapid decomposition is 25:1 to 30:1. Excess N beyond that level can provide immediate fertiliser value to crops. However, if the C:N ratio is greater than 30:1, the result can be the immobilisation of N from the soil by micro-organisms as they attempt to utilise the available C (Rosen *et al.,* 1993). This may cause N deficiency symptoms in associated crops. The C:N ratio of tagasaste residue is low (14) hence, under favourable climatic conditions, it should decompose quickly enough to release N for crop uptake.

2.3 Changing soil fertility and characteristics with rotations

2.3.1 Rotations with Perennial species

Many workers (Dalland *et al.,* 1993; Xu *et al.,* 1993a; Ganeshan, 1998) have reported that legumes increase soil fertility and improve the productivity of succeeding non legume crops. Xu *et al.* (1993a) observed significant increase in maize DM production and N uptake with the incorporation of *Leucaena* prunings compared to plots without *Leucaena* prunings. This increase in yield correlated strongly with the total amount of N applied from the *Leucaena* prunings (Dalland *et al.,* 1993). The method of residue application (*ie* incorporation or surface application) however, did not influence crop uptake and the final crop yield (Read *et al.,* 1985; Xu *et al.,* 1993b). Xu *et al.* (1993b) reported that incorporation of *Leucaena* residues in the soil did not increase the recovery of *Leucaena* N by maize compared with placement of the residues on the soil surface. Read *et al.* (1985) obtained similar results in a field trial. However, results from a pot trial showed that soil incorporation of *Leucaena* residue was more effective than surface application in increasing maize DM production.

Barreto *et al.* (1994) observed N fertiliser substitution values of 158 kg Urea N/ha for *Canavalia ensiformis* and 127 kg N/ha for Mucuna species when the residues were soil incorporated. In New Zealand, clovers fix large quantities of N in the soil annually. Askin *et al.* (1982) observed the fixation of 175 kg N/ha/yr by *Lupinus angustifolius* on a low fertility soil. Walker (1995) reported that a clover paddock in New Zealand fixed 210 kg N/ha/yr which was equivalent to 4.5 million tonnes of urea annually. This reduces the fertiliser cost of growing subsequent crops (Taylor, 1980). In Kenya, the yield of maize intercropped with *L. leucocephala* and cowpea (*Vigna unguiculata*) was increased, and the need for fertiliser N reduced (Mureithi *et al.,* 1995). Experiment by Reeves *et al.* (1984) gave higher soil mineral N levels in a wheat : lupin rotation than in a continuous wheat rotation. They reported an average increase in mineral N of 41 kg/ha at 0-20 cm soil depth.

2.3.2 Soil physical changes

Tree legumes improve soil physical characteristics such as bulk density and increase the stability of soil aggregates (Sharma and Singh, 1970). Reeves *et al.* (1984) measured bulk densities and water-stable aggregates in wheat : lupin rotations and concluded that the lupin crop improved the soil structure.

Organic materials when incorporated into the soil reduce soil bulk density (Dalland *et al.,* 1993; Marshall *et al.,* 1996; Yamoah, 1997). At 10 t/ha of *Leucaena* application, soil bulk density was reduced by 2.6 % compared with the control (Yamoah 1997). This confirms an earlier report by Opara-Nadi (1993) that soil bulk density and the amount of organic material incorporated are inversely related. Salau *et al.* (1992) attributed some of this reduction to increased soil biological activity, resulting in higher soil porosity. Furthermore, organic matter is less dense (1.3 g/cm^3) than mineral particles (2.65 g/cm^3) hence soils with large amount of humus generally have lower bulk densities than those with little humus (Marshall *et al.,* 1996; McLaren and Cameron, 1996). Marshall *et al.* (1996) and Thanh (1996) have reported that soil bulk density increases with depth. Thanh (1996) recorded bulk densities of 1.25 and 1.45 g/cm^3 at 5 and 20 cm depth respectively on no tillage plots. Additionally, organic matter lowers penetration resistance of the soil and increases infiltration rate and pore volume fraction (Dalland *et al.,* 1993). This can increase the soil water holding capacity (Jacobowitz and Steenhuis, 1984). Furthermore, it binds mineral particles into granules that are generally responsible for the easily managed condition of productive soils and reduces plasticity and cohesion (Brady, 1990).

2.3.3 Soil chemical changes

Tree legumes also have a beneficial effect on soil chemical properties. Dalland *et al.* (1993) reported significant increases in soil organic C, N, potassium (K), cation exchange capacity (CEC) and pH values under a hedgerow of *Leucaena* than in urea plots. They noted that higher levels of organic C in alley cropping accounted for the improvements observed in the soil physical properties.

Organic matter is a major source of phosphorus (P) and sulphur (S) and is the primary source of N. Young (1989) reported that organic matter improves the availability of micro-nutrients and also provides a favourable soil environment for N fixation. Another chemical effect of organic matter is the considerable enhancement of CEC by the humus-clay complexes. Young (1989) noted that raising the CEC improved nutrient retention (both naturally recycled elements and of those added in fertilisers). When organic matter decomposes, the humus formed exerts a buffering action against acidity and raises the soil pH (Jacobowitz and Steenhuis, 1984). Significant increase in soil pH, organic C and total N have been reported by Opara-Nadi (1993) in plots treated with 12 t DM/ha of *Pennisetum purpureum* compared to the control. The soil pH increased from 6.7 to 7.5, the organic C and total N respectively increased by 5 and 4 %. In contrast, McLaren and Cameron (1996) reported that organic matter decomposition can increase H^+ and increase soil acidity.

Fertilisers containing N in the ammonium (NH_4^+) form results in the production of H^+ ions which lower the soil pH. The H^+ increases with further oxidation by soil micro organisms. *Nitrosomonas* and *Nitrobacter* oxidise NH_4^+ to nitrite (NO_2^-) and further oxidise NO_2^- to nitrate (NO_3^-) by the process of nitrification, at the same time releasing H^+ into the soil (McLaren and Cameron, 1996).

2.3.4 Residue incorporation and crop yield

The incorporation of legume plants in rotations increases subsequent crop yields. Janson (1984) noted that when lupins (*Lupinus angustifolius*), tick beans (*Vicia faba*) and peas (*Pisum sativum*) were ploughed into the soil, the grain yields of a succeeding wheat crop was higher (4,870 kg/ha) than after fallow (4,140 kg/ha). Read *et al.* (1985) and Mulongoy *et al.* (1993) obtained significant increases in maize grain yield following soil incorporation of *Leucaena* prunings. Read *et al.* (1985) observed that the application of *Leucaena* leaves significantly increased ear leaf N by 17 % and maize grain yield by 15 % compared with the control. Application of 100 kg N/ha resulted in maize ear leaf N values and yields that were similar to those obtained with the application of the *Leucaena* leaves. However, they noted that *Leucaena* leaves were not as effective as inorganic N in increasing maize DM production or grain yield. On the other hand, unlike inorganic fertiliser (CAN), *Leucaena* leaves had a significant residual effect on the subsequent planting. Kang *et al.* (1981) reported similar results. Using only *Leucaena* prunings, they were able to maintain maize yields at 3,800 kg/ha for 2 years. Yield from the control was only 1,800 kg/ha.

From the works of Janson (1984) and Read *et al.* (1985) it appears that the increase in the succeeding maize crop grain yield was probably due to increased soil N. Lowlor *et al.* (1987) noted that the increase in soil N can increase the rate of photosynthesis per unit leaf area by increasing the concentration of photosynthetic pigments and enzymes. However, the largest effect is usually due to increasing the plant's size per area of soil by increasing the LAI (Lieffering, 1995).

2.4 Maize

2.4.1 Introduction

Maize belongs to the family Gramineae, within the tribe triticeae. In terms of production throughout the world, it is at present the third most important grain crop following closely upon wheat (*Triticum aestivum*) and rice (*Oryza sativa*). It is the world's most widely distributed crop. Although requiring a frost-free climate for growth and reproduction, maize is now increasingly grown in temperate regions, not only as a forage crop for silage but also for production of grain. In New Zealand, it is the third most important cereal after barley (*Hordeum vulgare*) and wheat in terms of area sown (18,559 ha) with 209,710 t of grain produced in 1996 (Agriculture Statistics, 1996). Most of the grain (70 %) is used for feeding pigs and poultry (Hardacre *et al.,* 1991) while forage maize is used for the production of silage for ruminant feeding, particularly cattle. Maize is an important cereal in many tropical countries as it constitutes bulk of the diet. However, the main agricultural soils in the tropics are low in N, and the availability of N for plant uptake is a serious constraint to productivity (Williams *et al.,* 1985). Moreover, moisture stress affects N uptake by maize which may result in poor growth and low DM and grain yield.

2.4.2 Growth and dry matter accumulation

Growth may be used to refer to changes in dry weight or changes in size (area or numbers of a plant or its organs (Monteith, 1981; Gallagher *et al.,* 1983). Dry weight increase is the result of the relationship between photosynthesis, respiration and translocation (Gallagher *et al.,* 1983). Vigorous growth and high yields of the maize plant are attributed to the C_4 pathway of photosynthesis. Being a tropical plant, the growth of maize is influenced by temperature and photoperiod as well as light, nutrients and moisture availability. Gardner *et al.* (1985) pointed out that the primary factors affecting total DM production are solar radiation absorbed and the efficiency of utilising that energy for CO_2 fixation.

Following the approach of Charles-Edwards (1982), biomass (B) accumulation by a crop is described as the integral of the crop growth rate (C), which is the product of the intercepted photosynthetically active radiation (PAR) (Q) and radiation use efficiency (RUE) (A):

$$B = \int (C.dt) = \int (A.Q.dt) \ldots\ldots 2.1$$

Hay and Walker (1989) expressed DM yield (Y) of a crop over a given period of time as:

$$Y = S_a \times RUE \times HI \ldots\ldots 2.2$$

where S_a is absorbed solar radiation, RUE is radiation use efficiency, and HI is harvest index. They pointed out that in certain crops, notably grasses, there is limited scope for improvement of yield by variation in S_a and HI, and that increased production can come only from increases in RUE. Muchow *et al.* (1990) reported a direct relationship between DM production and PAR interception by a maize crop canopy (reviewed in section 2.4.2.3). Agronomic practices such as N fertilisation (Lieffering, 1995) and moisture stress (Muchow, 1989) can influence the RUE of cereals and consequently affect DM accumulation.

2.4.2.1 Leaf Area Index

Leaf area index (LAI) is leaf area per unit ground area. It is a measure of the extent to which plants develop their photosynthetic tissues. Leaf area index and leaf angle determine the fraction of available PAR intercepted by the canopy and hence DM production. Studies on LAI for many crops have shown an increase in LAI with time to a peak around the onset of rapid reproductive growth. Muchow (1988) reported maximum LAI of 3.8 for maize. The LAI afterwards declines towards maturity as a result of leaf senescence (White and Izquierdo, 1991). Thus the rate of establishment of leaf area after emergence and the time taken to reach critical LAI (the LAI at which the crop intercepts 95 % of incident PAR) is important to subsequent crop growth (Gallagher, 1979) and final seed yield (Sinclair *et al.,* 1981). Brougham (1960) reported critical LAI of 7.4 in maize.

Leaf area index increases as the number of leaves and their mean size increases. Lieffering *et al.* (1993) reported that additional N increased total plant leaf area in some temperate cereals by increasing leaf number. Ile *et al.* (1996) observed that LAI of maize fertilised with urea were larger than those on *Mucuna pruriens* fallow plots which in turn had a higher LAI than the control. Both DM and grain yields followed similar trends in that study. Research has also shown that the LAI of cereals decreases with moisture stress which in turn influences the final DM and grain yields. A reduction of 54 % in LAI of maize plants growing under drought conditions was reported by Singh and Singh (1995).

2.4.2.2 Leaf area duration

The integral of LAI over time defines leaf area duration (LAD). Leaf area duration may be highly correlated with yield because interception of solar radiation over longer periods of time generally means greater total DM production (Gardner *et al.,* 1985). A strong linear relationship between grain dry weight and green LAD from anthesis to final harvest in maize has been reported by Wolfe *et al.* (1988). A long grain-filling period and delayed foliar senescence can increase maize grain yield (Tollenaar, 1991; Bolanos, 1995) by promoting the translocation and immobilisation of more assimilate into the sinks. Leaf area duration can increase through N fertiliser application (Lieffering, 1995) by increasing leaf number and leaf size. It can also increase through irrigation by delaying leaf senescence (Wolfe *et al.,* 1988).

2.4.2.3 Radiation interception and radiation use efficiency

Light levels have a profound influence on plant growth and yield. Plants convert light energy into organic compounds through photosynthesis. The amount of DM accumulated by a range of crops, including maize (Tollenaar and Bruulsema, 1988; Muchow *et al.,* 1990; Andrade *et al.,* 1992), barley (Gallagher and Biscoe, 1978), oat (Martin, 1996), sorghum (Muchow and Davis, 1988) and pinto beans (Dapaah, 1997) has been reported to be linearly related to the amount of PAR intercepted. The gradient of the line of relationship is the utilisation coefficient or the radiation use efficiency (RUE).

There have been extensive reports on RUE in maize. Several of these authors have noted that DM production in maize is related more closely to the RUE than to the amount of PAR intercepted (Daughtry *et al.,* 1983; Christy *et al.,* 1986; Tollenaar and Bruulsema, 1988). Hay and Walker (1989) reported that in certain crops, notably grasses, there is limited scope for improvement of yield by variation in intercepted PAR and harvest index (HI), and that increased production can come only from increases in RUE. Generally, C_4 species, (eg maize) have higher rates of leaf photosynthesis and therefore higher values of RUE than C_3

species. In some species, RUE declines during the reproductive phase. Gallagher and Biscoe (1978) found RUE of cereals up to anthesis to be 3.00 g DM/MJ PAR, but over the entire growth of the crop averaged 2.20 g DM/MJ PAR. This was confirmed by Muchow and Davis (1988) who reported maximum RUE in maize during the vegetative growth. During grain filling, as a result of remobilisation of leaf N to the grain, the RUE consequently declined. Andrade *et al.* (1992) reported a linear relationship between cumulative intercepted PAR and DM accumulation of maize with a RUE of 2.96 g DM/MJ PAR. Andrade (1995) and Westgate *et al.* (1997) obtained similar RUE values of 2.77 and 2.70 g DM/MJ PAR respectively for maize whereas Kiniry (1994) reported higher RUE values ranged 3.42-3.75 g DM/MJ PAR.

Among the factors which affect the RUE of crops are N (Muchow and Davis, 1988; Gimenez *et al.*, 1994; Muchow and Sinclair, 1994; Lieffering, 1995), irrigation (Muchow, 1989; Mckenzie and Hill, 1991; Jamieson *et al.,* 1994; Jamieson *et al.,* 1995b) and temperature (Andrade *et al.*, 1993). For example, Gimenez *et al.* (1994) found that increased soil N fertility resulted in both an increased specific leaf N content and increased the RUE. Application of 240 kg N/ha increased the RUE of maize by about 50 % (Muchow and Sinclair, 1994). Muchow and Davis (1988) observed a close correlation between RUE and average canopy leaf N per unit leaf area. They reported that DM production of maize and sorghum with increasing N supply was associated with both higher intercepted PAR and RUE. The RUE varied more with N supply than did intercepted PAR. This observation was contrary to the findings of Wright *et al.* (1985) who reported that differences in above-ground biomass accumulation in sorghum supplied with different levels of N could be attributed primarily to differences in intercepted PAR, with only small differences in RUE.

Muchow (1989) observed a reduction in the RUE of maize under drought conditions. Drought reduced the amount of PAR intercepted and RUE of barley plants and resulted in low DM production (Jamieson *et al.,* 1994). Jamieson *et al.* (1995b) also found that the timing and duration of a drought treatment were important in interpreting RUE. They compared the RUE of barley subjected to 12 irrigation treatments. They observed that while RUE decreased in those treatments with early drought, it did not alter when drought was imposed at middle or late periods during the growing season. It must be emphasised that, the response of RUE to water deficits therefore depends on the phenological period the deficit was imposed and the severity of the water deficit.

Environmental factors, for example temperature, can influence the photosynthetic activity of leaves and may alter RUE. Sinclair and Horie (1989) found that any factor, that decreased leaf photosynthesis to the range of low photosynthetic rates had a direct consequence in lowering RUE. Sands (1996) calculated that temperature might influence RUE depending on leaf photosynthetic response to temperature. Andrade *et al.* (1992) concluded that low RUE values for maize grown at Balcarce, Argentina, were a result of low temperature. In additional experiments with maize using varying sowing dates, Andrade *et al.* (1993) found a linear decrease in RUE associated with a decrease in mean temperature from 21 to 16 °C. The leaf photosynthetic rate of peanut decreases in an approximately linear relationship with night temperature lower than 16 °C (Sinclair *at al.*, 1994).

Since crop yield is linked directly to the capacity of plants to utilise the intercepted solar energy in the accumulation of DM, RUE provides the measure that directly reflects the efficiency in the use of radiant energy.

2.4.3 Grain Yield

Grain yield for cereals is usually positively correlated with DM production (Biscoe and Gallagher, 1978). In New Zealand, maize grain yields of 9,600-12,000 kg/ha (Jamieson *et al.,* 1992); 10,900 kg/ha (Johnstone and Wilson, 1991); 8,900-10,000 kg/ha (Wilson *et al.*, 1994) and 3,500-10,800 kg/ha (Wilson *et al.,* 1995) and 8,000 kg/ha for Janna cultivar (Millner *et al.,* 1996) have been reported. Due to the cool temperatures in Canterbury, maize grain yields can be lower than the values cited especially, with late planting and early onset of frost (Wilson *et al.,* 1991).

2.4.4 Nitrogen Fertiliser

The growth, development and yield of cereal crops can be adversely affected by a deficient, or excessive supply of any of the essential macronutrients (Hay, 1981). Low N availability is generally the main soil factor limiting the growth and yield of temperate cereals (Lieffering *et al.,* 1993). Extensive research has shown that N application increases grain yield of cereals such as maize (Sridhar *et al.,* 1991; Chen, 1992; Silva *et al.,* 1992; Muchow, 1994), wheat (Martin, 1997) and barley (Lieffering, 1995). Sridhar *et al.* (1991) reported grain yield increases of 168 % more than the control with NPK. In two 3-year maize trials, the average grain yields ranged 4,870-7,680 and 4,600-7,440 kg/ha in the control and after 202 kg of broadcast N/ha respectively for the two trials (Stecker *et al.,* 1993). Wheat grain yield increased by 2,500 kg/ha with the application of 150 kg N/ha (Martin, 1997).

