SOME ASPECTS OF COMPETITION BETWEEN A TROPICAL GRASS AND A TROPICAL LEGUME

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ABSTRACT

Verano stylo (Stylosanthes hamata c.v Verano) and Guinea grass (Panicum maximum c.v Coloniao) are two tropical pasture species reported to be superior in performance to many other species in the northeast of Thailand. A mixed pasture of these two species, therefore, has a potential to produce a high herbage yield in terms of both quantity and quality. Little is known, however, about the compatibility of these two species. A glasshouse experiment was set-up to establish competitive situations between these two species. The experimental design was based on the de Wit model (Replacement series principle).

Dry matter yield per plant of both species decreased markedly when the grass proportion increased. The reduction in dry matter yield was not proportional to the increase in grass proportion. Branch number in legume and tiller number in grass was the yield component most sensitive to plant competition. The results of relative replacement rate analysis indicated that during early stages of growth verano stylo was very sensitive to competition from grass. Verano stylo appeared to compete with the guinea grass more successfully after it had approximately 20 leaves.

An increasing grass proportion had no affect on the shoot/root ratio of the guinea grass but decreased the shoot/root ratio of legume plants

Plant height of guinea grass was decreased by increasing plant competition while legume height was not affected. In contrast, leaf area distribution of legume was affected by increasing plant competition while that of guinea grass was not affected.

Increasing plant competition decreased herbage quality in both species as measured by the leaf/non-leaf ratio. In addition, under severe competition legume plants also showed a reduction in leaf nitrogen concentration.

Flowering time of verano stylo was markedly affected by competition from guinea grass. Flowering occurred after 7 weeks in the monoculture. In association with grasses flowering was delayed on average 11 weeks in two treatments while in the mixture containing the highest proportion of grass the legume plants remained vegetative throughout the trial.

The results demonstrated that there was no yield advantage from any of mixtures between these two species over the monoculture under the conditions of this study. One of the posssible reasons for this severe suppression of verano stylo from the guinea grass plants could have been associated with a consequent reduction in the legume capacity to fix nitrogen. The legume monoculture appeared to produce a higher yield than the other combinations in terms of protein content. Management strategies to help overcome legume suppression are discussed. Options such as reducing grass population relative to legume, establishing the legume before the grass, earlier defoliation, and/or the strategic application of fertilizers.

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CHAPTER 1

INTRODUCTION AND OBJECTIVE

1.1 Introduction

About half of the world's grazing animals are in the tropics, but output of animal products from this land is very much less than the rest of the world (Humphreys, 1980b). One of the reason is due to the grazing animal's heavy reliance on natural grassland resource, with its low productivity (Jones, 1972; Humphreys, 1980a; Shelton, 1983). The productivity of natural grassland is limited both in terms of quantity and quality. These limitations may be partly overcome by oversowing natural grassland with improved legume species, or by replacing the natural grass land species with selected high quality sown grass and legume species. The oversown legume species increases the natural grassland productivity by increasing the amount of forage grown, by its high nutitive value, and improving soil fertility (through its nitrogen fixation). For an intensively managed improved pasture, legume species also play an important role in pasture productivity ,maintaining soil fertility, and animal production. This can be seen in many temperate countries, for instance in New Zealand where pasture production is based on a mixed legume-grass sward. However, the question "What is the best proportion between grass and legume to get the highest yield in term of both quality and quantity?" remains unanswered. This is generally due to grasses having the potential to produce a higher yield than legumes but the nutritive value of legumes is considerably higher than that of grasses in terms of dry matter digestibility and voluntary intake. For instance Playne and Haydock (1972) found that dry matter digestibility of Stylosanthes humilis was 58 percent while that of spear grass Heteropogon contortus at the same plant age (110 days) was 43 percent, and voluntary intake was 67 and 31 (g/day/$W^{0.75}$), respectively. When legumes and grasses are grown as a mixture their combined productivity is affected by competitive relationships between species in the community. Therefore, the quantity and quality of a mixed pasture is likely to be determined by the proportions of grass and legume.

In the northeast of Thailand, Panicum maximum and Stylosanthes hamata have been reported to be superior in performance to many other pasture species. Topark-ngarm et al (1977a) and Gutteridge (1979) showed that Stylosanthes hamata (cv. Verano) "verano stylo" produced a higher yield than Centrosema pascuorum (Commonwealth Plant Introduction (CPI) 40060), C. pubescens, Macroptilium atropurpureum cv. siratro, S. hamata (CPI 55831), S. guianensis (CPI 40294,cv. Endeavour), S. humilis (cv. Patterson, CPI 61674), Alysicarpus vaginalis. Verano stylo also grew more successfully than many other legume species including the species mentioned above when grown with pasture grass species such as "Sabi" grass (Urochloa mosambicensis) (Topark-ngarm et al 1977; Gutteridge, 1979; Torssel, et al., 1976).