Nitrogen fertiliser increases yield of cereals by increasing the LAI, RUE (Muchow, 1994) and by increasing LAD (Lieffering, 1995). This in turn results in greater intercepted PAR and DM production (Hay and Walker, 1989; Muchow, 1994; Lieffering, 1995). Moreover, N fertiliser increases forage and DM yield of maize (Palled *et al.,* 1991; Muchow, 1994) and thereby increasing silage production per unit area. The application of 200 kg N/ha raised forage yield by 20.1 and 7.4 % more than the application of 100 and 150 kg N/ha respectively (Palled *et al.,* 1991). Nitrogen enables crops to develop broader and greener leaves which enhances their ability to intercept solar radiation and may increase their RUE. Muchow (1994) observed that a decline in DM yield of maize as a result of low N supply was associated with a much larger decrease in RUE rather than in PAR intercepted. Research by Muchow (1994) and Below and Gentry (1992) have shown that the duration of vegetative growth is more sensitive to N supply than is the grain filling period. Muchow (1994) reported that the component of yield most affected by additional N was the grain number.

2.4.5 Sowing date

The time of sowing is an important determinant of crop yield because it is strongly associated with many factors of the plant environment which influences crop growth and yield. For example, in environments where crop growth and yield are likely to be limited by temperature and water availability, the sowing date strongly influence crop productivity. Maize is a tropical crop, sensitive to frost (Wilson *et al.,* 1991) and drought (Jamieson and Francis, 1991). It should therefore be sown to coincide growth and grain filling with periods of high temperature and moisture availability. The influence of drought is more severe during tasselling and grain filling period.

Extensive research on the effects of sowing date on maize grain yield has shown that in most cases, early sowing gives higher grain yields than late sowing (Johnstone and Wilson, 1991; Sheu and Juang, 1991; Ahmadi *et al.,* 1993; Wilson *et al.*, 1994; Swanson and Wilhelm, 1996). A study in Canterbury, New Zealand, to assess maize yield responses to time of sowing by Johnstone and Wilson (1991) showed that October sown crops yielded 19 % more grain than November sown crops. On the other hand, Ahmadi *et al.* (1993) and Swanson and Wilhelm (1996) noted that delaying planting by four weeks, decreased grain yield of corn and maize by 55 and 48 % respectively. However, to avoid frosty weather thereby ensuring good plant population at establishment with subsequent high DM and grain yield, Wilson *et al.* (1991) recommended that sowing should not commence before 15 October in Canterbury. For example, Wilson *et al.* (1994) reported that maize (cv P3902) sown on 10 October in Canterbury produced only 16,100 kg DM/ha while the 29 October sown crop had 20,400 kg DM/ha. Delaying planting further to 26 November resulted in lower DM yield (16,700 kg/ha). They reported similar pattern for grain yield with changes in sowing date. The maize sown on 10 October, 29 October and 26 November yielded 9,000, 10,700 and 5,700 kg/ha respectively. Late sowing has been found to shorten the period of vegetative growth (ie reduces the period to silking) by El-Zahab and Rady (1990) and El-Shaer *et al.* (1991).

2.4.6 Irrigation response

Moisture stress experienced by a maize crop can affect growth, DM and grain yield by influencing the rate and duration of growth. In the absence of adequate rainfall or irrigation, moisture availability can be the main environmental factor responsible for yield variability (Barta, 1990). It is therefore important to avoid water stress especially early in growth when the root system is shallow and the sensitivity of DM production to drought is high. Moisture stress experienced at anthesis may reduce grain yield by reducing the number of grains that will be filled (Hall *et al.,* 1981; Grant *et al.,* 1989). The effect of irrigation on crop production could be variable depending on the amount and distribution of rainfall received during the growing period. In wet seasons, irrigation often depresses crop yield whereas under dry conditions, yield responses of maize to irrigation have been favourable.

Several authors have reported maize DM and grain yield increases with irrigation (Barta, 1990; Jamieson and Francis, 1991; Palled *et al.,* 1991; Adamsen, 1992; Silva *et al.,* 1992; Jamieson *et al.,* 1995a; Singh and Singh, 1995). Jamieson *et al.* (1995a) and Adamsen (1992) reported that irrigation increased maize grain yield by 2,360 and 2,320 kg/ha respectively. Barta (1990) gave yield responses of 6,620-7,700 and 10,020-10,600 kg/ha on unirrigated and irrigated plots respectively. However, Singh and Singh (1995) and Silva *et al.* (1992) respectively obtained much higher grain yields of 60 and over 300 % higher with irrigation than the unirrigated maize. Dry matter production of 15,000 kg/ha (Millner *et al.,* 1996) and 15,200-20,600 kg/ha (Jamieson and Francis, 1991) were obtained from trials in Palmerston North and in Canterbury for the maize cultivars Janna and P3902 respectively. Similar DM yields have been reported in the literature for irrigated maize (Muchow *et al.,* 1990; Liang *et al.,* 1991; Wilson *et al.*, 1994). Palled *et al.* (1991) reported forage yield of 44,500 kg FW/ha which was 29 % higher than the yield from unirrigated maize crops.

Irrigation has been shown to increase total DM by increasing LAD, intercepted PAR and RUE in cereals (Gallagher and Biscoe, 1978; Jamieson *et al.,* 1994). Jamieson *et al.* (1994) reported that drought reduced the amount of PAR intercepted and RUE of barley plants and resulted in low DM production. The obvious effect of drought on barley DM production is on the LAI as drought accelerates leaf senescence and early maturity reported Jamieson *et al.* (1994). It also keeps leaves from reaching their potential size regardless of time of senescence. Water stress can reduce LAI and LAD by decreasing overall leaf number (Sinclair, 1994), duration and rate of leaf expansion (Jones and Hesketh, 1980) and by increasing the rate of leaf senescence and abscission (Sinclair, 1994). Wilson (1987) noted that water deficit lowers seed yield mainly by reducing PAR interception, by shortening the growth duration and by affecting canopy development. Severe water stress has been reported by Gardner *et al.* (1985) to cause stomatal closure, which reduces CO_2 uptake and DM production as a result of reduced photosynthesis. The yield component of maize which is mostly affected by drought is the mean grain weight (Jamieson and Francis, 1991; Jamieson *et al.,* 1992). Jamieson and Francis (1991) reported no significant variation in the number of grains under drought conditions in Canterbury.

2.4.7 Yield Components

One useful method for examining yield performance is to partition the yield into its components. Grain yield/m^2 (Y) is determined from the ear number/m^2 (En), grain number per ear (Gn) and mean grain weight (Gw) using the relation:

$$Y = En \ x \ Gn \ x \ Gw \text{..................................} 2.3$$

Most experimental work suggests that the effects of water stress on yield components of maize depend on the timing of imposition of stress. The maize yield component most affected by water stress is the mean grain weight (Jamieson and Francis, 1991; Jamieson *et al.,* 1992). However, if the moisture stress is imposed or experienced around the time of anthesis, the grain number is affected most (Hall *et al.,* 1981; Grant *et al.,* 1989). Low grain numbers, due to water shortages around the time of anthesis, have been attributed to poor synchronisation in emergence of male and female flower components (Hall *et al.,* 1981) and to embryo abortion (Westgate and Boyer, 1986). Jamieson *et al.* (1995a) reported that grain yield in maize was correlated with mean grain weight, but was not correlated with grain number in their drought study. However, under normal growing conditions, Below and Gentry (1992), Muchow (1994) and Andrade (1995) have shown that the main determinant of grain yield is grain number per ear. Furthermore, the grain number is more responsive to N than mean grain weight (Muchow, 1994). Wilson *et al.* (1994) reported mean grain weight of 220-242 mg for maize sown on 1 November 1989-90 in Canterbury.

2.4.8 Harvest index

Biological yield and economic yield are used to describe partitioning of DM by plants. Biological yield (By) represents the total above ground DM accumulated by a plant and economic yield (Ey) refers to the weight of economic organs such as grain, seed or tuber yield. Pilbeam (1996) defined HI as the ratio of seed weight to total above-ground dry weight per unit area. Mathematically,

$$HI = Ey/By \text{...........................} 2.4$$

(Gardner *et al.,* 1985). Crosbie and Mock (1981) showed that increases in both biological yield and HI were responsible for increased grain yield of three maize populations. Maize cultivars commonly used in temperate regions have HI's of 0.50-0.55 (Russell, 1985; Tollernaar, 1991) which have been shown to be stable, unless exposed to extreme high or low temperatures, high population density or water stresses (Hay, 1995). Millner *et al.* (1996) reported a HI of 0.51 for Janna maize in New Zealand and Andrade (1995) had 0.45 for maize grown in Argentina.

There is considerable evidence that different levels of crop management may affect the value of the HI. For example, increased plant density (Rees, 1986), increased N fertilisation (Fischer and Kohn, 1966; Muchow, 1994) and irrigation (Angus *et al.,* 1983) have all been shown to reduce HI as they may promote excessive vegetative growth. Long photoperiod and high temperatures, promote vegetative growth and reduce DM partitioning into the sinks and consequently reduce the HI (Cure *et al.,* 1982). Environmental stresses such as water deficit generally reduce HI by affecting canopy development and partitioning of assimilates into sinks. Lemcoff and Loomis (1994) and Lieffering (1995) reported no significant difference in HI with additional N contrary to the findings by Muchow (1994) and Fischer and Kohn (1966).

2.5 Conclusions

Research has shown that maize DM production and grain yield are influenced by organic and inorganic fertilisers, sowing date and irrigation. Both grain and DM yields have been reported to increase significantly with N fertilisers in soils with low N levels provided soil moisture is not limiting. In low rainfall regions, organic fertilisers as a result of conserving more soil moisture, may be more sustainable and give higher crop yield than inorganic fertilisers. Early sowing of maize is preferred to late sowing as grain yield declines with late sowing. Early sowing in Canterbury is important as, at least with early maturing cultivars, early sowing can help to ensure the crop matures before the onset of early frost.

CHAPTER THREE

Materials and Methods

3.1 Introduction

Using legume plant residues to improve soil productivity in agricultural systems in countries which use low inputs of nitrogen (N) fertilisers is once more attracting interest. Both Dalland *et al.* (1993) and Ganeshan (1998) have shown through experiments that soil fertility can be improved significantly through the incorporation of legumes in crop rotations. Furthermore, research has shown that incorporated organic matter improved both the physical and chemical properties of the soil.

The application of organic materials to crops has generally, but not always, given a significant yield response. For example, immature compost applied to crops can result in phytotoxicity from intermediate organic compounds (Zucconi *et al.,* 1981). Organic matter with high C:N ratio (ie greater than 30) causes immobilisation of soil N by micro-organisms (Rosen *et al.,* 1993). Organic matter breakdown may be determined by soil factors such as moisture and temperature which may vary with sowing date. Hence, both the time of incorporation and the quality of organic material incorporated into the soil can influence soil fertility and crop yield.

The time of sowing has been shown to influence the grain yield of maize. In most cases, early sowings have advantages over late sowings. A study in Canterbury, New Zealand, to assess maize yield responses to time of sowing by Johnstone and Wilson (1991) showed that October sown crops outyielded November sown crops. Early sowing in Canterbury is important to ensure that the crop matures before the onset of early frost (Wilson *et al.,* 1991). The aims of this study were to:

I. Assess the effects of tagasaste residues and fertiliser on soil N, organic carbon, pH, bulk density and volumetric soil moisture content.

II. Examine total dry matter (DM) and grain yield of maize after incorporation of varying amounts of tagasaste.

III. Assess the effects of time of incorporation and sowing date on the growth and yield of maize.

IV. Assess the effect of fertiliser and tagasaste incorporation on grain and DM yield of maize under two different soil moisture regimes.

To achieve these objectives, two field experiments were carried out at Lincoln University during the cropping seasons of 1997-98 and 1998-99. The organic matter used for this study was a legume tree species, tagasaste which serves as a fence for paddock.

3.2 Experimental site

The experiments were conducted on a Templeton silt loam soil at Lincoln University, Canterbury, New Zealand (Soil Bureau, 1968). Both experiments were in the same paddock, adjacent to each other and the area had previously been in ryegrass (*Lolium perenne*). Soil analysis for the surface soil (0-25 cm depth) showed soil characteristics were similar and the soil total N was relatively low (Table 3.1).

Table 3.1 Soil chemical analysis for 1997-98 and 1998-99 research sites at 0-25 cm depth.

	pH	C:N	Total N (%)	Organic C (%)	NO_3^- (ppm)	NH_4^+ (ppm)
1997-98	5.7	9.8	0.18	1.8	12.7	2.0
1998-99	5.7	11.3	0.18	2.1	23.8	3.0

3.3 Experimental design

The first experiment (1997-98) was a 2 x 4 factorial randomised complete block design consisting of two sowing dates and four levels of tagasaste incorporation. Tagasaste was incorporated at 0, 5, 10 and 15 t DM/ha and as a fertiliser control, two levels of calcium ammonium nitrate (CAN) (100 and 200 kg N/ha) were applied. Maize seed (cv. Janna) was sown four and eight weeks after tagasaste incorporation. There were three replicates and plot size was 6.3 m x 5.0 m.

The second experiment (1998-99) was a split-plot randomised complete block design. The main plot treatments were two irrigation levels (nil and full) and the sub-plots were 200 kg N/ha of CAN, 0 or 10 t DM/ha tagasaste incorporation. There were three replicates and the sub-plot size was 8.4 m x 5.0 m. Sowing was done four weeks after the tagasaste incorporation.

3.4 Crop husbandry

In both years, the sites were cultivated by ploughing and dutch harrowing before sowing. Tagasaste biomass was harvested and applied fresh after subsampling for DM, N and carbon (C) percentages. In 1997-98 maize seed (cv. Janna) was sown 28 (November 7) and 56 (December 5) days after tagasaste incorporation. In 1998-99 sowing was done on November 2 (ie 28 days after tagasaste incorporation). In both experiments, the fertiliser treatment was broadcast 14 days after seedling emergence and all plots were irrigated with 18 mm of water. The tagasaste residues consisted of leaf : stem ratio of 3.0 and were chopped into small pieces (about 1.0 cm thick) with a chipper and incorporated with a rotary hoe to 15 cm depth. Nitrogen and C contents of the tagasaste were 3.3 % and 46.9 % respectively and were determined using a Leco CNS-2000 analyser. Thus, giving a C:N ratio of 14.0.

Maize seed was treated with carboxin and thiram fungicide at 200 g/l and sown at 17 and 12 seeds/m^2 for the 1997-98 and 1998-99 experiments respectively using an Öyjord cone seeder. Plant population at establishment in 1997-98 was 15 and 16 plants/m^2 for the November and December sown crops respectively. In 1998-99, the plant population at establishment were 10 and 11 plants/m^2 for the tagasaste incorporated plots and the control or 200 kg N/ha plots respectively. Weeds were controlled by hoeing in 1997-98 and by atrazine at 1.5 kg/ha applied at 400 k.p.a. pressure in 1998-99. In 1997-98, crops were irrigated according to a water budget. In 1998-99, fully irrigated crops were given about 20 mm of water each time the volumetric soil moisture content reached 17 % by sprinkler. Irrigation was done four times before tasselling and four times after tasselling. At the last irrigation only 10 mm of water was applied. The unirrigated and irrigated crop respectively received a total of 190 and 340 mm of water. In 1997-98, tasselling of the crop started 73 days after sowing (DAS) on January 19 for the November sown crop and 66 DAS (February 9) for the December sown crop. In 1998-99, tasselling started on January 7 (66 DAS) for the unirrigated crop and on January 14 (73 DAS) for the irrigated crop.

3.5 Measurements

Maize DM, leaf area index (LAI), and the amount of radiation transmitted through the canopy (T_i) were recorded starting 38 DAS and continuing fortnightly until final harvest. In each plot, half of the area was assigned for sequential destructive harvests throughout the season and the remainder was left for final hand harvests. Dry matter was estimated from 0.36 and 0.72 m^2 quadrats for the 1997-98 and 1998-99 experiments respectively. Plants sampled were cut just above the soil surface and oven dried to a constant weight at 70 ^oC. The LAI and T_i were measured using a LICOR LAI 2000 Plant Canopy Analyser. Four readings were randomly taken from each plot during cloudy periods of each sampling day from above and beneath the crop canopy. The LAI was used to calculate the leaf area duration (LAD) using the relationship:

$$LAD = \Sigma(L_{A\,1} + L_{A\,2})(T_2 - T_1)/2 \qquad 3.1$$

where L_A = leaf area and T = time (Gardner *et al.*, 1985). The proportion of radiation intercepted (F_i) by the canopy was calculated according to Gallagher and Biscoe (1978):

$$F_i = 1.0 - T_i \qquad 3.2$$

The amount of photosynthetically active radiation (PAR) intercepted, S_a was calculated from Szeicz (1974):

$$S_a = F_i \times S_i \times 0.5 \qquad 3.3$$

where S_i was the total incident solar radiation recorded at the Broadfield Meteorological Station from the time of crop emergence to physiological maturity. Photosynthetically active radiation was assumed to be equal to 0.5 of S_i. Radiation use efficiency was calculated in most instances as the gradient of the relationship between DM production and cumulative intercepted PAR from seedling emergence to maturity. However, seasonal RUE was based on total DM and total intercepted PAR. Graphs showing the relationship between DM production and cumulative intercepted PAR were plotted from the means of each treatment.

In both experiments final DM and grain yields were estimated at 136 or 150 DAS for the December and unirrigated crop or November and irrigated crop respectively from a single 1.0 m^2 sample. After the number of ears/m^2 were counted, four plants were randomly subsampled and the ears counted and then hand threshed. In the 1998-99 trial, seven plants were subsampled for DM and grain yield determination. The grain was oven dried to a constant weight at 70 °C, weighed and counted.

Another sub-sample of three plants was dried at 60 °C for 24 hours and the N and C levels of the whole plant determined using a Leco CNS-2000 analyser. The plant samples for N and C levels were prepared by grinding with a Cyclotec 1093 Sample Mill.

3.6 Functional growth analysis

Gompertz curves (Pegelow *et al.,* 1977) and generalised logistic curves (Gallagher and Robson, 1984) were used to describe DM accumulation in the 1997-98 and 1998-99 experiments respectively using the relationships:

$$Y = C^* \, exp(-exp(-b(x-m))) \quad \ldots\ldots\ldots\ldots\ldots 3.4$$

$$Y = C/\,(1+T \, exp(-b(x-m)))^{1/T} \quad \ldots\ldots\ldots\ldots 3.5$$

where;

Y = dry matter yield (kg/ha),

C = upper asymptote or maximum dry matter (Y) produced,

T = is a constant,

b = a rate of constant for the curve,

m = point of curve inflection on the x axis which represents time to 50 % of maximum dry matter yield which is also the point of maximum growth rate (kg/ha/d).