Topark-ngarm et al (1979b) showed that "Guinea" grass (Panicum maximum) produced a consistantly higher yield than many other grass species including Cenchrus ciliaris (cv.Biloela), Melinis minutiflora, Chloris gayana, Setaria anceps (cv. Nandi), and Brachiaria decumbens (cv.Signal). The two pasture species (Guinea grass and Verano stylo) were selected for this study as they appear to have the highest potential productivity in a mixed sward and also little is known about their compatibility.

1.2 Objective

This study has two objectives.

1. To investigate the effect of the different proportion of grass and legume on total dry matter yield.

2. To investigate the effects of plant competition on morphology, quality, growth and development of guinea grass and in particular verano stylo.

This study conducted over the establishment phase only.

CHAPTER 2

REVIEW OF LITERATURE

2.1 Plant species studied

2.1.1 Stylosanthes hamata c.v.Verano

Stylosanthes is a genus of the subtribe Stylosanthinae, tribe Aeschynomeneae, subfamily Papilionoideae, family Leguminosae (Polhill and Raven 1981), with its natural distribution in tropical and subtropical regions of the Americas, in tropical Africa and South -east Asia ('t Mannetje, 1984). The genus Stylosanthes was first established with two species and later new species were added to the genus by various authors throughout the last two centuries (Sousa Costa and Ferreira, 1984). In recent reviews it has been considered that there are about 40-45 species and subspecies (Burt, 1984; Stace and Camenron, 1984; and Williams *et al*., 1984).

Stylosanthes hamata is a short-lived perennial legume, native to the West Indies and the land which borders the Caribbean Sea (Humphreys, 1980a). The cultivar verano was introduced into Thailand from Australia in 1976 (Topark-ngarm, 1981).It was used throughout the northeast of Thailand to replace S. humilis which suffered severe damage from anthracnose (Colletotrichum gloeosporioides).

Verano stylo is a non-determinate plant with a semi-erect habit and a branching pattern which is often dichotomous (Mackay, 1975). It is low growing and often develops a flat crown under grazing; erect stems may grow to a height of 80 cm under good conditions. It has narrow pointed trifoliate leaves (Humphreys, 1980a). Verano stylo also displays charateristics of an annual plant (Burt *et al.*, 1980; Humphreys, 1980a). In Australia, Gardener (1981) reported that only 0.03 percent of verano plants persisted three years after sowing under field conditions. Persistence of this legume, therefore, depends on high seed reserves and ready regeneration from seed. Under optimum growing conditions in growth cabinet studies it was observed to start flowering 5 weeks after germination (Argel and Humphreys, 1983). At Khon Kaen, Thailand, verano stylo seedlings in swards flowered 9.5 weeks after sowing (Waikakul, 1984) with similar results reported in Australia (Mackay, 1975).

Verano stylo can grow on a very wide range of soils, and is especially suited to well drained sandy soils of low fertility. It is very tolerant of high acidity, and the legume-rhizobium nitrogen fixation is less impaired by high exchangeable aluminuim in the soil than it is in almost all other cultivated pasture legumes (Humphreys, 1980a).

2.1.2 *Panicum maximum c.v.Coloniao* (Giunea grass)

Guinea grass (*Panicum maximum*) is one of the most successful cultivated grasses in the tropics (Grof and Harding, 1970). It is an erect perennial bunch grass, native to tropical and sub-tropical Africa (Humphreys, 1981). It is well established throughout tropical countries. Parsons (1972) plotted its spread via slaveships from the Guinea Coast of West Africa to Barbados during the seventeenth century and Brazil in the eighteenth century. Guinea grass is concentrated in Africa, Central and South America, Northern Australia, India, South-East Asia and the Pacific Islands (Motta, 1953). There are a number of varieties of Panicum maximum, which have marked differences in time of flowering, degree of leafiness, and other morphological and physiological characteristics (Motta, 1953). In Australia, the commercially available varieties of P. maximum were divided into two groups based on agronomic characters and its environmental requirement, namely, the Guinea cultivars (Riversdale, Hamil, Doloniao, Embu, Makveni, Coarse guinea) and the Panic cultivars (Petrie, Sabi, Gatton). The guinea types are most productive in areas of high rainfall (more than 1300 mm) tropical lowland whilst the panic types are suitable for parts of the sub-tropics or elevated moist tropics (McCosker and Teitzel, 1975).

Several P. maximum cultivars from both groups have been introduced into Thailand from Australia over the past 15 years. The guinea cultivars are potentially a highly productive plant with dry matter yields up to 62 tonne/ha reported in Australia (Middleton and McCosker, 1975), and they can adapt to a wide range of soils (Motta, 1953). In a mixed pasture, guinea grass is compatible with many legume species, e.g S. guianensis, Centrosema pubescens, Pueraria phaseoloides , Phaseolus atropurpureum cv. Siratro (Grof and Harding, 1970). P. maximum cv. Coloniao, the available guinea cultivar in Palmerston North, was used in the studies described in this thesis. It is regarded as a very palatable type. It is a very tall variety growing to 3 metres, practically hairless, and has thick, fleshy stems. The leaf blades are smooth and almost free from hairs (Humphreys, 1980a). Leaves are blue-green in colour, 80-90 cm in length and 20-30 mm. wide (Middleton and McCosker, 1975). It flowers later than other guinea grass varieties and has a slightly longer growing season (Humphreys, 1980a).

2.2 Plant competition

There are many kinds of interelationships between plant neighbors:- namely competition, the excretion of toxins (allelopathy), the trasfer of microbially fixed nitrogen, and the modification of the microclimate to alter its suitability as a habitat for pests or pathogens. In this review emphasize will be on plant competition.

Although the published data on competition between pasture plants is voluminous, little information is available for tropical pasture species. It is unavoidable, therefore, that use will be made of the published data on temperate pasture species as examples in this review. Available data in tropical species will be used wherever possible.

2.2.1 Definition

Many definitions of biological competition have been proposed over the last half-century (Williamson, 1957; Milne, 1961). The term is often used in different ways in different fields of biology or even in the same field (Williamson, 1957, Harper, 1961; Milne, 1961). This confusion over the meaning is probably due to the adoption of the word into science from an ordinary every day usage where it is used in association with human activities such as sport, games and with certain principles of economics (Harper, 1961, Milne, 1961). In ordinary every day usage, according to the Oxford English Dictionary, competition means 'the action of endeavouring to gain what another endeavours to gain at the same time, the striving of two or more for the same object, rivalry'. The definition of competition, in a biological sense, however, has been widely discussed by many scientists (e.g. Birch, 1957; Harper, 1961,1977; Milne, 1961; Tinnin, 1972; Rennie, 1974; Grime, 1977; Hall, 1978). The word competition in this thesis will be defined as proposed by Donald (1963). This defines competition as a phenomenon which occurs when each of two or more organisms seeks the measure it wants of any particular factor or thing and when the immediate supply of the factor or thing is below the combined demand of the organisms. Donald developed the definition based on the definition of plant competition of Clements *et al* (1929) and the definition of animal competition by Milne(1961). This definition is a widely accepted biological definition of competition (e.g. Rhodes, 1968; Hall, 1978; Sangakkara, 1983).

2.2.2 Nature of plant competition

Plants require many factors for growth. These include "supply factors" such as water, nutrients, light, oxygen, carbon dioxide, and physical space also "environmental factors" such as a suitable temperature and pH range. Temperature and pH are not commodities in finite supply and hence are not the subject of competition. Thus, plants may compete for water, nutrients, light, oxygen, carbon dioxide, space and agents of pollination and dispersal may be added in the reproductive phase. However, light, nutrients, and water are the most common factors involved in competition between pasture plants(Donald, 1963).

2.2.2.1 Competition for light

Competition for light differs from competition for water and nutrients. There is no common pool from which plants continue to draw their light supply until it is depleted. It occurs not only between plants but also between any leaves or photosynthetically active parts within a plant when the net production of the photosynthesising component is reduced by the shading effect of another part of the plant. A shaded leaf will die if it remains below compensation point for long periods, because light energy can not be redistributed from other leaves (Donald, 1963). Under pasture conditions, there are three situations when competition for light is absent or minimal. These are, the early stage of an establishing pasture, the early stage of regrowth following severe defoliation (Rhodes and Stern, 1978) and during very severe competition within the root zone.

As light falls on a pasture canopy it will be absorbed, transmitted or reflected by the canopy. This will alter the quality and reduce the quantity of light penetrating down into the depth of the canopy (Ludlow, 1978). The changes of light quality and quantity are therefore influenced by both the size and structure of the pasture canopy .

Monsi and Saeki (1953) pointed out that light interception by a canopy of leaves is exponential (Beer's law), whereby

$$I_1 = I_o e^{-kl}$$

where I_1 = Light intensity beneath a leaf area index of 1

I_o = Incident light energy

K = Extinction coefficient for light energy.

This means that light intensity decreases progressively with an increase in leaf area index until all incidental light is interceped.Figure (2.1.) shows clearly the relationship between light interception and leaf area index.