The weighted mean absolute growth rate (WMAGR) is the mean growth rate over the period when the crop accumulated most of its DM. The duration of exponential growth (DUR) is the duration of crop growth over which most growth occurred. Using the Gompertz function, the WMAGR, DUR and the maximum crop growth rate (C_m) were calculated for the crop using the values of C, b and e in the following equations:

$$WMAGR = Cb/4 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.6$$

$$DUR = C/WMAGR \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.7$$

$$C_m = Cb/e \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.8$$

Using Generalised logistic curves, the WMAGR, DUR and C_m were calculated from the following equations:

$$WMAGR = Cb/ 2(T+2) \qquad 3.9$$

$$DUR = 2(T+2)/ b \qquad 3.10$$

$$C_m = Cb/ (T+1)^{(T+1/T)} \qquad 3.11$$

where e is base of natural logarithm and equals approximately 2.718. Curves were fitted with the Maximum Likelihood Program (MLP) and the least squares technique was used (Ross *et al.,* 1979).

3.7 Soil analysis

Soil samples were taken from each plot prior to tagasaste incorporation and at two and half and six months after the tagasaste incorporation using a soil corer. Samples taken at two and half and six months after tagasaste incorporation were termed 'at emergence' and 'after harvest' respectively. Four cores were randomly taken from 0-25 cm soil depth and analysed for total N, organic C, pH, NO_3^- and NH_4^+. Soil total N was determined by a semi-micro Kjedahl method with a Selenium catalyst. Soil pH was determined using a pH meter. A 1:10 extraction was performed on a sub-sample using 2 M Potassium chloride as the extractant. Nitrate-N was measured on a flow inlection analyser using a cadmium reduction column. Ammonium-N was measured colorimetrically using a modified Gehrke-Wall (1972) procedure on a technicon auto-analyser. The soil chemical tests were repeated after seed harvest.

Soil bulk density was determined after final harvest using a MC-S-36 strata gauge. One reading was taken from each plot at depths of 5, 10, 15, 20 and 25 cm in both experiments and the mean value computed as the soil bulk density. Volumetric soil moisture content (θ) was determined two times during grain filling and once after the final harvest using Time Domain Reflectometry (TDR). The TDR measurements taken during grain filling were recorded at 48 and 96 hours after a 30.9 mm rainfall. For measurements of θ, two 30 cm transmission rods were inserted into the soil and the soil moisture content was recorded. Three measurements were randomly taken from each plot. All results were analysed by analysis of variance (ANOVA) and mean separation was based on LSD tests at the $\alpha = 0.05$ level.

CHAPTER FOUR

Results

4.1 Climate

Climate data was recorded at the Broadfield Meteorological Station, Lincoln University, about 1.0 km from the experimental site. The cropping season for 1997-98 was considerably drier and warmer than the average long term means (Figure 4.1). Total rainfall, maximum and minimum temperatures from October, 1997 to April, 1998 were 170 mm, 21.8 and 9.7 °C compared with the long term (1975-91) means of 384 mm, 19.8 and 9.0 °C over the same period. The total incident solar radiation of 4,310 MJ/m^2 was approximately 17 % higher than the long term value of 3,680 MJ/m^2 over the same period.

As shown in figure 4.1, there was more rainfall in the 1998-99 cropping season than in the previous cropping season (1997-98) although the total rainfall of 270 mm was still only 70 % of the long term mean. Maximum and minimum temperatures from October 1998 to April 1999 followed the long term pattern with mean temperatures of 19.6 and 10.3 °C respectively. The total incident solar radiation of 3,990 MJ/m^2 was higher than the long term value but this was 8 % less than in 1997-98.

4.2 Effects of incorporation on soil properties

4.2.1 Soil chemical properties

In 1997-98, the total soil nitrogen (N), organic carbon (C), C:N ratio, pH and bulk density did not differ with sowing date (Table 4.1) but NO_3^- levels was higher for the December sowing. Both total soil N and C levels increased with 10 and 15 t DM/ha incorporation. Generally, soil NO_3^- levels increased at all rates of tagasaste incorporation compared with the control plots. The 10 t DM/ha recorded the highest level at 30.3 ppm and the control had the lowest at 16.3 ppm. Tagasaste incorporation had no effect on the C:N ratio or soil pH.

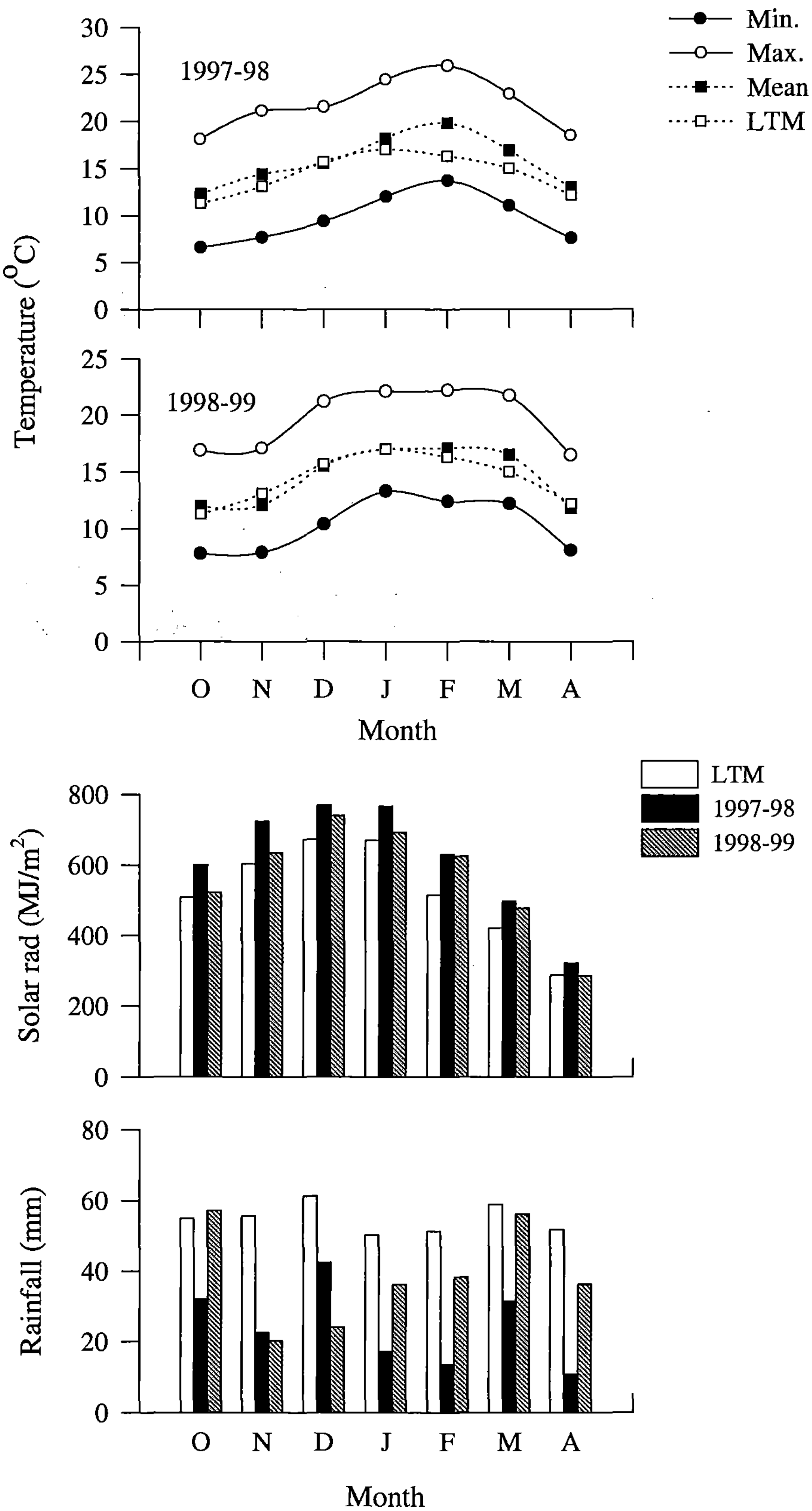

Figure 4.1 Weather data for the 1997-98 and 1998-99 growing seasons and the long term mean (LTM) from 1975-91 for Lincoln University, Canterbury, New Zealand.

Table 4.2 shows that soil tests for total N, C, C:N ratio, NO_3^-, NH_4^+ and pH at seedling emergence did not vary with irrigation in 1998-99. The highest total soil N levels was obtained with the application of 200 kg N/ha which increased the total soil N by 11 % from 0.18 to 0.20. Incorporation of 10 t DM/ha of tagasaste increased the total soil N by only 6 % but did not change the C:N ratio.

Soil tests after harvest in 1998-99 (Table 4.3) again showed higher total soil N levels in the 200 kg N/ha plots than in both the control and the tagasaste incorporated plots. The interaction between incorporation of tagasaste or 200 kg N/ha and irrigation was significant for soil NH_4^+ levels (Table 4.4). While the 200 kg N/ha plots had the lowest NH_4^+ levels of 5.3 ppm in the irrigated (Full) plots, it recorded the highest levels of 20 ppm in the unirrigated (Nil) plots. As shown in Appendix 1, in the 200 kg N/ha plots, NH_4^+ levels were higher in the plots that were irrigated than those that were not irrigated at emergence. Soil tests after harvest showed that the NH_4^+ levels were rather higher in the plots that were not irrigated than those that were irrigated.

There was a positive, linear relationship between total soil N and C (Figures 4.2 and 4.3) in both seasons. In 1998-99, the soil C percentage at emergence and after harvest did not vary with incorporation of either 10 t DM/ha of tagasaste or 200 kg N/ha but the later values were higher than the former. This resulted in a higher C:N ratio (12.0) after harvest compared with a C:N ratio of 11.1 at emergence. The lowest C:N ratios at both emergence and after harvest were from the 200 kg N/ha plots (Tables 4.2 and 4.3) at 10.8 and 11.5 respectively. The highest NO_3^- and NH_4^+ levels at emergence and after harvest in 1998-99 were all recorded from the 200 kg N/ha plots but the levels after harvest were lower than those at emergence.

The soil NO_3^- levels in the 10 t DM/ha plots were similar in both experiments for tests conducted after harvest with a mean of 31 ± 1 ppm. Soil pH did not vary with the incorporation of 10 t DM/ha but it was reduced by application of 200 kg N/ha both at emergence and after harvest in 1998-99. In both analyses, the control and the 200 kg N/ha treatments had the highest and lowest soil pH with respective means of 5.8 and 5.5.

Table 4.1 The effect of tagasaste incorporation and date of sowing maize on the soil chemical and physical properties six months after incorporation in 1997-98.

	N (%)	C (%)	C:N	NO_3^- (ppm)	pH	Bulk density (g/cm^3)
Sowing date						
November	0.196	2.2	11.1	20.7	6.0	1.40
December	0.202	2.2	11.1	30.6	5.9	1.37
Significance	ns	ns	ns	**	ns	ns
SEM	0.003	0.02	0.11	1.78	0.04	0.01
Incorporation						
0 t DM/ha	0.182	2.0	11.0	16.3	6.0	1.42
5 t DM/ha	0.195	2.2	11.2	25.8	5.9	1.41
10 t DM/ha	0.203	2.3	11.1	30.3	5.9	1.35
15 t DM/ha	0.214	2.4	11.1	30.0	5.9	1.35
Significance	**	**	ns	**	ns	*
SEM	0.004	0.03	0.16	2.52	0.05	0.02
Interaction	ns	ns	ns	ns	ns	ns
CV (%)	5	4	4	24	2	3

ns, non-significant; *, $P < 0.05$; **, $P < 0.01$

4.2.2 Soil physical properties

The soil bulk density decreased from 1.42 g/cm^3 in the control plots to 1.35 g/cm^3 in the 10 and 15 t DM/ha plots in the 1997-98 experiment (Table 4.1). The soil bulk densities in 1998-99 (Table 4.3) were similar to those of 1997-98. In 1998-99, the control and 10 t DM/ha plots had mean bulk densities of 1.41 and 1.37 g/cm^3 respectively and were significant at 5 %. The volumetric soil water content for the unirrigated plots was approximately 66 % of the irrigated plots at grain filling. However, it did not vary with the incorporation of 10 t DM/ha or 200 kg N/ha.

Table 4.2 Soil chemical properties at ten weeks after incorporation of tagasaste or two weeks after application of fertiliser (ie at emergence) in 1998-99.

	N (%)	C (%)	C:N	NO_3^- (ppm)	NH_4^+ (ppm)	pH
Irrigation						
Nil	0.20	2.23	11.2	37.3	6.2	5.5
Full	0.18	1.97	11.0	39.4	10.2	5.7
Significance	ns	ns	ns	ns	ns	ns
SEM	0.016	0.155	0.12	1.16	2.16	0.03
Incorporation						
0 t DM/ha	0.18	2.05	11.3	23.8	3.0	5.7
10 t DM/ha	0.19	2.14	11.3	33.2	1.8	5.6
200 kg N/ha	0.20	2.11	10.8	58.2	19.8	5.5
Significance	**	ns	**	**	*	*
SEM	0.002	0.034	0.08	3.76	3.86	0.04
Interaction	ns	ns	ns	ns	ns	ns
CV (%)	2.3	4.0	1.8	24.0	115.0	1.6

ns, non-significant; *, $P < 0.05$; **, $P < 0.01$.

Table 4.3 The effects of irrigation and incorporation of tagasaste or fertiliser on the soil chemical and physical properties six months after the incorporation (ie after harvest) in 1998-99.

	N (%)	C (%)	C:N	NO_3^- (ppm)	NH_4^+ (ppm)	pH	θ (%)	Bulk density (g/cm^3)
Irrigation								
Nil	0.194	2.33	12.0	45.2	10.7	5.5	13.8	1.37
Full	0.171	2.04	11.9	32.3	6.7	5.8	21.0	1.43
Significance	ns	ns	ns	ns	ns	ns	*	ns
SEM	0.013	0.168	0.09	9.18	1.44	0.15	0.84	0.015
Incorporation								
0 t DM/ha	0.175	2.16	12.3	30.3	6.5	5.8	17.4	1.41
10 t DM/ha	0.180	2.19	12.2	32.0	6.8	5.7	18.1	1.37
200 kg N/ha	0.193	2.21	11.5	54.0	12.7	5.4	16.7	1.42
Significance	*	ns	**	ns	*	**	ns	*
SEM	0.004	0.032	0.12	17.75	1.58	0.06	0.58	0.012
Interaction	ns	ns	ns	ns	*	ns	ns	ns
CV (%)	5.6	3.6	2.5	112	44.7	2.4	8.2	2.1

ns, non-significant; *, $P < 0.05$; **, $P < 0.01$; θ, volumetric soil moisture content

Table 4.4 The irrigation by incorporation of tagasaste or fertiliser interaction on soil NH_4^+ concentration after harvest in 1998-99.

	NH_4^+ (ppm)
Irrigated	
0 t DM/ha	7.0
10 t DM/ha	7.7
200 kg N/ha	5.3
Unirrigated	
0 t DM/ha	6.0
10 t DM/ha	6.0
200 kg N/ha	20.0
SEM	2.24

4.3 Growth and dry matter production

Dry matter production for all levels of incorporation was sigmoid (Figure 4.4). There was a rapid near linear growth phase which was preceded an initial phase of slow DM accumulation. The final phase was characterised by a reduction in growth rate as the crop reached the reproductive phase.

In 1997-98, maize DM yield increased by 29 % following tagasaste incorporation (Table 4.5) with yields ranging from 19,700 to 25,400 kg/ha for 0 and 15 t DM/ha incorporation respectively. Dry matter production was not affected by sowing date and there was no interaction between sowing date and tagasaste incorporation. The addition of 100 or 200 kg N/ha gave DM yields of 22,900 or 27,600 kg/ha respectively and these were similar to the yields from the 10 and 15 t DM/ha plots respectively. The DM yield increased by 16 or 40 % with the application of 100 or 200 kg N/ha respectively compared with the control plots.

Dry matter yield increased by 21 % from 18,400 kg/ha in the control plots to 22,300 kg/ha (Table 4.6) in the 10 t DM/ha plots in 1998-99. Plots which received 10 t DM/ha or 200 kg N/ha produced a mean of 22,600 kg/ha. The irrigated plots produced 5,200 kg DM/ha more than the unirrigated plots.