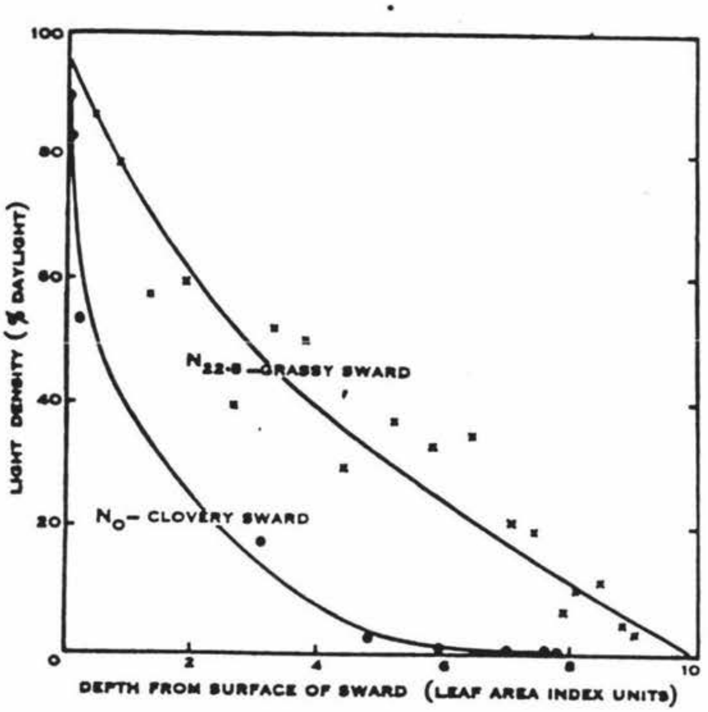


Fig.2.1 Relationship between light interception and leaf area index (After Stern and Donald, 1962)

The degree of light attennuation is related to the extinction coefficient (K), which is influenced by canopy structures (Loomis and Williams, 1969), namely, leaf angle, the vertical distribution of leaf layers, and leaf dispersion within any layer. Brougham (1958) showed that at leaf area index 2.25, 74 percent of the incoming light penetrated into an erect-leaved perennial ryegrass canopy whereas only 54 percent of the same incident light penetrated into a horizontal-leaved white clover canopy. Similarly, Stern and Donald (1962) (Figure 2.1) also showed that light penetration into the erect-leaved perennial ryegrass canopy was greater than light penetration into the horizontal-leaved white clover canopy. At leaf area index 2.25 light penetration was approximately 58 and 20 percent for ryegrass and clover respectively.

The affect of the vertical distribution of leaf layers and leaf density on light penetration can be seen simply from the following example. A canopy of leaf area index 1, made up of a continuous layer of leaves of zero transmissibility, could intercept all the light. If on the other hand, the same canopy of leaf area index 1, was made up of many layers with lower leaf area index on the top layer and higher leaf area index down the profile, then clearly, depending on the depth between the layers, a great deal of light would penetrate. Dispersion of leaves may range from uniform (with regular or mosaic patterns), to random, and to contiguous distribution (clumped or aggregated patterns). More light penetrates into a canopy of clumped or random foliage than into regular foliage (Loomis and Williams, 1969).

When pasture plants are shaded or grown under low light intensity, the immediate response is lowered leaf net photosynthetic rate. Although dark respiration also decreases (Thomas and Hill, 1949; Kumura, 1968; Ludlow, 1978), this reduction in the rate of respiration is unable to compensate for the lowered photosynthetic rate (Ludlow, 1978). This results in reductions in plant growth and development, which include reduction in the rate of leaf appearance per plant (Mitchell, 1955; Mitchell and Coles, 1955; Forde, 1966), the rate of tillering per plant (Donald, 1958; Knight, 1961; Langer, 1963; Evans et al., 1964; Rhodes, 1968; Ludlow et al., 1974), the rate of branching (Stern, 1965; Ludlow et al., 1974), the size of tillers (Donald, 1958; Ludlow, et al., 1974), seed production per plant (Lambert, 1968); root/shoot ratio (Troughton, 1960; Beard and Daniel, 1966; Cooper and Tainton, 1968; Ludlow et al., 1974), and leaf thickness (Mitchell, 1954; 1955; Forde, 1966; Cooper and Tainton, 1968; Taylor et al., 1968; Ludlow and Wilson, 1971b; Ludlow et al 1974), but increases specific leaf area (Cooper and Tainton, 1968; Taylor et al., 1968; Ludlow and Wilson, 1971b; Ludlow et al., 1974). The rate of increase in the number of tillers or branches is reduced by shading partly because the slower rate of leaf appearance provides fewer leaf axil sites from which tillers can develop, and partly because fewer of these sites develop tillers or branches (Evans et al., 1964; Cooper and Tainton, 1968; Ludlow et al., 1974.)