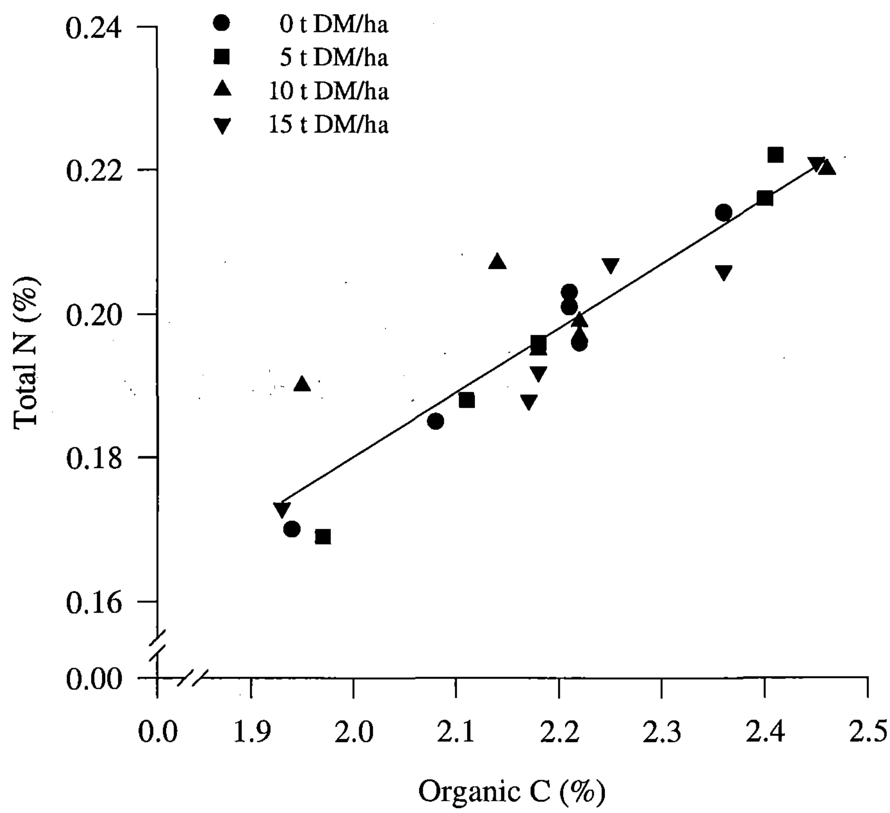

Figure 4.2 Relationship between organic carbon and total nitrogen of soil with 0, 5, 10 and 15 t DM/ha incorporation in 1997-98.
$Y = 0.001 + 0.09x$ ($r^2 = 0.87$)

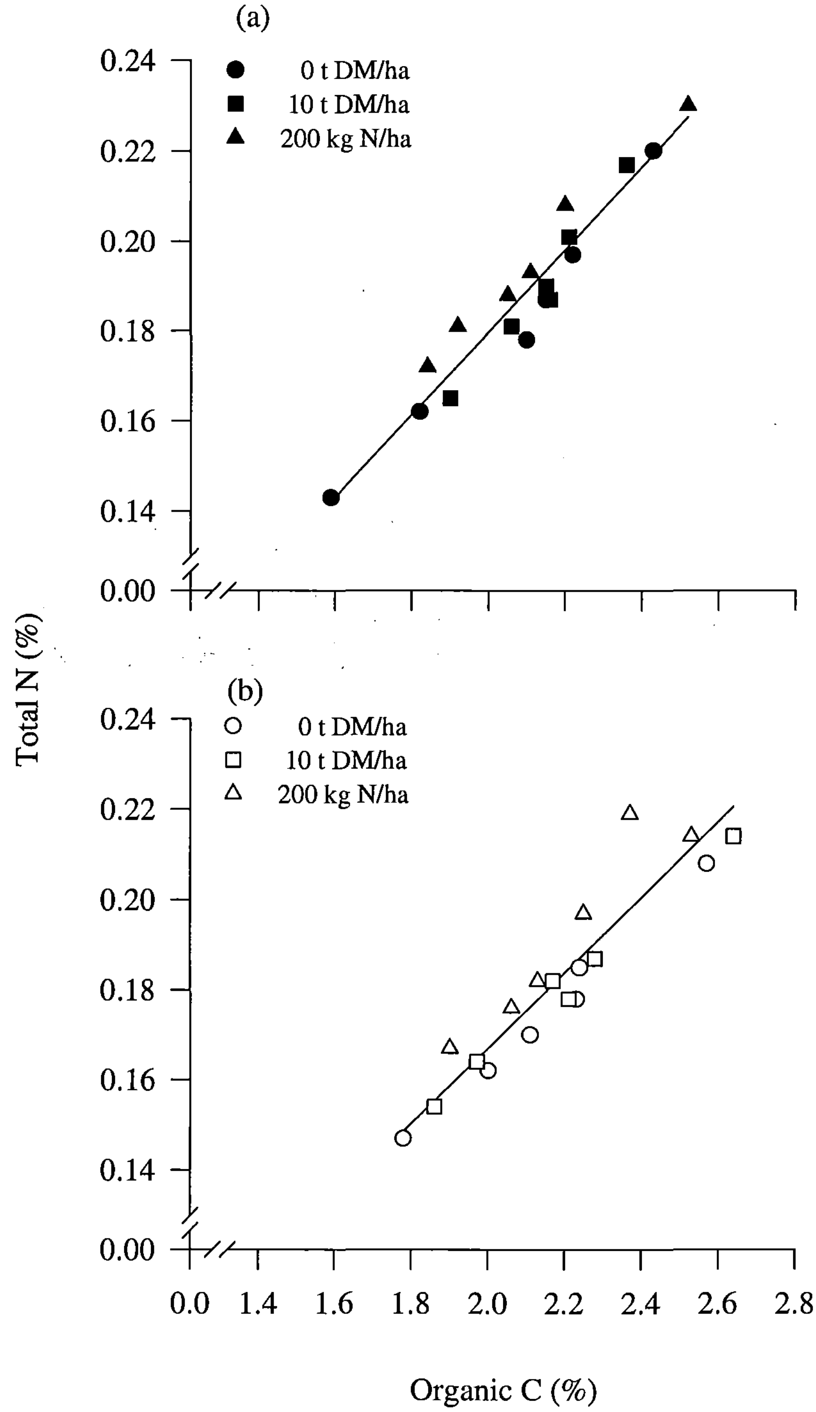

Figure 4.3 Relationship between soil organic carbon and total nitrogen in 1998-99 with incorporation of 0 and 10 t DM/ha or 200 kg N/ha
(a) at emergence: $Y = -0.004 + 0.09x$ ($r^2 = 0.93$) and
(b) after harvest: $Y = 0.004 + 0.08x$ ($r^2 = 0.88$)

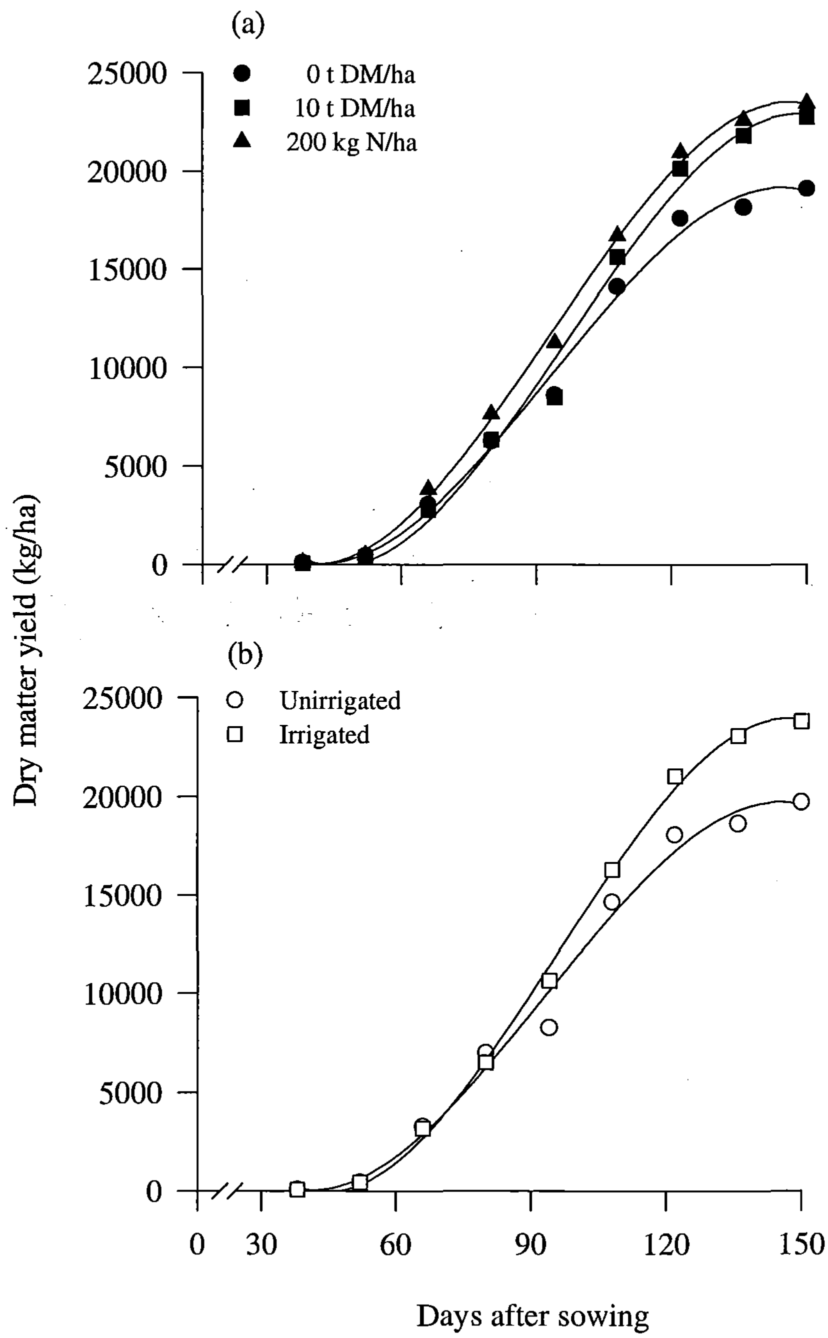

Figure 4.4 Dry matter accumulation of maize with (a) incorporation of 0 and 10 t DM/ha or 200 kg N/ha, (b) full or no irrigation in 1998-99.

Table 4.5 The effects of sowing date and incorporated tagasaste on dry matter (DM), intercepted PAR and radiation use efficiency (RUE) based on cumulative DM and intercepted PAR of maize sown on November and December 1997-98.

	DM (kg/ha)	PAR (MJ/m^2)	RUE g DM/MJ PAR
Sowing date			
November	23,500	970	2.63
December	22,100	810	3.14
Significance	ns	**	*
SEM	552.6	8.7	0.09
Incorporation			
0 t DM/ha	19,700	880	2.59
5 t DM/ha	22,600	890	2.89
10 t DM/ha	23,500	900	2.86
15 t DM/ha	25,400	910	3.22
Significance	**	ns	*
SEM	781.5	12.3	0.12
Control			
0 kg N/ha	19,700	nr	nr
100 kg N/ha	22,900	nr	nr
200 kg N/ha	27,600	nr	nr
Significance	**		
SEM	1,066.4		
Interaction	ns	ns	ns
CV (%)	8.4	3.4	6.0

ns, non-significant; *, $P < 0.05$; **, $P < 0.01$; nr, not recorded

There was a significant interaction between incorporation of tagasaste or 200 kg N/ha and irrigation for DM production. In the irrigated plots, the 200 kg N/ha and the control respectively had the highest and the lowest DM yields (Table 4.7). Dry matter yield from the irrigated plots with 200 kg N/ha (27,000 kg/ha) was higher than the yield from plots with 10 t DM/ha incorporated which was 23,800 kg/ha. These DM yields were similar to the yields observed in 1997-98 for the same incorporation levels. However, in the unirrigated plots, DM yields were similar in the 10 t DM/ha and 200 kg N/ha plots. Both treatments gave higher DM yield than the control.

Table 4.6 The effects of irrigation and incorporation of tagasaste or fertiliser on dry matter (DM), intercepted PAR and radiation use efficiency (RUE) based on cumulative DM and intercepted PAR of maize in 1998-99.

	DM (kg/ha)	PAR (MJ/m^2)	RUE (g DM/MJ PAR)
Irrigation			
Nil	18,600	730	2.97
Full	23,800	860	3.42
Significance	*	**	ns
SEM	713.9	5.8	0.196
Incorporation			
0 t DM/ha	18,400	780	2.86
10 t DM/ha	22,300	830	3.30
200 kg N/ha	22,900	780	3.45
Significance	**	**	**
SEM	482.0	7.0	0.093
Interaction	*	**	ns
CV (%)	5.6	2.2	7.1

ns, non - significant; *, $P < 0.05$; **, $P < 0.01$

The observed DM and expected DM yield (ie calculated maximum C) correlated strongly for both 1997-98 ($r^2 = 0.83$) and 1998-99 ($r^2 = 0.76$) seasons at all incorporation levels. Figure 4.5 shows a stronger relationship for the 1997-98 than for the 1998-99 season.

4.4 Intercepted photosynthetically active radiation

The amount of intercepted photosynthetically active radiation (PAR) decreased with late sowing but it did not vary with tagasaste incorporation in the 1997-98 experiment. As shown in Table 4.5, maize sown in November intercepted 970 MJ/m^2 while the December sown crop intercepted only 810 MJ/m^2. The November and December sown crops respectively intercepted a maximum of 95 and 98 % of the total incident radiation. Maximum interception or canopy closure occurred at LAI's of 3.7 and 4.3 for the November and December sown crops respectively. The plots where tagasaste was incorporated intercepted a mean of 895 MJ/m^2.

Table 4.7 The irrigation by incorporation of tagasaste or fertiliser interaction on dry matter (DM) yield and intercepted PAR of maize in 1998-99.

	DM (kg/ha)	PAR (MJ/m^2)
Irrigated		
0 t DM/ha	20,600	860
10 t DM/ha	23,800	850
200 kg N/ha	27,000	870
Unirrigated		
0 t DM/ha	16,300	700
10 t DM/ha	20,900	810
200 kg N/ha	18,700	690
SEM	681.6	9.9

In 1998-99, maize from the tagasaste incorporated plots intercepted more PAR (830 MJ/m^2) than the control and the 200 kg N/ha plots which intercepted 780 MJ/m^2 (Table 4.6). There was a significant interaction between irrigation and incorporation for the amount of PAR intercepted. The amount of PAR intercepted by the irrigated plants was unaffected by the incorporation of either 10 t DM/ha of tagasaste or 200 kg N/ha (Table 4.7). The grand mean was 860 MJ/ha. However, in the unirrigated plots, maize which received 200 kg N/ha intercepted the lowest amount of PAR (690 MJ/m^2) while those with 10 t DM/ha of tagasaste intercepted the highest (810 MJ/m^2). Irrigation increased intercepted PAR by 18 % from 730 to 860 MJ/m^2. There was a linear relationship between total intercepted PAR and total DM yield (Figure 4.6).

In both experiments, there was a strong relationship between cumulative intercepted PAR and DM production (Figures 4.7 and 4.8). Of the two experiments, crops sown in 1997-98 intercepted more PAR with a mean of 895 MJ/m^2 while the 1998-99 sown crop intercepted only 795 MJ/m^2.

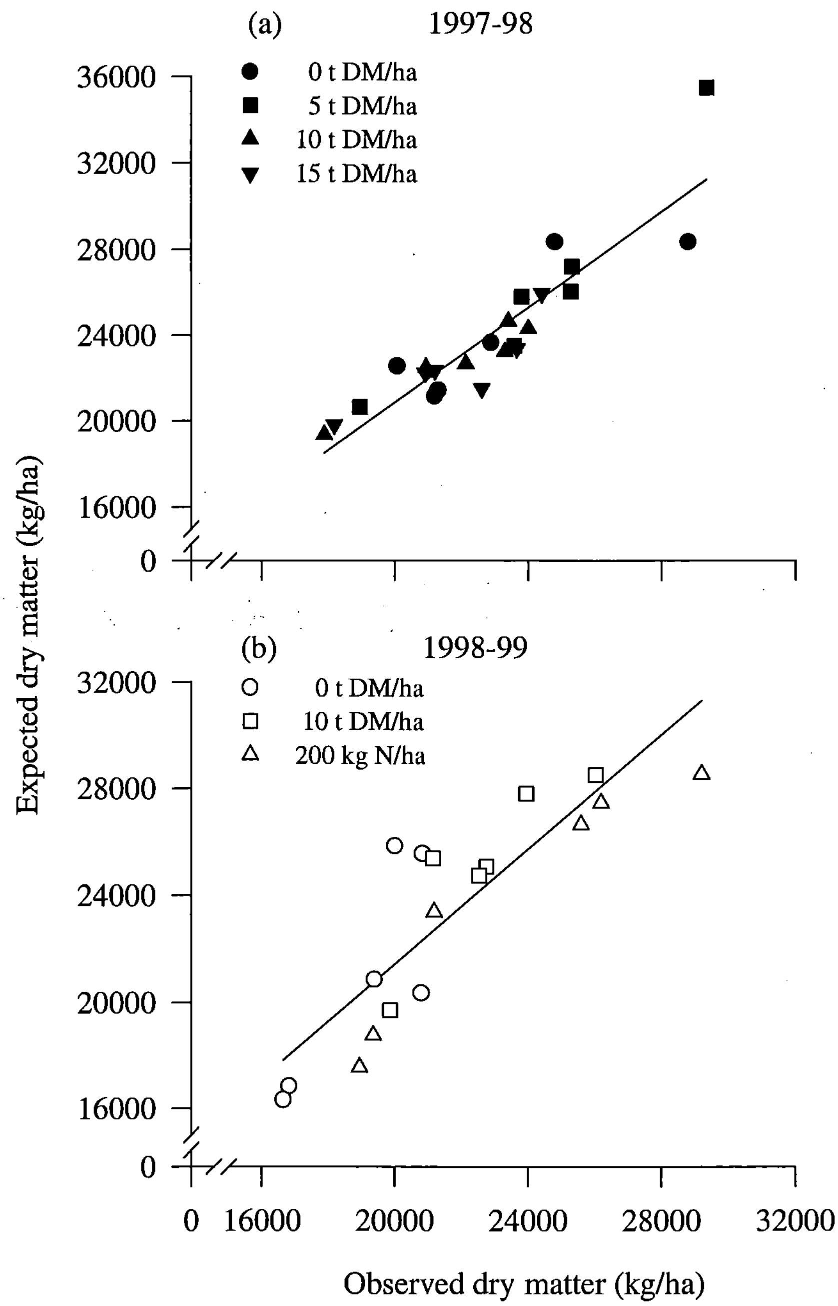

Figure 4.5 Relationship between observed and expected dry matter yield of maize in (a) 1997-98 with 0, 5, 10 and 15 t DM/ha $Y = -1{,}330 + 1.11x$ ($r^2 = 0.82$), (b) 1998-99 with 0 and 10 t DM/ha or 200 kg N/ha. $Y = -56 + 1.07x$ ($r^2 = 0.75$)

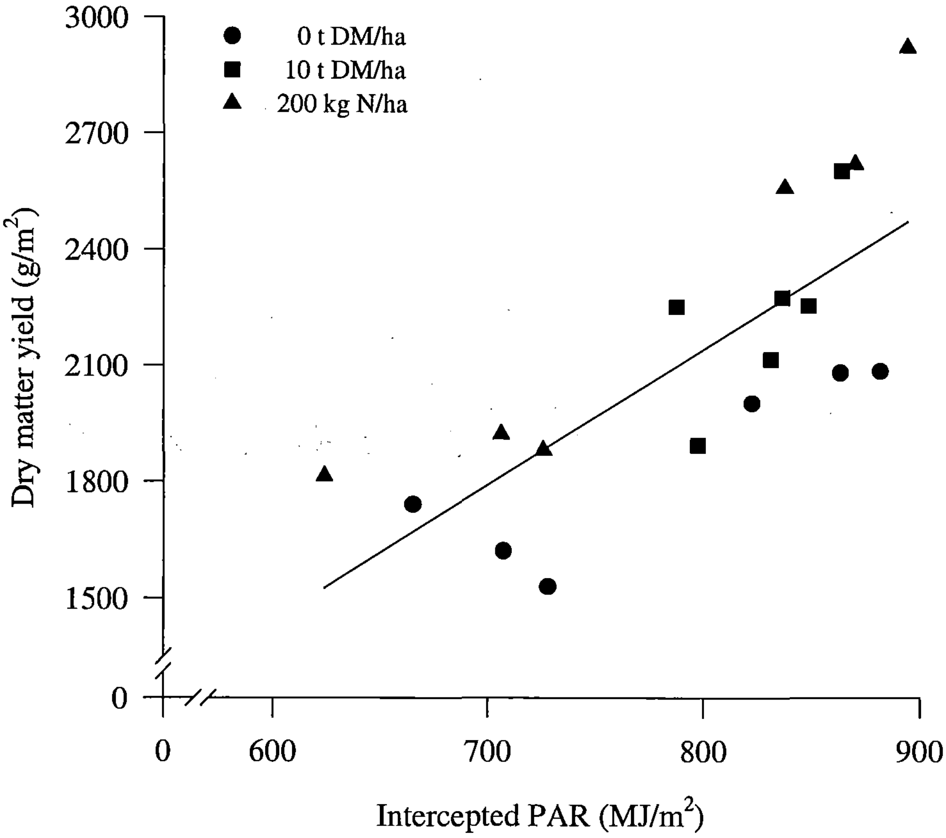

Figure 4.6 Relationship between dry matter yield and intercepted PAR of maize with 0 and 10 t DM/ha incorporation or 200 kg N/ha. $Y = -654 + 3.49x$ ($r^2 = 0.57$)

4.5 Radiation use efficiency

Radiation use efficiency (RUE) based on cumulative intercepted PAR from emergence to physiological maturity varied from 2.59 to 3.22 g DM/MJ PAR in the 0 and 15 t DM/ha plots respectively in 1997-98 (Table 4.5). The December sown maize had a higher RUE of 3.14 g DM/MJ PAR than the November sown crop (2.63 g DM/MJ PAR).