The lowered leaf net photosynthetic rate due to shading also results in the reduction in carbohydrate supply to the root system (Butler et al., 1959). This causes a reduction in nodulation (Butler et al 1959, Chu and Robertson, 1974) and nitrogen fixation capacity. The capacity of nitrogen fixation is reduced because the conversion of nitrogen in the nodule to nitrogen compounds depends upond the supply of carbohydrate through the root to nodule tissue (Humphreys, 1981). However, the severity of this effect on nitrogen fixation capacity may depend on the degree of shading.

Chu and Robertson (1974) found no immediate decrease in the acetylene reduction activity due to 15 percent light intensity reduction of normal summer daylight in Palmerston North, New Zealand.

As radiation passes down through a canopy the quality of light is changed. In particular, the ratio of the quantum fluxes in the 660 nm (Red light) and the 730 band (far-red light). The red/far-red light ratio decreases with depth in the canopy (Holmes and Smith, 1975). The relative enhancement of the far red will alter the photoequilibrium of the two phytochromes Pr $\rightleftharpoons$ Pfr. The Pr form is a red-light absorbing form that has an absorption maximum in the red (660 nm). The Pfr form is a far-red absorbing that has an absorption maximum in the 'far red' (730 nm). (Jones, 1983). An absorption of light by the Pr form converts it to Pfr while light absorption by Pfr converts it back to Pr (Jones, 1983). The relatively high far-red light in the shaded plant, therefore, tends to convert most of the phytochrome present to the Pr form. The Pr form promotes stem elongation, reduces leaf size and thickness,decreases leaf/non-leaf ratio (Holmes and Smith, 1975; Kendrick and Frankland, 1978), and influences flowering (Vince-Prue, 1976). The promotion of stem elongation is an advantage for a shaded plant to compete for light with the dominant plant. Elliott (1975, quoted by Ludlow, 1978) suggested that there are two coordinated photosensitive processes that assist shaded seedlings to compete with taller neighbours for light. The first, which has an action spectrum inhibits leaf expansion and promotes stem elongation at low illuminances, allowing the seedling to grow tall. The second assumes control when the seedling reaches the high illuminance at the top of the canopy, and promotes leaf expansion and overtopping of its neighbours.

2.2.2.2 Competition for nutrient

Since Donald (1958) introduced a technique to investigate the relative role of competition for light (shoot competition), nutient and water (root competition) many investigations on many plant species have been caried out including those of Aspinall (1960), Rhodes (1968), Snaydon (1971), Remison (1978), Remison and Snaydon (1980), Scott and Lowther (1980), Sangakkara (1983). All these studies concluded that competition for nutrient and water is more important than competition for light. Thus, it can be considered that competition for nutrient and water between pasture species in mixtures determines, to a large extent the outcome of competitive relationships. This effect will be most prominant in the early stages of plant growth, when shoot systems do not overlap. However, under condition where competition for light occurs over long periods, the effect of competition for light may override the effect of competition for water and nutrient.

When plant roots absorb nutrients, the nutrients in the close vicinity of the root are depleted. This depletion creates a gradient between the concentration of these substances near the root surface and their concentration nearby.This gradient then causes diffusion towards the root (Nye, 1966; Dunham and Nye, 1974). Once the depletion zones of a plant overlap those of another, competition for nutrients begins.

Tropical soils are well known to be generally low in fertility (Uehara, 1977). Competition for nutrients, particularly, N,P, and K may occur even during the early establishment phase or at the beginning of the growing season. Competition for nitrate ions may occur earlier and be more severe than that for potassium or phosphate, because nitrate ions are more mobile than potassium or phosphate (Bray, 1954 ; Barley, 1970). After diffusion for 20 days, the depletion zone extending from a root surface for nitrate ions was found to be 20-60 mm. (Newman, 1983), while for potassiun ions 6-20 mm , and for phosphate ions 0.6-2 mm (Nye and Tinker, 1977). Thus, once these nutrients are absorbed by roots the depletion zones of the more mobile nitrate ions around the roots enlarge faster and overlap more rapidly than those of phosphate and potassium ions (Bray, 1954; Andrews and Newman, 1970). In addition, the nitrate ions are usually taken up by plants at a faster rate than phosphate and potassium ions (Brewster and Tinker, 1970; Hanway and Weber, 1971). However, in a mixed grass-legume pasture, competition for nutrients other than nitrogen may be more intense while effective nitrogen fixation is occuring.

Under conditions of competition for nutrients the suppressed species demonstrate a decrease in some or all of the following: rate of tillering in grasses (Langer, 1959 a,b ; O'Brien, 1960; Ryle, 1964,1970; Jewis, 1972), rate of leaf appearance (Ryle, 1964; McIntyre, 1964) leaf size (Langer, 1959 a; Ryle, 1964; Rhodes, 1968), shoot/root ratio (Troughton, 1960; Robinson and Jones, 1972; Welbank et al., 1974), content of the competed-for element (Donald, 1958; Welbank, 1964; Snaydon, 1971), and Leaf/non-leaf ratio (Burt, 1968 ; Robinson and Jones, 1972).