In 1998-99, RUE ranged from 2.86 g DM/MJ PAR for the control plots to 3.45 g DM/MJ PAR for the 200 kg N/ha plots (Table 4.6). The 10 t DM/ha of tagasaste incorporated plots produced 3.30 g DM/MJ of PAR intercepted and this was higher than that of the control plots. Incorporating 10 t DM/ha of tagasaste increased the RUE by approximately 15 % while 200 kg N/ha increased it by about 21 %. However, the RUE did not vary between the 10 t DM/ha of tagasaste and the 200 kg N/ha treatments. The irrigated plots produced DM at a rate of 3.42 g DM/MJ PAR while in the unirrigated plots, it was only 2.97 g DM/MJ PAR.

Radiation use efficiency was higher in the second season with a mean of 3.20 g DM/MJ PAR than in the first season (2.89 g DM/MJ PAR). For example, in 1997-98, the control plots and the plots which had 10 t DM/ha of tagasaste incorporated respectively produced 2.59 and 2.86 g DM/MJ of PAR intercepted. In 1998-99, the control plots produced DM at a rate of 2.86 g DM/MJ PAR while in the 10 t DM/ha of tagasaste incorporated plots, it was 3.30 g DM/MJ PAR. Compared to the control, the incorporation of 10 t DM/ha of tagasaste raised the RUE by 10 % in 1997-98 and by 15 % in 1998-99.

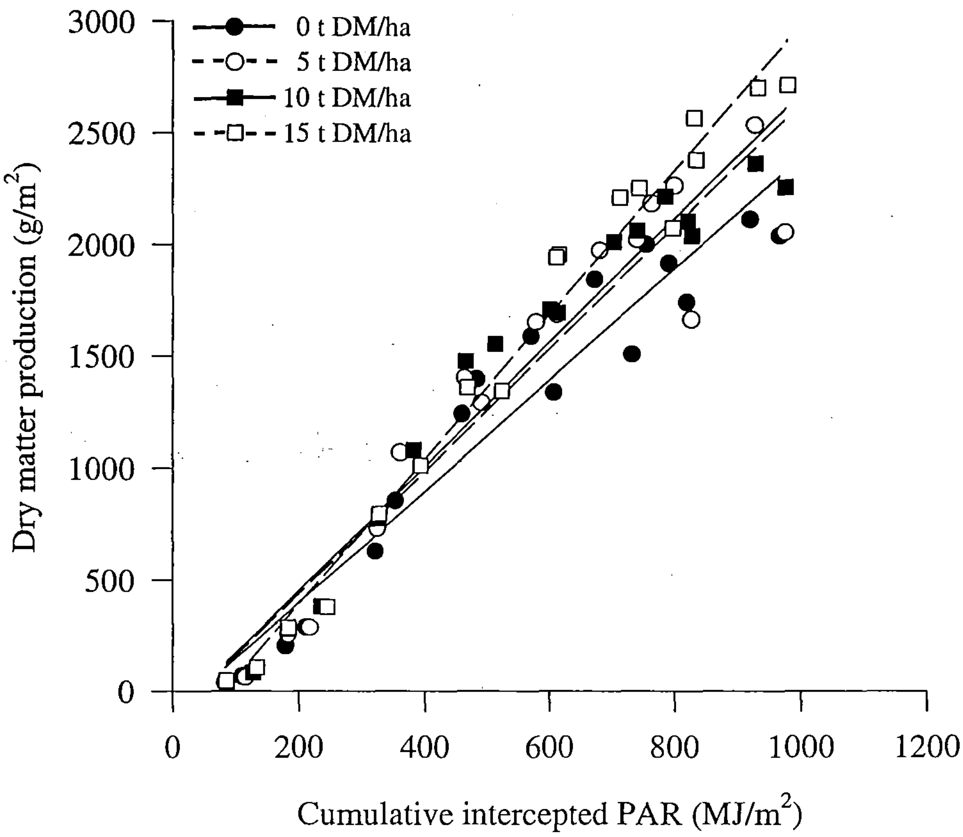

Figure 4.7 Relationship between dry matter production and cumlative intercepted PAR of maize with incorporation of 0, 5, 10 and 15 t DM/ha in 1997-98.

$Y_{\bullet} = -99 + 2.49x$ ($r^2 = 0.94$)

$Y_{\circ} = -111 + 2.74x$ ($r^2 = 0.92$)

$Y_{\blacksquare} = -103 + 2.78x$ ($r^2 = 0.95$)

$Y_{\square} = -255 + 3.23x$ ($r^2 = 0.98$)

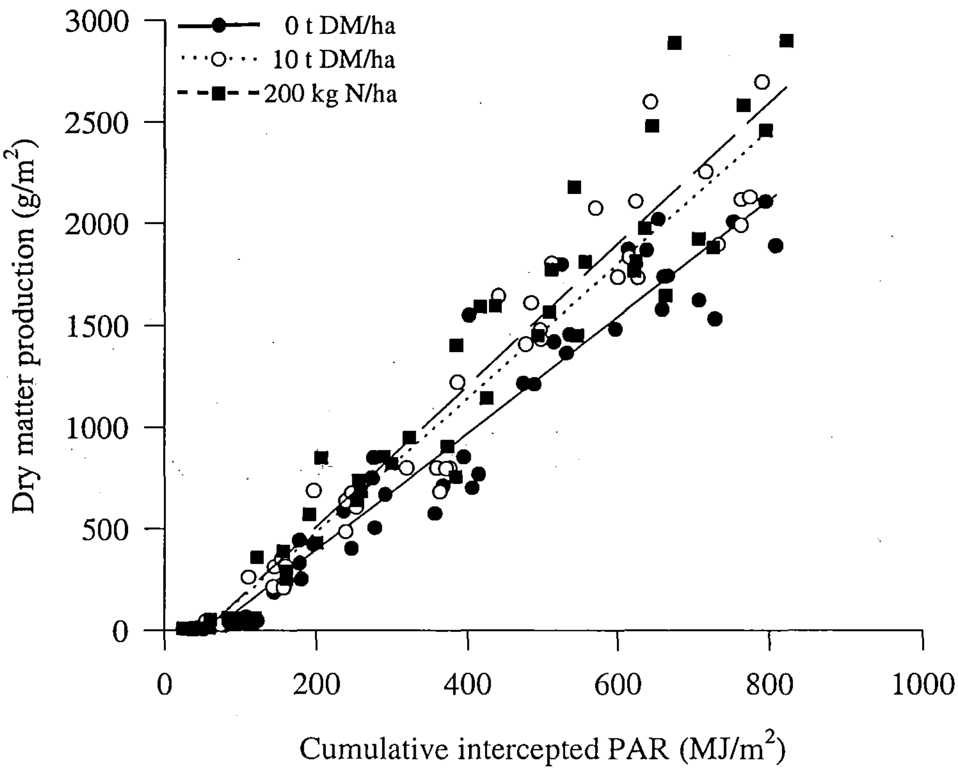

Figure 4.8 Relationship between dry matter production and cumulative intercepted PAR of maize with incorporation of 0 and 10 t DM/ha or 200 kg N/ha in 1998-99.

$Y_{\bullet} = -177 + 2.87x$ ($r^2 = 0.94$)
$Y_{\circ} = -176 + 3.30x$ ($r^2 = 0.95$)
$Y_{\blacksquare} = -187 + 3.48x$ ($r^2 = 0.93$)

4.6 Extinction coefficient

The relationship between leaf area index (LAI) and the proportion of radiation transmitted is shown in Figure 4.9. The slope of the relationship indicates an extinction coefficient (-k) which was stable for both experiments at 0.84. The highly significant coefficient of determination (r^2) of 0.99 showed that no single treatment deviated from the extinction coefficient.

4.7 Intercepted radiation and leaf area index

The relationship between the proportion of radiation intercepted by the canopy and LAI was satisfactorily described by a simple exponential function (Figure 4.10). At low LAI's, small increases in LAI resulted in large increases in radiation intercepted. For example, between LAI of 0.5 - 3.0, the crop intercepted between 30 and 93 % of incoming radiation. About 95 % of the incoming radiation was intercepted at a LAI of 3.2 which is the critical LAI. Above the critical LAI, further increases in LAI only resulted in marginal increases in radiation interception. The 1997-98 crop had higher LAI and consequently intercepted more incoming radiation (approximately 99 %) than the crop sown in 1998-99 which intercepted a maximum of about 95 % of the incoming radiation.

4.8 Functional growth analysis

Plots receiving 15 t DM/ha had faster weighted mean average growth rates (WMAGR) and maximum crop growth rates (C_m) of 26 % over the control plots in 1997-98. The highest and lowest WMAGR of 300 and 240 kg/ha/d were observed in the 15 and 0 t DM/ha plots respectively (Table 4.8). The duration of exponential growth (DUR) was unaffected by either tagasaste incorporation or the date of sowing.

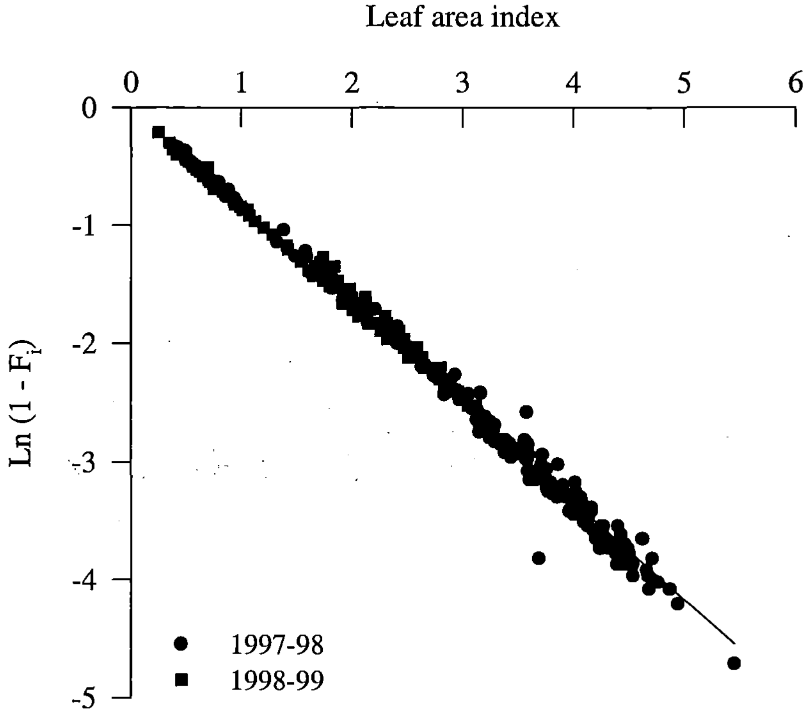

Figure 4.9 Relationship between leaf area index and Ln (1 - F_i) of maize sown in 1997-98 and 1998-99. Y = 0.03 - 0.84x (r^2 = 0.99) (Slope = extinction coefficient).

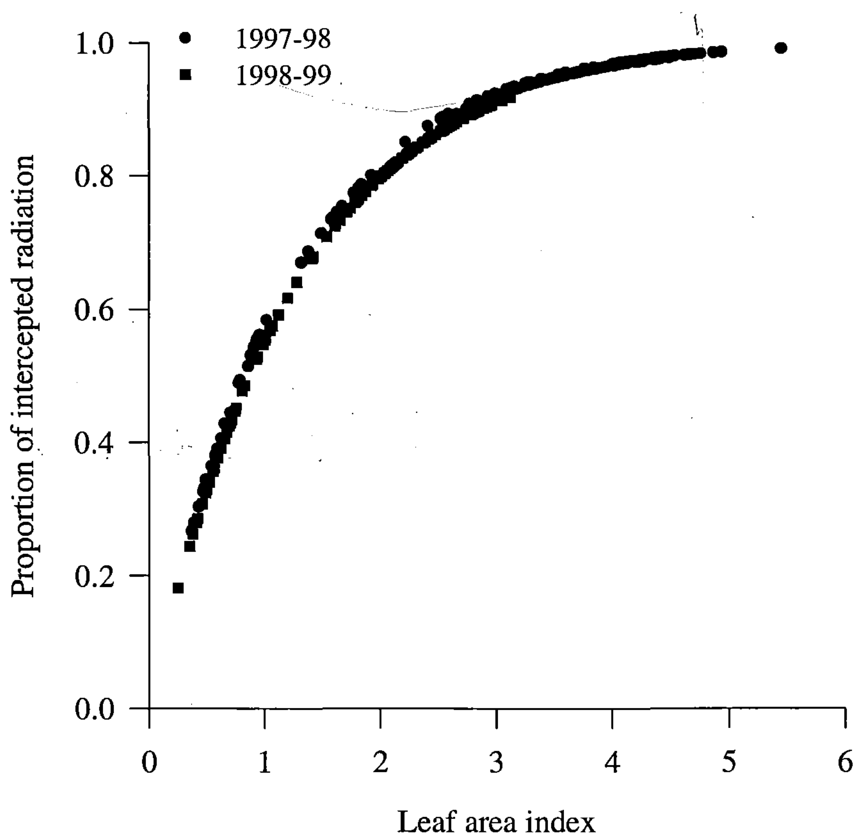

Figure 4.10 Relationship between leaf area index and the proportion of intercepted radiation of maize sown in 1997-98 and 1998-99. $Y = 1 - e^{-0.84 LAI}$

Table 4.8 The effect of sowing date and tagasaste incorporation on the weighted mean absolute growth rate (WMAGR), duration of exponential growth (DUR) and maximum crop growth rate (C_m) of maize in 1997-98.

	WMAGR kg/ha/d	DUR days	C_m kg/ha/d
Sowing date			
November	270	96	400
December	280	87	410
Significance	ns	ns	ns
SEM	16.1	7.1	23.7
Incorporation			
0 t DM/ha	240	91	350
5 t DM/ha	260	95	380
10 t DM/ha	290	88	430
15 t DM/ha	300	91	450
Significance	*	ns	*
SEM	22.8	10.0	33.5
Interaction	ns	ns	ns
CV (%)	20.3	26.9	20.3

ns, non-significant; *, $P < 0.05$

The WMAGR was highest in the 200 kg N/ha plots (290 kg/ha/d) and this was 26 and 16 % higher than that of the control and 10 t DM/ha treatments respectively in 1998-99 (Table 4.9). Maximum crop growth rate (C_m) followed a similar pattern to WMAGR with the 200 kg N/ha having the highest rate of 430 kg/ha/d. The lowest C_m of 350 kg/ha/d for both seasons was obtained in the control plots. The mean WMAGR and C_m were all higher in 1997-98 than in 1998-99. For instance, in the first season, plants in the 10 t DM/ha plots produced DM at a rate of 290 kg/ha/d but in the second season, the rate was only 250 kg/ha/d. The mean DUR for both experiments remained almost constant at 93±1 days. No significant interaction between sowing date and incorporation or between irrigation and incorporation was observed in the 1997-98 or 1998-99 experiments respectively.

Table 4.9 The effects of irrigation and incorporation of tagasaste or fertiliser on the weighted mean absolute growth rate (WMAGR), duration of exponential growth (DUR) and maximum crop growth rate (C_m) of maize in 1998-99.

	WMAGR (kg/ha/d)	DUR (days)	C_m (kg/ha/d)
Irrigation			
Nil	230	91	340
Full	280	97	420
Significance	ns	ns	ns
SEM	32.9	8.8	49.0
Incorporation			
0 t DM/ha	230	95	350
10 t DM/ha	250	103	360
200 kg N/ha	290	84	430
Significance	**	ns	*
SEM	11.2	8.1	17.4
Interaction	ns	ns	ns
CV (%)	10.7	21.1	11.2

ns, non-significant; *, P < 0.05; **, P < 0.01

4.9 Leaf number, leaf area index and duration

Leaf number was very stable and did not vary with either sowing date or tagasaste incorporation (Table 4.10). The maximum number of leaves produced per plant in 1997-98 was 13 which occurred on 76 and 52 DAS for the November and December sown crops respectively.

The difference in leaf area index (LAI) between the two sowing dates became significant at about 38 DAS and remained different throughout subsequent sampling (Figure 4.11) in the 1997-98 experiment. Maize sown in December had an 18 % higher maximum LAI than the November sown crop (Table 4.10). Sowing date did not alter the period to attain maximum LAI but it influenced maximum LAI. The November and December sown crops attained maximum LAI of 3.8 and 4.5 respectively at about 94 DAS. Incorporation of 15 t DM/ha gave the highest LAI of 4.4 which was about 10 % higher than the LAI of the control plots. Maximum LAI at all tagasaste incorporation levels occurred at 94 DAS. Additionally, the 15 t DM/ha had the highest leaf area duration (LAD) at 340 days and this was about 13 % greater than the LAD of the control treatment.

Table 4.10 The effect of sowing date and tagasaste on leaf number, maximum leaf area index (LAI) and leaf area duration (LAD) of maize in 1997-98.

	Maximum Leaf number/Plant	Maximum LAI	LAD (days)
Sowing date			
November	13.3	3.8	310
December	13.0	4.5	320
Significance	ns	**	ns
SEM	0.13	0.08	4.7
Incorporation			
0 t DM/ha	12.9	4.0	300
5 t DM/ha	13.1	4.1	320
10 t DM/ha	13.5	4.2	320
15 t DM/ha	13.3	4.4	340
Significance	ns	*	*
SEM	0.18	0.11	6.6
Interaction	ns	ns	ns
CV (%)	3.3	6.2	5.1

ns, non-significant; *, $P < 0.05$ **, $P < 0.01$

Both maximum LAI and LAD were unaffected by either incorporation or irrigation treatments in 1998-99 (Table 4.11). Maximum LAI for all the incorporation treatments was attained at 94 DAS, except the tagasaste treatment which peaked at 122 DAS (Figure 4.12). As shown in Appendix 2, the LAI however differed at 66 DAS with the 200 kg N/ha plots having the highest compared to the control or the 10 t DM/ha of tagasaste plots. The unirrigated maize attained maximum LAI of 2.4 at 94 DAS; about 28 days before the irrigated crop peaked.

Table 4.11 The effect of irrigation and incorporation of tagasaste or fertiliser on leaf area index (LAI) and leaf area duration (LAD) of maize in 1998-99.

	LAI (122 DAS)	LAD (days)
Irrigation		
Nil	2.2	200
Full	2.7	240
Significance	ns	ns
SEM	0.10	6.86
Incorporation		
0 t DM/ha	2.3	210
10 t DM/ha	2.6	220
200 kg N/ha	2.4	230
Significance	ns	ns
SEM	0.10	5.48
Interaction	ns	ns
CV (%)	10.4	6.1

ns, non - significant

Generally, maximum LAI and LAD at all levels of incorporation were higher in 1997-98 than that of 1998-99. For example, in 1997-98, the 10 t DM/ha plots had LAI and LAD of 4.2 and 320 days respectively compared with LAI of 2.6 and LAD of 220 days in 1998-99. There was a highly significant relationship between LAD and DM production for the tagasaste treatment (Figure 4.13). The regression accounted for 85 % of the variation.

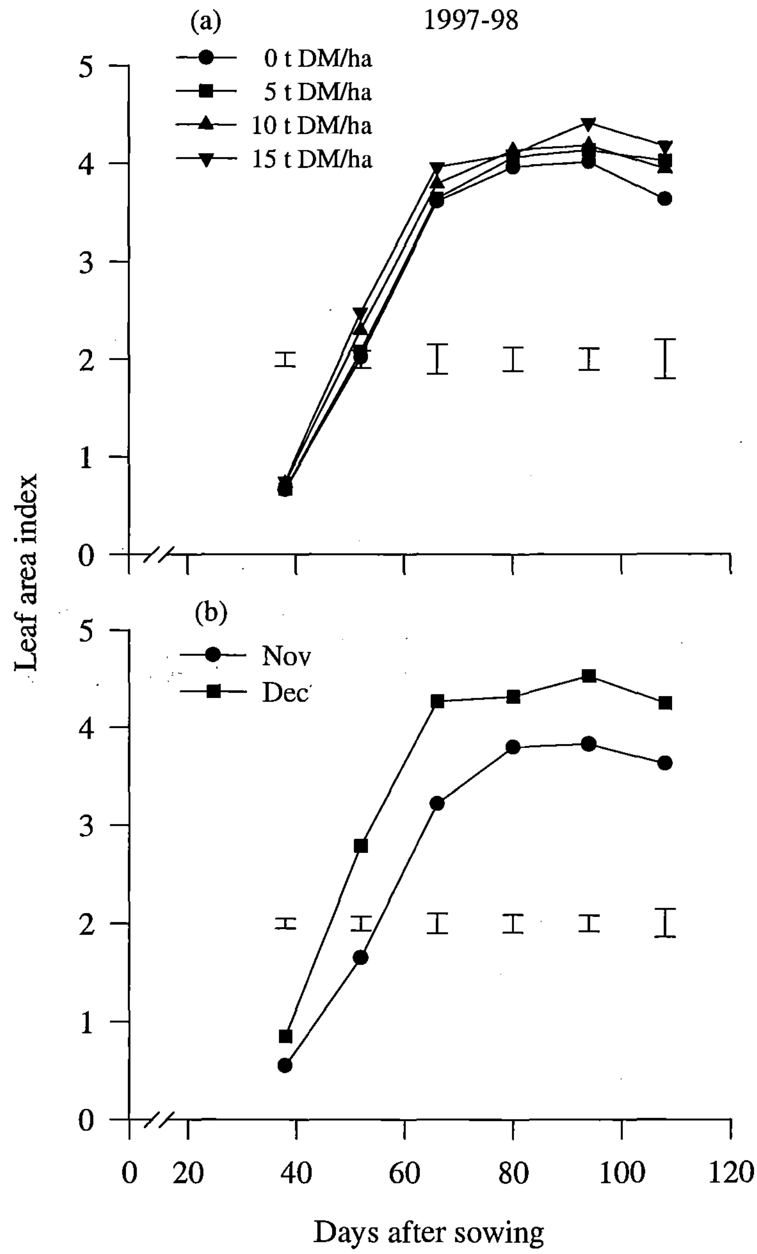

Figure 4.11 Leaf area index over time of growth of maize (a) with 0, 5, 10 and 15 t DM/ha incorporation, (b) sown in November and December 1997-98. (Error bars are SEM)

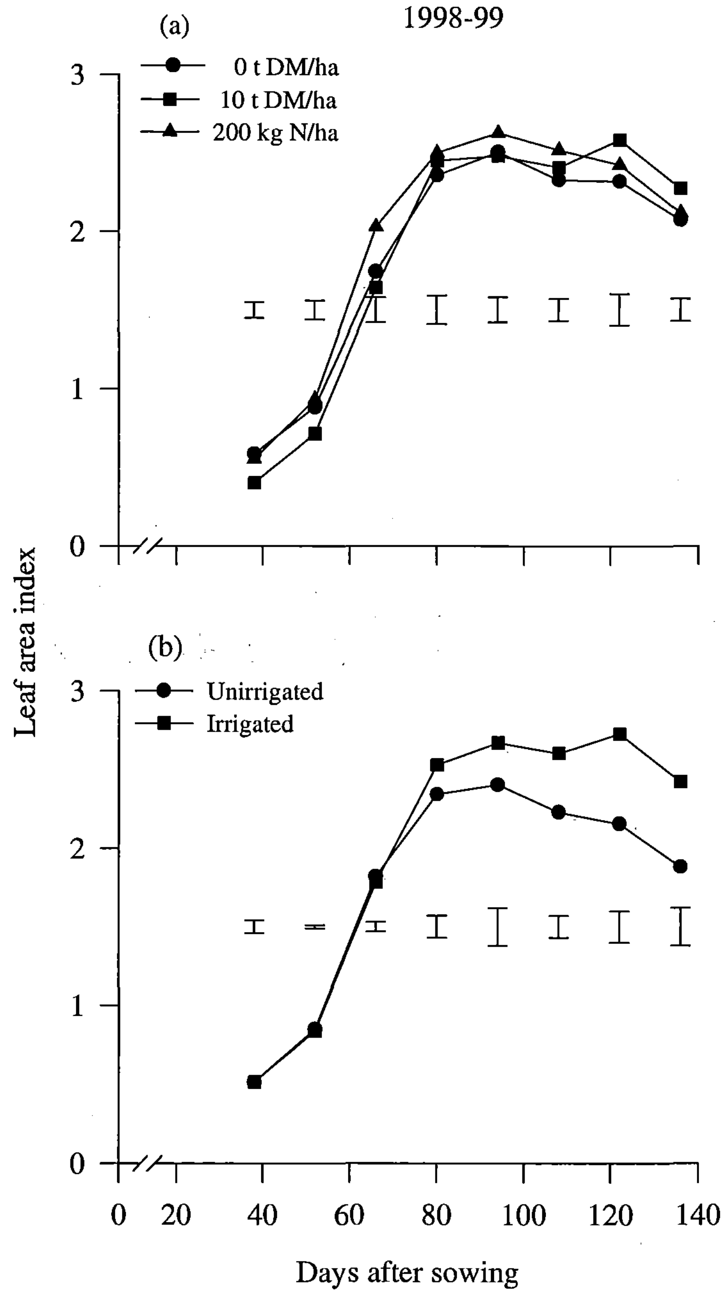

Figure 4.12 Leaf area index over time of growth of maize with (a) incorporation of 0 and 10 t DM/ha or 200 kg N/ha (b) full or no irrigation in 1998-99.
(Error bars are SEM)

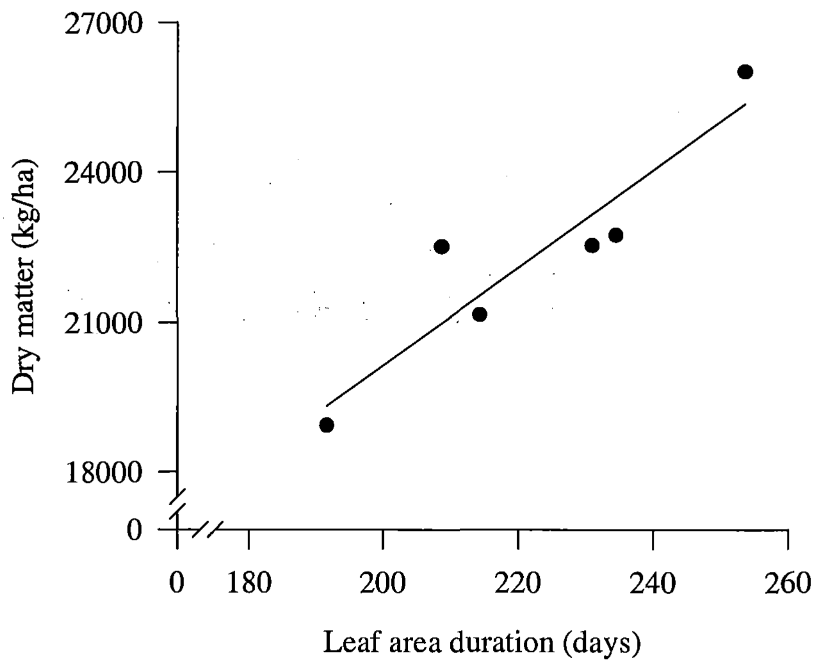

Figure 4.13 Relationship between leaf area duration and dry matter yield of maize with incorporation of 10 t DM/ha in 1998-99. $Y = 627 + 97.6x$ ($r^2 = 0.85$)

4.10 Grain yield

Grain yield increased by 33 % from 7,600 to 10,100 kg/ha (Table 4.12) with incorporation of 15 t DM/ha in 1997-98. The lowest and highest grain yields were recorded in the 5 and 15 t DM/ha incorporation plots respectively. The addition of 100 and 200 kg N/ha gave a grain yield of 8,800 and 11,800 kg/ha respectively and these were similar to yields from the 10 and 15 t DM/ha of tagasaste incorporated plots respectively. However, the increase in grain yield was only significant at the 200 kg N/ha rate. The November sown crop produced 42 % more grain (9,800 kg/ha) than the December sown crop which produced only 6,900 kg/ha.

In 1998-99, tasselling started on 66 and 73 DAS for the unirrigated and the irrigated crops respectively. Plots which received 10 t DM/ha of tagasaste produced a grain yield of 10,500 kg/ha (Table 4.13) which was similar to that of the 200 kg N/ha plots (10,100 kg/ha). Both yields were however, higher than that of the control plots. The highest grain yield was obtained in the 10 t DM/ha plots and this was approximately 24 % higher than the control yield of 8,500 kg/ha. Grain yield did not differ with irrigation and the overall mean was 9,700 kg/ha ($P = 0.067$).

Generally, grain yield for all levels of incorporation was lower in 1997-98 than that of 1998-99. For instance, in 1997-98, incorporation of 10 t DM/ha of tagasaste gave grain yield of 8,400 kg/ha which was only 80 % of the grain yield in 1998-99. The only exception was the grain yield for the 200 kg N/ha plots (11,800 kg/ha) which appears to be higher in 1997-98 than in 1998-99 (10,100 kg/ha). However, considering only the irrigated plots, the grain yield of 12,400 kg/ha for 1998-99 was higher than the yield obtained in 1997-98. As shown in Figures 4.14 and 4.15, DM and grain yield related positively and linearly for both 1997-98 and 1998-99 experiments but, the latter related stronger ($r^2 = 0.84$) than the former ($r^2 = 0.45$). Additionally, the relationship between DM and grain yield was stronger for the irrigated maize ($r^2 = 0.99$) than those that were not irrigated ($r^2 = 0.89$) (Figure 4.16). Total intercepted PAR and grain yield were also positively and linearly related (Figure 4.17).

Table 4.12 The effect of sowing date and tagasaste incorporation on the grain yield and harvest index (HI) of maize in 1997-98.

	Grain yield kg/ha	HI
Sowing date		
November	9,800	0.41
December	6,900	0.32
Significance	**	**
SEM	530.7	0.02
Incorporation		
0 t DM/ha	7,600	0.38
5 t DM/ha	7,400	0.33
10 t DM/ha	8,400	0.35
15 t DM/ha	10,100	0.39
Significance	*	ns
SEM	750.5	0.03
Control		
0 t DM/ha	7,600	0.39
100 kg N/ha	8,800	0.38
200 kg N/ha	11,800	0.42
Significance	**	nd
SEM	753.5	nd
Interaction	ns	ns
CV (%)	22	19

ns, non-significant; *, $P < 0.05$; **, $P < 0.01$; nd, not determined

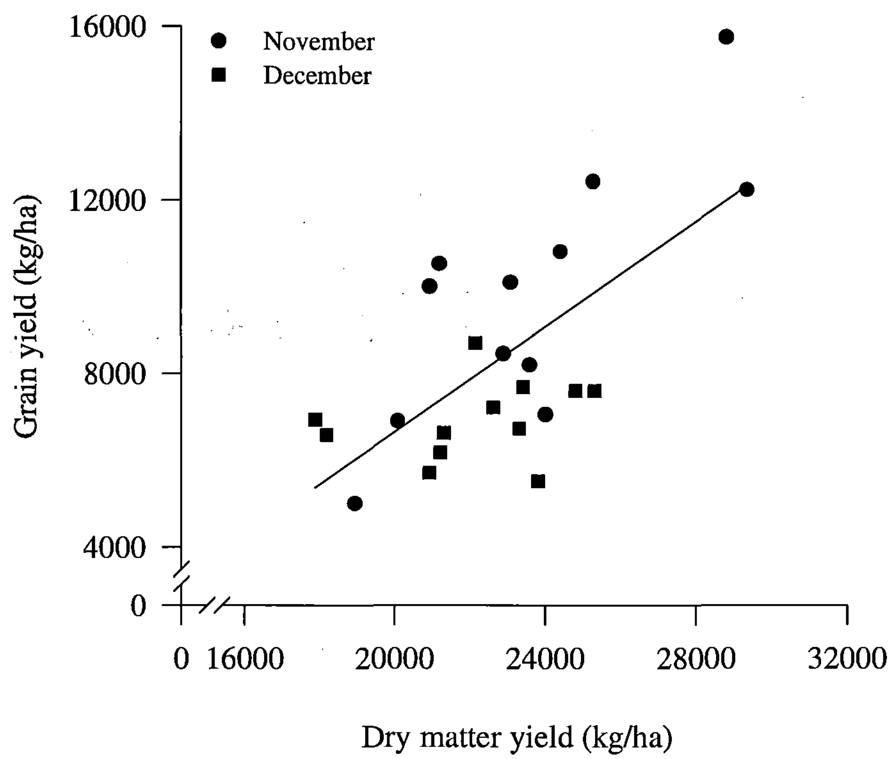

Figure 4.14 Relationship between dry matter and grain yield of maize sown in November and December 1997-98. $Y = -5{,}448 + 0.61x$ ($r^2 = 0.45$)

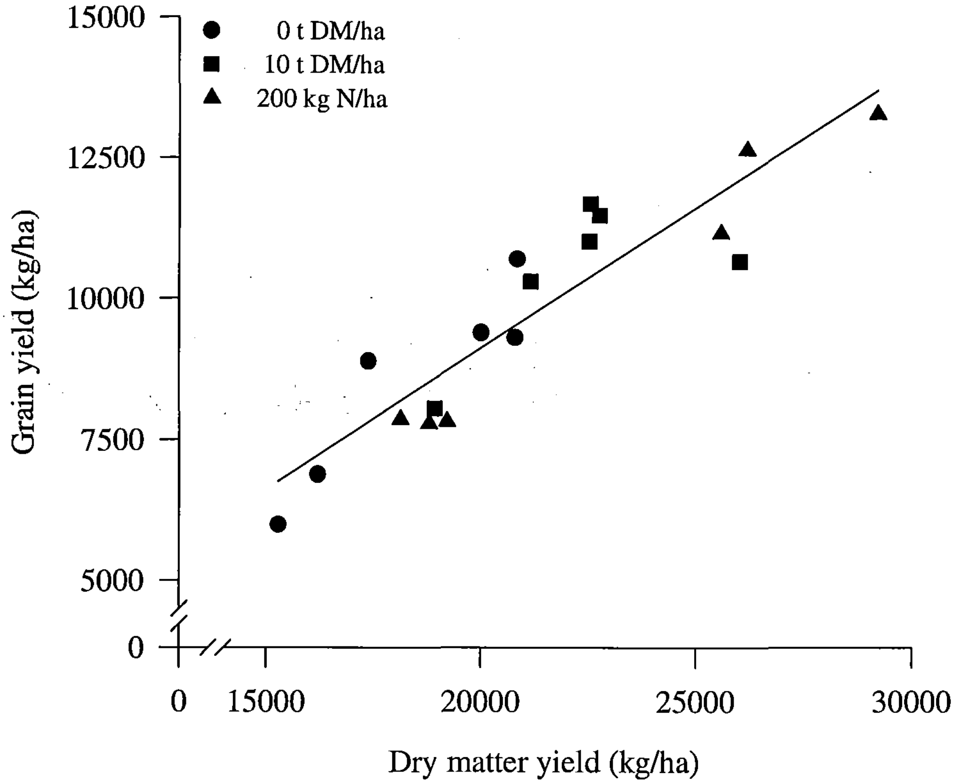

Figure 4.15 Relationship between dry matter and grain yield of maize with 0 and 10 t DM/ha incorporation or 200 kg N/ha in 1998-99. Y = -829 + 0.50x (r^2 = 0.84)

Table 4.13 The effects of irrigation and incorporation of tagasaste or fertiliser on the grain yield and harvest index (HI) of maize in 1998-99.