Plant characters associated with competitive ability for nutrients will be discussed in section 2.3.1.3.

2.2.2.3 Competition for water

Competition for water is similar to competition for nitrate ions. Water is very mobile. Thus, competition for water can occur rapidly between species exploiting the same root zone in the soil profile.

Competitive ability under conditions of soil moisture deficiency depends on two major factors; namely the ability to increase uptake of water to the plant and the ability to restrict transpiration. The greater ability of P. maximum (Jacq) in competition for water with Glycine wightti has been attributed to both these factors (Suárez, 1977).

Factors which influence the ability to increase uptake of water to the plant are root characters and the relative distribution of assimilate to roots. The affects of root characters will be discussed in section 2.3.1.3

According to Humphreys (1981), plants may adapt to drought conditions by altering the distribution of assimilate to shoot and root. Restricted shoot growth reduces potential water loss and reduces the amount of moisture required to maintain the turgor of aerial tissue; accelerated root growth promotes the capacity for water absorption. Plants with lower shoot/root ratios, therefore, have a greater resistance to drought than plants with higher shoot/root ratios. For instance, Cenchrus ciliaris was found to have a lower shoot/root ratio than the more drought susceptible P. maximum var. Trichoglume (Humpreys, 1981), while work by Suárez (1977) showed that P. maximum had a lower shoot/root ratio and a greater resistance to drought than Glycine wightti.

The ability of pasture plants to restrict respiration is associated with the following characters: leaf movements, leaf-covering structures and other morphological features, control of leaf expansion and senescence, and stomatal resistance. These topics have been comprehensively reviewed by Turner and Begg (1978), Humphreys (1981), and Fisher and Ludlow (1984).

2.2.2.4 Interaction between competition for light and nutrient

In a plant community which establishes from seed, the component species with the fastest growing root system generally gains an advantage over other species in early competition for soil factors (Trenbath,1974). This can lead to better shoot growth and a consequent advantage in light interception. Those species with slower growing root systems may therefore also suffer from shading effects as well. Shading decreases root growth, lowers root/shoot ratio (Troughton, 1960; Beard and Daniel, 1966; Cooper and Tainton, 1968; Ludlow et al ., 1974) ,and ultimately decreases root competitive ability. In a grass-legume mixed pasture, shading of legumes by grasses restricts the supply of carbohydrates to the root system, thus causing death of nodule tissue (Butler and Bathurst, 1956 ; Butler et al., 1959; Chu and Robertson, 1974; Chestnutt and Lowe, 1970) and possibly an increase in the rate of nitrogen transfer to competing grasses(Chestnutt and Lowe, 1970). This would encourage more grass growth and ultimately increase more shading effects on the legume. The interaction between competition for light and nutrient has been summarized clearly by Donald (1958).

2.3 Factors affecting competitive ability

Competitive ability of a plant in relation to its neighbours can be attributed to two major sets of factors; plant related and environmental related.

2.3.1 Plant characters

Three important plant characters which affect competitive ability are seedling growth rate, shoot characters, and root characters.

2.3.1.1 Seedling growth rate

A rapid seedling growth rate is an important factor in confering competitive advantage in later stages of growth. A faster rate of root growth will confer an advantage in obtaining water and nutrients, and subsequently lead to enhanced shoot growth. A small difference in plant height can provide a competitive advantage at a later stage, as shown clearly by Black (1958) for *Trifolium subteraneum*.

Early studies by Stapledon and Davies (1927) and Davies and Thomas (1928) demonstrated the importance of rapid early shoot growth of ryegrass in gaining competitive advantage over other grasses. The competitive success of two wheatgrasses (*Agropyron spp.*) in competition with cheatgrass (*Bromus tectorum*) also has been attributed to their seedling growth rates (Rummel, 1946). The importance of seedling growth rate to competitive success has been emphasized by numerous subsequent workers (Erdmann and Harrison, 1947; Blaser et al, 1953; 1956; Dalrymple and Dwyer, 1967; Cocks and Donald, 1973 b; and Laskey and Wakefield, 1978). The difference in seedling growth rate may be due to two major factors; photosynthetic pathways and seed size.

Based on plants photosynthetic characteristics, plants may be divided into C_3 species and C_4 species. The C_3 species (includes temperate grasses and legumes, tropical legumes and most broad-leaf plants) have the Calvin pathway of CO_2 fixation. The C_4 species (includes all improved and most native grasses of tropical and sub-tropical areas) have the C4-dicarboxylix acid pathway of CO_2 fixation. The net photosynthesis in C_4 plants is much higher than in C_3 plants. The maximum photosynthetic rate measured for single leaves of C_4 plants may be up to 100-120 mg $CO_2/dm^2/hr$, while that of C_3 plants rarely exceeds 45 mg $CO_2/dm^2/hr$ (Whiteman, 1977). Ludlow and Wilson (1970) showed that the mean net assimilation rate of 8 C_4 grass species was 26.6 (range 21.9-30.6) $g/m^2/day$, while that of C_3 legume species was 18.3 (range 14.4-25.7) $g/m^2/day$. This difference leads to a higher growth rate in C_4 plants than in C_3 plants. The mean relative growth rate of the C_4 grass species was 0.486 g/g/day (range 0.407-0.555) and that of C_3 legume species was 0.323 g/g/day (range 0.307-0.363).

Between plants of the same photosynthetic pathways, seed size is an important factor affecting seedling growth rate during early establishment. Gardener (1978) investiging twenty-four lines of S. hamata, S. viscosa, S. frutieosa, S. humilis, S. subsericia, S. sundaica, and S. scabra found that seedling growth rate during early establishment was highly correlated with seed weight. Similar results have been reported in other pasture species, by many workers e.g. Black (1958), Beveridge and Wilsie (1959), Thomas (1966), Whiteman (1968), Ludlow and Wilson (1970a, 1972), Cocks and Donald (1973 b), and Sangakkara (1983). The faster seedling growth rate of a bigger seeded species is closely related to embryo size (Milthorpe, 1961; Cocks and Donald, 1973b; Gardener, 1978; and Sangakkara, 1983) and endosperm size (Cocks and Donald, 1973 b and Sangakkara, 1983). Selection or breeding for seed with large embryo and endosperm in tropical legumes would therefore improve the competitive ability of legumes during the early establishment phase and help offset the competitive advantages of tropical grasses which result from their superior photosynthetic characteristics.

2.3.1.2 Shoot characters

The most important function of shoots in plant competition is to compete for light (Donald, 1963). The ability of a plant's shoot system to compete effectively for light depends on their capacity to overtop their neighbours and expose leaves to high levels of irradiance. This is governed by both plant growth habit and plant stature. Twining growth habit legume species such as Macroptilium atropurpureum, and Centrosema pubescens can compete for light very well and even suppress the associated grasses (Whiteman, 1969; Partrigdge, 1979). They can twine on the associated grasses and elevate their leaves into zones of high illuminance. These leaves are also more effective in denying light to grass leaves below because of their planophile disposition (Humphreys, 1981).

Plant stature is the factor governing its capacity to overtop its neighbours. Plants with higher stature will have an advantage in competition for light. The shrub Leucaena leucocephala has lower potential growth rates than the C_4 grasses with which it grows; but its greater stature enables it to display its leaves in sunlight and to shade the herbage grasses beneath (Humphreys, 1981). Stylosanthes hamata can grow successfully with lower or similar height grasses such as Chrysopogon aciculatus, Dactyloctenium aegyptium, Brachiaria miliiformis , Digitaria adscendens (Wilaipon, 1980), Urochloa mosambicensis (Topark-ngarm et al., 1977; Gutteridge, 1979), Digitaria ciliaris (Torssell et al., 1976). However it does not compete well with the taller grass species such as Arundinaria pusila. (Gutteridge, 1978). Similarly, S. guianensis was severely suppressed when grown with a greater stature grass P. maximum under low stocking rate (Eng et al., 1978). It does, however,grow successfully with species of lower or similar plant height e.g. Axonopus affinis (carpet grass) (Kretschmer and Brolmann, 1984), Cenchrus ciliaris and Chloris gayana (Wallis, 1977). Studies on plant competition between clovers by Black (1960, 1961) and Williams (1963) showed clearly that the longer petioled clover cultivars have an advantage in competition for light over cultivars with shorter petioles.

2.3.1.3 Root characters

Root characters affecting root competition include root growth rate, root morphology, rooting depth, and root cation exchange capacity.

Plant species with rapid root growth rate will have an advantage over those with slower root growth rate, because they can take up the nutrients which are in short supply before the slower growing species. The importance of rapid root growth rate to competitive ability has been emphasized by many workers (e.g. Milthorpe, 1961; Harris, 1967; Vallis *et al*, 1967; McCown and Williams, 1968).

The root morphology of grasses differs from that of legumes. When Evans (1977) investigated root morphology of some pasture grasses and clovers, he found that generally grasses had longer, thinner, more finely branched roots and had longer and more frequent root hairs than clovers. He postulated that in a grass-clover pasture most of the clover roots would be competing with grass roots for available nutrients but only a small proportion of grass roots would be in competition with those of clover. These differences could give the grasses a strong competitive advantage over the clovers in nutrient and water uptake, especially for less mobile nutrients such as phosphate.