	Grain yield (kg/ha)	HI
Irrigation		
Nil	8,300	0.44
Full	11,100	0.47
Significance	ns	ns
SEM	547.8	0.021
Incorporation		
0 t DM/ha	8,500	0.46
10 t DM/ha	10,500	0.47
200 kg N/ha	10,100	0.44
Significance	*	ns
SEM	391.0	0.013
Interaction	ns	ns
CV (%)	9.9	7.8

ns, non - significant; *, $P < 0.05$; **, $P < 0.01$

4.11 Harvest index

The harvest index (HI) decreased with late sowing but it did not vary at all levels of tagasaste incorporation in 1997-98 (Table 4.12). The November sown crop had a higher HI of 0.41 than the December sown crop (0.32).

In 1998-99, HI did not differ among incorporation levels or between irrigation treatments (Table 4.13). The mean HI of 0.46 for the experiment conducted in 1998-99 was however, higher than the mean of 0.36 obtained for the 1997-98 experiment.

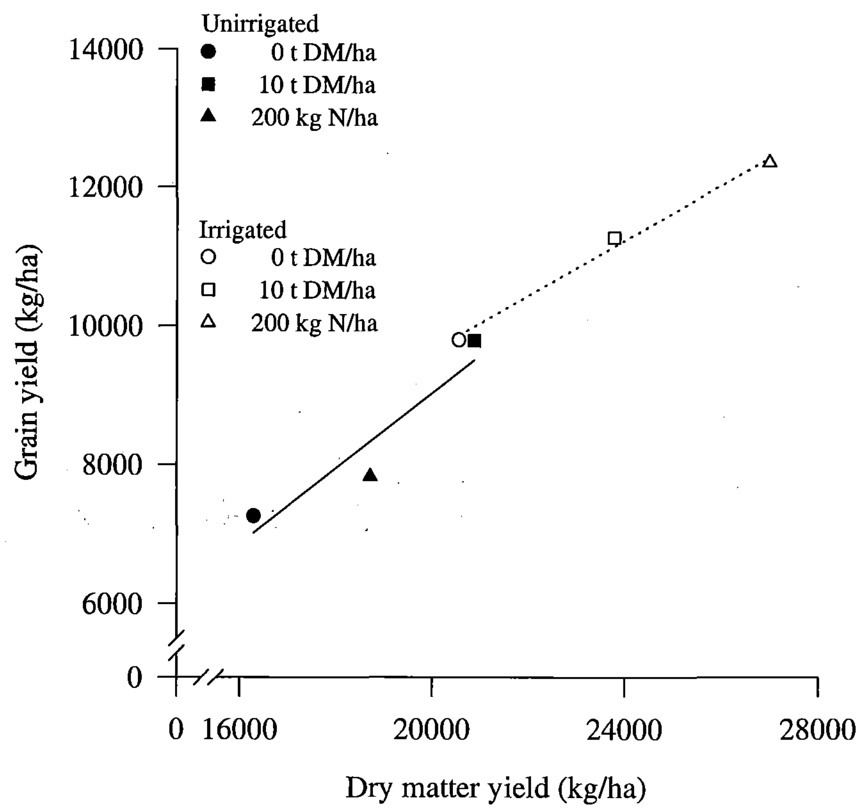

Figure 4.16 Relationship between dry matter and grain yield of unirrigated and irrigated maize with 0 and 10 t DM/ha incorporation or 200 kg N/ha in 1998-99.

Unirrigated: Y = -1,891 + 0.55x ($r^2 = 0.89$)
Irrigated: Y = 1,697 + 0.40x ($r^2 = 0.99$)

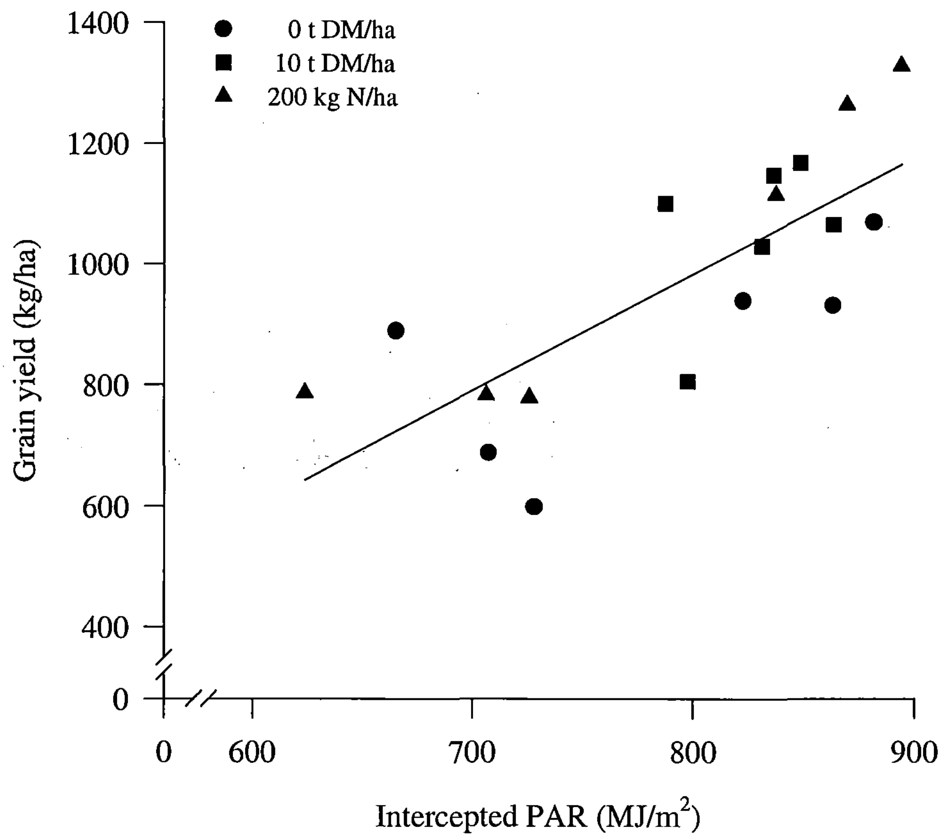

Figure 4.17 Relationship between intercepted PAR and grain yield of maize with 0 and 10 t DM/ha incorporation or 200 kg N/ha in 1998-99. $Y = -556 + 1.93x$ ($r^2 = 0.59$)

4.12 Grain yield components

Grain yield was measured as grain weight per given area (kg/ha) in 1997-98. In 1998-99, it was partitioned into yield components to determine the determinant component responsible for variation in grain yield. The components of grain yield were the number of cobs per square metre (cobs/m^2), number of grains per cob and the mean grain weight. The final grain yield was computed as the product of these three components.

Yield components were very stable in 1998-99, with only grain weight varying with treatments (Table 4.14). The number of cobs/m^2 was unaffected by any treatment and the grand mean was 10.6 cobs/m^2. Grains/cob was also unaffected by any treatment and the mean was 345 grains/cob. While grain weight was not affected by tagasaste incorporation, irrigated plants produced grains (290 mg) that weighed 21 % more than grains from unirrigated plants (240 mg). There was a positive and linear relationship ($r^2 = 0.61$) between the mean grain weight and grain yield (Figure 4.18). As shown in Appendix 3, shoot and grain N and C percentages did not vary with any treatment in 1998-99.

Table 4.14 The effects of irrigation and incorporation of tagasaste or fertiliser on the components of grain yield of maize in 1998-99.

	Cobs/m^2	Grains/cob	Mean grain weight (mg)
Irrigation			
Nil	10.2	340	240
Full	11.0	350	290
Significance	ns	ns	*
SEM	0.70	6.6	4.7
Incorporation			
0 t DM/ha	10.0	330	260
10 t DM/ha	10.8	350	270
200 kg N/ha	11.0	340	270
Significance	ns	ns	ns
SEM	0.42	17.5	6.1
Interaction	ns	ns	ns
CV (%)	9.7	12.6	5.6

ns, non - significant; *, $P < 0.05$.

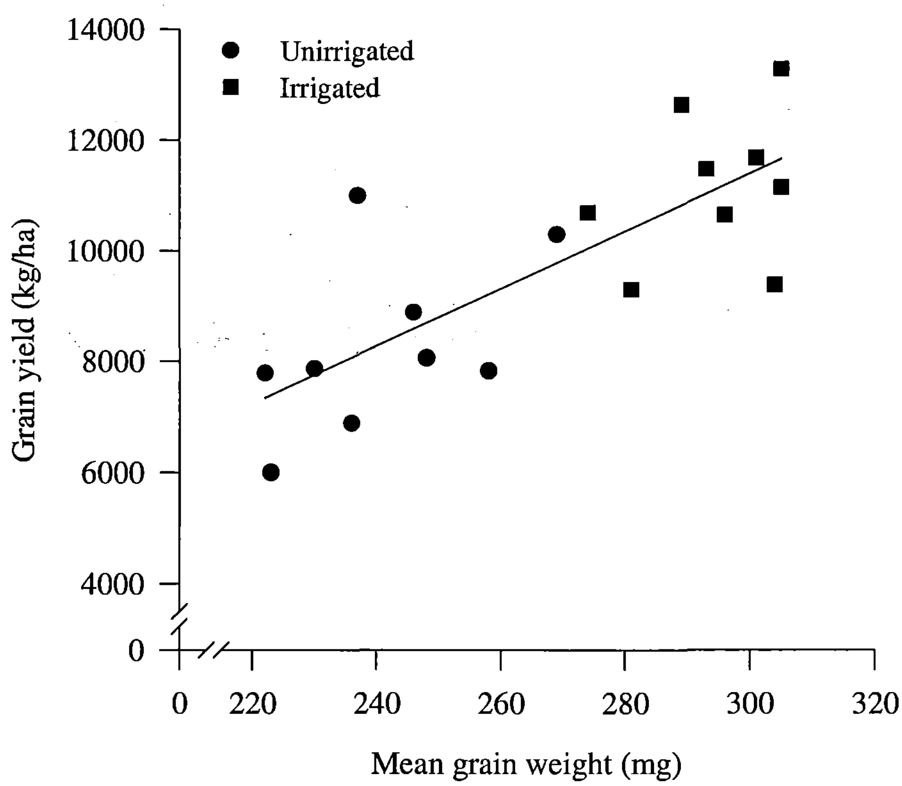

Figure 4.18 Relationship between the mean grain weight and grain yield of irrigated and unirrigated maize in 1998-99. $Y = -4,194 + 52x$ ($r^2 = 0.61$)

CHAPTER FIVE

General Discussion

5.1 Soil fertility

Total soil N and NO_3^- increased with the incorporation of at least 10 t DM/ha of tagasaste residues in both seasons. This confirms observations that organic matter improves soil fertility by Yamoah (1997) and Ganeshan (1998). Chemical analyses on the tagasaste residues showed a mean N content of 3.3 %. This implies that application of 10 t DM/ha will add approximately 330 kg N/ha to the soil when the material is fully decomposed. A fraction of this N though, is likely to be lost through volatilisation, leaching and denitrification.

Soil tests after harvest in both seasons showed higher total soil N levels in the 200 kg N/ha plots than in either the control or the tagasaste incorporated plots. Thus calcium ammonium nitrate proved to be more efficient in supplying plant N than tagasaste residues. Read *et al.* (1985) reported similar results comparing calcium ammonium nitrate and *Leucaena leucocephala* leaves on DM yield of maize. On the other hand, unlike inorganic fertiliser (100 kg N/ha), they found that *L. leucocephala* leaves had a significant residual effect on the subsequent planting.

Plots which had 10 t DM/ha of tagasaste incorporated had higher total soil N levels (0.203 %) in the first season than in the second season (0.180 %). The higher total soil N levels observed in the first season probably resulted from higher temperatures recorded during the 1997-98 cropping season. High temperatures increase the rate of organic matter decomposition (Pandey and Singh, 1982). Warm, wet climatic conditions enhance the decomposition rate while cold temperatures and drought slow down the rate. Moreover, sowing half of the 1997-98 treatments in December gave the incorporated materials a longer period (2 months) to decompose than in the 1998-99 season where the sowing was in November.

As a result of partial decomposition (not measured) of the incorporated tagasaste residues in 1998-99, plant population at establishment was slightly lower (10 plants/m^2) in the 10 t DM/ha of tagasaste plots compared with either the control or the 200 kg N/ha plots (11 plants/m^2). Additionally, from emergence until 66 DAS, crop growth rates and LAI (Appendix 2) were lower in the plots which had tagasaste incorporated than the control or the 200 kg N/ha plots. The possible cause for retardation in initial crop growth rates was immobilisation of soil N by micro-organisms decomposing the carbon compounds (Rosen *et al.,* 1993). However, the soil C:N ratio did not vary with tagasaste incorporation at 10 t DM/ha. Decomposition of organic materials by aerobic organisms releases carbon dioxide (CO_2) while anaerobic organisms release methane (CH_4) or ethylene (C_2H_4). These gases can be toxic to the developing seed embryo and may reduce germination percentage and seedling growth rate (Harper and Lynch, 1981). This suggests that in cool temperature regions, incorporation of organic materials should be done long enough before planting to allow for full decomposition of the organic materials.

In 1998-99, low total soil N values observed after harvest compared with those at emergence were probably due to crop uptake of nutrients for growth and reproduction. The interaction between incorporation of tagasaste or 200 kg N/ha and irrigation was significant for soil NH_4^+ levels (Table 4.4) in 1998-99. While the 200 kg N/ha plots had the lowest NH_4^+ levels of 5.3 ppm in the irrigated plots, they recorded the highest levels of 20 ppm in the unirrigated plots. Probably, nitrification of NH_4^+ to NO_3^- proceeded at a slow rate in the unirrigated plots due to moisture stress.

The increase in soil organic C with tagasaste incorporation did not raise the soil C:N ratio because the N levels was also increased. The tagasaste residues had a C:N ratio of 14 and therefore incorporation of at least 10 t DM/ha increased both the total soil N and C with no effect on soil C:N ratio. This might have resulted in little or no immobilisation of soil N as the tagasaste incorporated maize showed no N deficiency symptoms. Rosen *et al.* (1993) reported that organic materials with excess N beyond a C:N ratio of 30 can provide immediate fertiliser value to crops.

Soil pH did not vary at all rates of tagasaste incorporation in both experiments. The soil pH may decrease at higher rates (above 15 t DM/ha) of tagasaste incorporation. McLaren and Cameron (1996) reported that organic matter decomposition can increase the concentration of H^+ and increase soil acidity. On the other hand, soil pH decreased with the application of 200 kg N/ha as the use of fertilisers containing N in the ammonium (NH_4^+) form results in the production of H^+ ions which lower the soil pH. The H^+ increases with further oxidation by soil micro organisms. *Nitrosomonas* and *Nitrobacter* oxidise NH_4^+ to nitrite (NO_2^-) and further oxidise NO_2^- to nitrate (NO_3^-) by the process of nitrification, at the same time releasing H^+ into the soil.

In both seasons, plots with at least 10 t DM/ha of tagasaste incorporated had lower soil bulk densities compared with the control plots. The reduction of soil bulk density in tagasaste incorporated plots confirms reports by Marshall *et al.* (1996) and Yamoah (1997) that soils containing high organic matter have a lower bulk density than those with a low organic matter content. Furthermore, organic matter is less dense (1.3 g/cm^3) than mineral particles (2.65 g/cm^3) hence, the incorporation of at least 10 t DM/ha of tagasaste should lower the bulk density more than the control or the fertiliser plots. Salau *et al.* (1992) attributed some of this reduction to increased soil biological activity, resulting in higher soil porosity. The significant interaction between incorporation of either 10 t DM/ha of tagasaste or 200 kg N/ha and irrigation for maize DM production showed that the response to additional N depended on the soil nutrient status. This could also be due to improved soil physical condition as organic matter has been shown to lower penetration resistance of soil and increase infiltration rate and pore volume fraction (Dalland *et al.,* 1993). This can increase the soil water holding capacity (Jacobowitz and Steenhuis, 1984). In contrast, the volumetric soil moisture content (θ) did not change with tagasaste incorporation at 10 t DM/ha. As noted by Jacobowitz and Steenhuis (1984) the θ is more likely to increase at higher rates of organic matter incorporation at similar levels of water application.

5.2 Dry matter yield

Nitrogen

As pointed out earlier, incorporation of at least 10 t DM/ha of tagasaste increased total soil N and NO_3^- supply to the maize crop in both experiments. This enabled the maize in the tagasaste incorporated plots to produce bigger leaves which were maintained over a longer duration than those in the control plots in 1997-98. Similar observations were made by Hay and Walker (1989). Since the number of leaves produced per plant was not affected by any treatment, variation in LAI was probably due to changes in individual leaf size.

On the other hand, in 1998-99, the increase in total soil N did not increase maximum LAI, but the LAI differed at 66 DAS (Appendix 2). This contrast was probably due to the different times at which maximum LAI was attained. Maize which received 10 t DM/ha of incorporated tagasaste took longer (122 days) to attain maximum LAI compared with 94 days in the control and the 200 kg N/ha plots. Growth rates were lower in the plots which had tagasaste incorporated than in the control and the 200 kg N/ha plots. Hence by the time the maize in the tagasaste plots attained maximum LAI, leaf senescence had already begun in the control and the 200 kg N/ha plots. Maximum LAI observed in 1997-98 compares favourably with the 3.8 reported by Muchow (1988). In both experiments, the critical LAI of maize did not vary with any treatment and it was constant at 3.2. The critical LAI observed in this study is however, smaller than the 7.4 reported by Brougham (1960) which might be due to cultivar differences.

With increased soil N, LAI and LAD in 1997-98, the maize plants which had had at least 10 t DM/ha of tagasaste incorporated were more efficient in utilising the amount of intercepted photosynthetically active radiation (PAR). For example, the plots which had 15 t DM/ha of tagasaste incorporated produced DM at a rate of 3.22 g DM/MJ PAR while in the control plots it was only 2.59 g DM/MJ PAR. The higher LAD should enable the crops to intercept more PAR but it did not because LAI's were above critical in all treatments. This was probably due to the high plant density 17 plants/m^2, which led to canopy closure in all treatments. However, the 24 % increase in radiation use efficiency (RUE), higher weighted mean absolute growth rate (WMAGR) and increased crop growth rate (C_m) due to 15 t DM/ha incorporation, resulted in higher DM accumulation than in the control plots. This confirms a report by Lieffering (1995) that additional N increased LAD, WMAGR and C_m which resulted in higher DM yields in temperate cereals. This might be caused by increased rate of photosynthesis as shown by Lieffering (1995). Sinclair and Muchow (1999) showed that for maize, RUE achieves a saturation value at high leaf N contents and decreases with decreasing leaf N below the saturation content.

In the 1998-99 experiment, tagasaste incorporation at 10 t DM/ha increased dry matter yield by increasing the amount of intercepted PAR (due to delayed leaf senescence) and by increasing the RUE. As shown in Table 4.2, plots which had tagasaste incorporated had increased total soil N which might have increased leaf N content and the rate of photosynthesis. Consequently, the RUE increased in accordance with an observation by Gimenez *et al.* (1994) that increased soil N fertility resulted in both an increased specific leaf N content and increased RUE.

Sowing date and Radiation use efficiency

Although maize sown in November 1997-98 accumulated DM over a longer duration (150 days) than the December sown crop (136 days), sowing date did not affect DM yield. The longer duration for DM accumulation enabled the early sown crop to intercept more PAR than the late sown crop. It was therefore expected that this will increase DM yield of the early sown maize as a linear relationship usually exists between DM yield and the amount of PAR intercepted (Andrade *et al.*, 1992). However, the higher RUE of the December sown crop at 3.14 g DM/MJ PAR compensated, to some extent, for the shorter duration for DM accumulation. The maize sown in November produced only 2.63 g DM/MJ of PAR intercepted. Cool temperatures experienced by the November sown maize (14.0 ^{o}C) compared with a mean of 15.2 ^{o}C in December 1997, probably resulted in the lower rate of DM production. Andrade *et al.* (1992) and (1993) obtained similar results in maize sown at different dates in Argentina. Leaf photosynthetic rate increased with temperature. Hence the maize sown in November might have intercepted PAR which was not as efficiently utilised for DM production as by the December sown maize.

The mean values of RUE for maize in the 10 t DM/ha of tagasaste incorporated plots for the 1997-98 and 1998-99 experiments were 2.86 and 3.30 g DM/MJ PAR respectively. These values compare favourably with those reported by Andrade *et al.* (1992), 2.96 g DM/MJ PAR and Kiniry (1994), 3.42 g DM/MJ PAR. Dry matter production was related more closely to the RUE than the amount of PAR intercepted in both experiments. A similar observation was made by Tollenaar and Bruulsema (1988).

Irrigation

In 1998-99, the irrigated maize produced more DM than did unirrigated plots. This has also been reported by Jamieson *et al.* (1995a) and Singh and Singh (1995) in maize. The higher soil moisture content of the irrigated plots enhanced leaf longevity of the irrigated maize by 14 days. This enabled the irrigated crops to intercept more PAR (860 MJ/m^2) than the unirrigated crops (730 MJ/m^2). Similar results have been reported by Jamieson *et al.* (1994) with barley. They found that drought keeps leaves from reaching their potential size regardless of time of senescence. The unirrigated maize tasselled about a week before the irrigated maize and might not have accumulated as much DM as the irrigated maize. As shown in Appendices 4 and 5, the irrigated maize plants were taller than the unirrigated maize plants. Irrigation however, did not affect the RUE. According to a report by Jamieson *et al.* (1995b) moisture stress imposed at middle or late periods during the growing season did not affect the RUE in barley. All the maize crops were irrigated soon after fertiliser application, coupled with about 77.5 mm of rainfall received in October and November 1998. Therefore it is probable that the crops did not experience moisture stress during their early growth which is a critical period influencing RUE. In other words, the fact that moisture stress did not decrease the RUE may indicate that a significant soil water deficit was actually not developed. Moreover, the low degree of freedom for testing the effects of irrigation might be responsible for the lack of significant response. The RUE responded more to additional N as noted by Muchow and Sinclair (1994) and sowing date than to moisture stress. In contrast, Muchow (1989) reported a reduction in the RUE as a result of moisture stress which consequently affected DM accumulation.

200 kg N/ha

In 1998-99, the increase in DM yield of maize fertilised at 200 kg N/ha was mainly due to an increase in RUE and not the amount of PAR intercepted. The inability of the 200 kg N/ha treatment to increase the amount of PAR intercepted was mainly caused by the unirrigated maize component. Probably due to increased soil acidity in the 200 kg N/ha plots, the unirrigated crops withered and the leaves senescenced earlier than those in the tagasaste incorporated plots. Hence those crops intercepted only 690 MJ/m^2 of PAR compared with 810 MJ/m^2 of PAR intercepted by the maize in the tagasaste incorporated plots. The significant interaction between irrigation and incorporation showed that both N and soil moisture can influence maize growth and DM production. Liang *et al.* (1992) also found a significant interaction between N and irrigation. Application of 200 kg N/ha to unirrigated maize reduced the amount of PAR intercepted due to early leaf senescence. This resulted in low DM production at 18,700 kg/ha compared with DM yield of irrigated maize with 200 kg N/ha applied (27,000 kg/ha). This shows that moisture stress affects N uptake by maize which may result in poor growth and low DM yield. Furthermore, moisture stress reduces turgor pressure of the maize crop which gives smaller leaves.

In 1997-98, the addition of 100 or 200 kg N/ha gave similar DM yields as the addition of 10 or 15 t DM/ha of tagasaste respectively. This confirms the N fertiliser substitution using tree legumes such as *Canavalia ensiformis* shown by Barreto (1994).

DM yields for 1997-98 and 1998-99

The mean DM yields in both 1997-98 (22,800 kg/ha) and 1998-99 (21,200 kg/ha) were identical and comparable with DM yields of 20,600 and 20,400 kg/ha obtained by Jamieson and Francis (1991) and Wilson *et al.* (1994) respectively in Canterbury. These yields were however, higher than the DM yield reported by Millner *et al.* (1996) for maize cv. Janna of 15,800 kg/ha in the North Island. It appears from this study that increasing plant density from 12 to 17 plants/m^2 did not increase DM yield. Crops sown at high density in 1997-98, intercepted more PAR (895 MJ/m^2) than those sown at low density (795 MJ/m^2) in 1998-99. However, the crops sown at low density produced more DM per MJ of intercepted PAR (3.20 g DM/MJ PAR) compared with 2.89 g DM/MJ PAR at high density and therefore compensated for the low PAR intercepted. This confirms the recommendation by Pioneer Brand Forage products (1996-97) that plant density for silage production using Janna maize should be at 11 plants/m^2.

There was a linear relationship between observed maximum C and calculated maximum C with a gradient of approximately 1.1 for both experiments. This indicates that DM yield recorded in this study was predicted well using either Gompertz or Generalised logistic curves.

5.3 Grain yield and harvest index

Grain yield

Delaying sowing time of maize by four weeks significantly reduced grain yield by 42 % (Table 4.12). This is in accordance with the 48 % reduction in grain yield reported by Swanson and Wilhelm (1996) when sowing was delayed by four weeks. As noted by El-Shaer *et al.* (1991) the late sowing of maize reduced the period to silking by 8 days. According to Singh *et al.* (1987) sowing time regulates the amount of solar radiation received and influences soil moisture reserves. In principle, delaying sowing beyond a given date often results in a progressive reduction in the potential yield because an increasing proportion of the available solar radiation will not be intercepted by the crop canopy. Consequently, the maize sown in December intercepted less PAR than that sown in November. Another factor which could cause variation in grain yield between sowing dates was soil moisture content and temperature as both factors influence the rate of organic matter decomposition (Pandey and Singh (1982). Crops sown at different dates usually pass through each developmental stage at slightly different times and therefore under different environmental conditions (especially photoperiod and temperature), thus any one of the developmental stages which determine the components of yield could conceivably occur under more (or less) favourable conditions in a later-sown crop.

In 1998-99, unirrigated maize plants in the tagasaste incorporated plots maintained their photosynthetic tissues for 14 days after the control and the 200 kg N/ha plants had undergone leaf senescence. The longer grain-filling period increased the amount of PAR intercepted by those crops. Furthermore, it increased maize grain yield probably by promoting the translocation and remobilisation of more assimilate into the sinks.

Grain yield did not differ with irrigation and the overall mean was 9,700 kg/ha (P = 0.067). The failure of irrigation to increase grain yield was at least in part, due to the experimental design used for the analysis. Using a split plot design with only two levels of irrigation as the main plots gave only one degree of freedom for testing main plot effects. This reduced the precision of the ANOVA for the main plot. Irrigation however, increased the mean grain weight as a result of a prolonged grain filling period. This confirms the report of Jamieson *et al.* (1992) who found a significant reduction in the mean grain weight of maize under drought conditions. A strong linear relationship between grain yield and leaf area duration (Figure 4.13) substantiates earlier findings by Wolfe *et al.* (1988). This suggests that crop management which prolongs leaf area duration can increase the amount of radiation intercepted by crops. This can increase DM accumulation and grain yield provided that LAI is less than critical.

Grain yield was lower at 17 plant/m^2 in 1997-98 than at 12 plants/m^2 in 1998-99. For example, incorporating 10 t DM/ha of tagasaste gave a grain yield of 8,400 kg/ha in 1997-98 which was only 80 % of the grain yield obtained in 1998-99. The grain yields observed in this study compare favourably with the range (8,900-10,000 kg/ha) reported by Wilson *et al.* (1994) in Canterbury. As shown in Figures 4.14 and 4.15, the relationship between DM and grain yield was stronger in 1998-99 than in 1997-98. This may be due to reduced harvest index (HI) at the higher plant density. The recommended plant density for grain yield for cv. Janna is 10 plants/m^2.

Harvest index

The harvest index (HI) of maize was not affected by the incorporation of tagasaste or by the application of 200 kg N/ha in both experiments. The failure of additional N to effect HI contradicts the work of Muchow (1994) but confirms an observation by Lieffering (1995) in several temperate cereals. Delaying sowing time of maize to December reduced the HI by 22 %. The November sown crop as consequence of a higher HI, had a higher grain yield than the December sown crop. The late sowings tended to have a lower HI because the crops had higher population at establishment and flowered 8 days earlier than the early sowings. Pyke and Hedley (1985) reported that in peas this may result in more assimilate being partitioned into vegetative growth with a resultant drop in HI. The late sowings produced more shoot at the expense of grain because the vegetative growth phase coincided with long photoperiods and high temperatures. Cure *et al.* (1982) noted that long photoperiods and high temperatures promote vegetative growth and reduce DM partitioning into sinks. This was found to reduce the HI in soybeans.

The low HI (0.36) observed in the first season was partly due to the high plant density causing canopy closure and probably mutual shading. Hence, resulting in reduced net photosynthesis. This can reduce the amount of photosynthate translocated into the sinks for grain filling due to increased net respiration. Millner *et al.* (1996) observed a decline in HI of maize with increased plant density. The mean HI for the second season (0.46) was similar to the HI of 0.45 reported by Andrade (1995) and 0.46 by Millner *et al.* (1996) at a plant population of 10 plants/m^2. The implication is that HI of maize is stable.

The extinction coefficient (-k) was stable for both experiments at 0.84 (r^2 = 0.99). This is slightly higher than the 0.70 reported by Hay and Walker (1989) for maize. Montieth (1977) noted that in horizontal leaves, -k may be as high as 0.90. The high value observed in this study is partly due to the canopy architecture which had horizontal leaves at the top of the canopy. This implies that large proportion of the of incoming PAR was intercepted at the top of the canopy and photosynthesis tended to be distributed over the top leaves. This might have increased mutual shading and reduced the net assimilation rate especially, at high plant densities.

5.4 Conclusions

Total soil N and NO_3^- increased with the incorporation of at least 10 t DM/ha of tagasaste or 200 kg N/ha. The tagasaste residues reduced the soil bulk density, but had no effect on pH or the C:N ratio. The application of 200 kg N/ha increased the soil acidity. The volumetric soil moisture content did not vary at 10 t DM/ha of tagasaste incorporation or 200 kg N/ha. The recommended level of tagasaste incorporation is at least 10 t DM/ha and that gave a similar DM yield to 100 kg N/ha.

Incorporating at least 10 t DM/ha of tagasaste residues increased both the DM and grain yield of maize by increasing the RUE in both seasons. Sowing maize in early

November gave maximum grain yield but it made no difference to DM production. The application of 200 kg N/ha gave higher DM yield than the 10 t DM/ha of tagasaste in the irrigated plots. However, under moisture stress, DM yields were similar in both plots. Dry matter yield of maize generally increased with irrigation in Canterbury. Incorporation of tagasaste residues should be done long enough before planting to allow for full decomposition in cool regions like Canterbury.

5.5 Recommendations for future research

There is the need for further research in the following areas:

1. The decomposition rate of tagasaste residues.
2. The influence of environmental factors such as soil temperature and soil moisture on the rate of decomposition of tagasaste residues.
3. Work on soil type differences and tagasaste incorporation.
4. Residual effects of tagasaste incorporation on soil fertility.
5. Influence of higher rates of tagasaste incorporation (ie above 10 t DM/ha) on volumetric soil moisture content.

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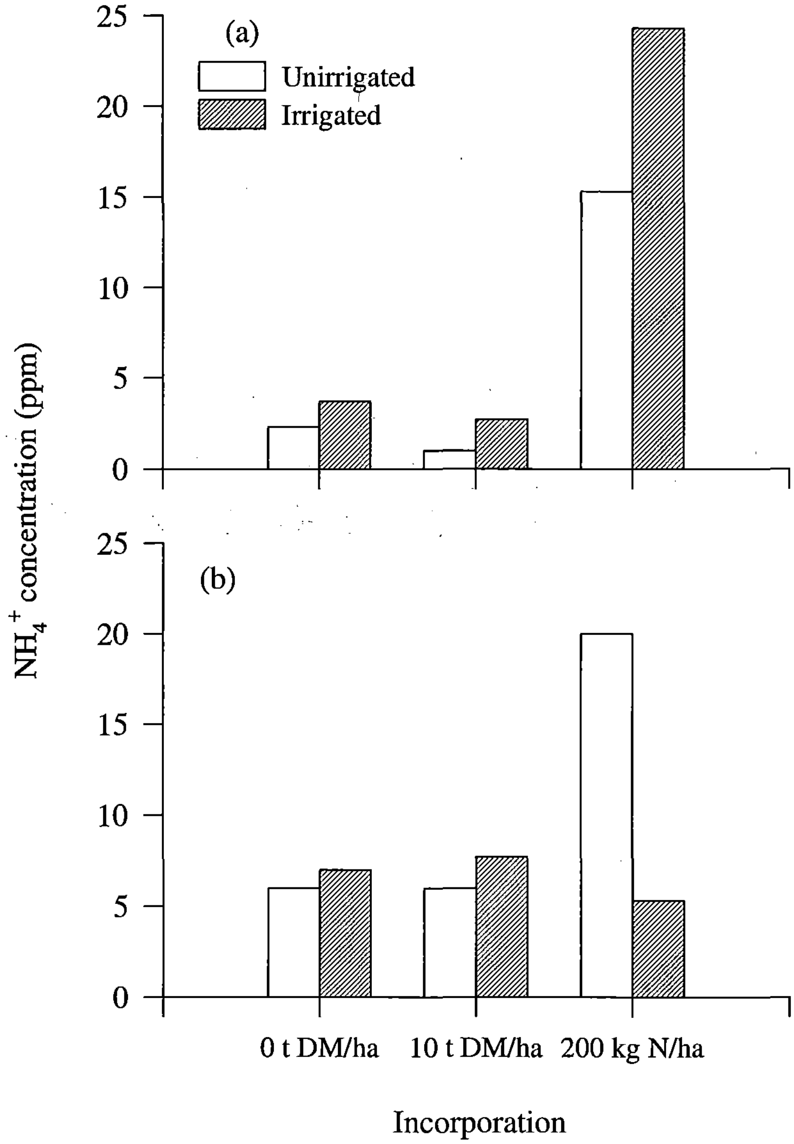
Appendices



Appendix 1. The irrigation by incorporation of tagasaste or 200 kg N/ha interaction on soil NH_4^+ concentration (a) at emergence and (b) after harvest in 1998-99.

Appendix 2. Leaf area index of irrigated and unirrigated maize sown in 1998-99 with incorporation of tagasaste or fertiliser

	38 DAS	52 DAS	66 DAS	80 DAS	94 DAS	108 DAS	122 DAS	136 DAS	150 DAS
Irrigation									
Nil	0.5	0.8	1.8	2.3	2.4	2.2	2.2	1.9	1.4
Full	0.5	0.8	1.8	2.5	2.7	2.6	2.7	2.4	1.9
Significance	ns	ns	ns	ns	ns	P=0.056	P=0.055	ns	ns
SEM	0.05	0.02	0.01	0.07	0.12	0.06	0.09	0.12	0.10
Incorporation									
0 t DM/ha	0.6	0.9	1.7	2.4	2.5	2.3	2.3	2.1	1.5
10 t DM/ha	0.4	0.7	1.6	2.5	2.5	2.4	2.6	2.3	1.7
200 kg N/ha	0.6	0.9	2.0	2.5	2.6	2.5	2.4	2.1	1.6
Significance	ns	ns	*	ns	ns	ns	ns	ns	**
SEM	0.05	0.06	0.08	0.09	0.08	0.06	0.01	0.07	0.06
Interaction	ns	ns	ns	ns	ns	ns	ns	ns	ns

ns, non-significant; *, $P < 0.05$; **, $P < 0.01$

Appendix 3. The effects of irrigation and incorporation of tagasaste or 200 kg N/ha on carbon and nitrogen percentage of maize shoot and grain in 1998-99.

	C	N
	%	%
Irrigation		
Nil	41.9	1.51
Full	41.8	1.66
Significance	ns	ns
SEM	0.16	0.08
Incorporation		
0 t DM/ha	41.65	1.43
10 t DM/ha	41.68	1.70
200 kg N/ha	42.13	1.64
Significance	ns	ns
SEM	0.24	0.08
Interaction	ns	ns
CV(%)	1.4	11.6

ns, non - significant

Appendix 4. Irrigated maize plants in 1998-99.

Appendix 5. Unirrigated maize plants in 1998-99.

Appendix 6. Leaf area index of maize sown in November or December with different rates of tagasaste incorporation in 1997-98.

	38 DAS	52 DAS	66 DAS	80 DAS	94 DAS	108 DAS	122 DAS
Sowing date							
November	0.6	1.7	3.2	3.8	3.8	3.6	3.7
December	0.9	2.8	4.3	4.3	4.5	4.3	3.3
Significance	**	**	**	**	**	**	*
SEM	0.05	0.07	0.10	0.09	0.08	0.14	0.11
Tagasaste							
0 t DM/ha	0.7	2.0	3.6	4.0	4.0	3.6	3.4
5 t DM/ha	0.7	2.1	3.6	4.1	4.1	4.0	3.6
10 t DM/ha	0.7	2.3	3.8	4.1	4.2	3.9	3.4
15 t DM/ha	0.8	2.5	4.0	4.1	4.4	4.2	3.8
Significance	ns	*	ns	ns	*	ns	ns
SEM	0.07	0.09	0.15	0.12	0.11	0.20	0.16
Interaction	ns	ns	ns	ns	ns	ns	ns

ns, non-significant; *, P < 0.05; **, P < 0.01