Rooting depth also differs between pasture species and/or cultivars. Burton *et al* (1954) showed that *Axonopus affinis* and *Paspalum notatum* rooting down to 0.6 m. depth, *Paspalum dilatatum* and a Common Bermuda *Cynodon dactylon* rooting to 1.2 m. *Digitaria decumbens* cv. Pangola 1.8 m, while Coastal Bermuda *Cynodon dactylon* rooting down to 2.4 m. Differences in rooting depth between other pasture species also have been reported by O'Brien *et al*., (1967); Cook *et al*., (1976); and Evans (1978). Under water stress conditions, the deeper rooting species would have an advantage over the shallower rooting species by their ability to take up nutrients or water from greater depths in the soil profile if they are available. For example, Torssell *et al*., (1976) reported that in the mixture *Digitaria ciliaris* and *Stylosanthes humilis*, the dominance of *S. humilis* was related to its superior depth of root penetration. However, when the annual *S. humilis* was grown with the perennial *Urochloa mosambicensis* it became the suppressed species (Ive, 1976). Many shallow rooted seedlings of *S. humilis* died when soil moisture in the top 40 cm fell below wilting point, while the established root system of the perennial grass had the advantage of access to moisture at depth.

It has been reported that root cation exchange capacity (CEC) can affect the plants competitive ability to uptake nutrients. Drake *et al* (1951) showed that the high CEC root species (legume) can absorb divalent Ca and Mg better than the lower CEC root species (grass). In contrast, the low CEC species can absorb monovalent ions such as P and K better than the high CEC species (Mouat and Walker, 1959).

Thus, consideration of root characters, demonstrates clearly that grasses have an advantage over legumes in competition for nutrients, particularly, the three major nutrients N,P,and K; which plants usually absorb in the monovalent form (Mengel and Kirkby, 1982).

2.3.2 Environmental factors

Environmental factors can be devided into two major categories; soil and management.

2.3.2.1 Soil

The level of some nutrients in the soil can influence the competitive ability between pasture species. Previous discussion (Section 2.3.1.3.) indicated that, generally, legumes compete poorly with grasses for nutients. Thus, low nutrient conditions, with the exception of nitrogen, would lead to a suppression of legume growth. For example, Hall (1971) showed that the growth of *Desmodium intortum* was markedly depressed by *Setaria anceps* at a low K, but not at a high K level. A similar result has been reported in other grass and legume associations (eg.Rossiter, 1947). In a *P. maximum* cv.Typica and *Stylosanthes guianensis* cv.Guianensis mixed pasture, Teitzel (1969) showed that *S. guianensis* growth was suppressed under low copper more than under high copper conditions. In contrast to other nutrients, low soil nitrogen conditions are relatively more favourable to the legume component. For example, *Glycine javanica* was dominant under low soil nitrogen conditions, while *P. maximum* was dominant under high soil nitrogen condition (de Wit *et al*., 1966).

The effect of nutrient status on the relative competitive ability of grasses and legumes is more complex. The balance between nitrogen and other nutrients is important in determining their competitive ability. Generally, when soil nitrogen is low, an application of all other deficient nutrients except nitrogen leads to legume dominance. In contrast in a soil high in nitrogen or where there is a release of nitrogen following cultivation, correction of other deficiencies may lead to grass dominance (eg.Blunt and Humphreys, 1970; Chesnutt and Lowe, 1970; Bruce, 1972; Winter and Gillman, 1976; Wildin, 1979;

Snaydon and Baines, 1981; Lambert *et al*., 1982;). Bruce (1972) showed that the proportion of *S. guianensis* cv.Schofield in a mixture with *Melinis minutiflora* and *P. maximum* grown in a granitic soil was positively related to the level of a single superphosphate application over the range 0-625 kg/ha in the first season after application. Subsequently grass dominance occurred at the higher levels of phosphorus application. This was due to the limitation of grass response to phosphorus being overcome by a reduction in nitrogen deficiency resulting from nitrogen accretion from the nodulated legume.

Some exceptions to the above generalisation, however, have been reported by Norman (1965), Jone (1968), Tietzel (1969), Woods and Dance (1970), Eng *et al* (1978), and Shelton and Wilaipon (1984), where relative aggresssiveness between grasses and the selected *Stylosanthes sp.* remained the same for applied phosphate under conditions of low nitrogen supply. This was due to the low response of the *Stylosanthes sp*.to the phosphate fertilizer application. One of the reasons for the low responses may result from the ability of Stylosanthes to extract phosphorus from low P soils (Andrew, 1966; Andrew and Robins,1969a). However, a wide range in response to P of Stylosanthes accessions has been reported (Jones, 1974).

Interaction between other nutrients also has been reported to affect the competitive ability of grasses and legumes. Wildin (1979) showed that *P. maximum* var Tricholum had an advantage over *M. atropurpureum* under high phosphorus and low potassium, whereas low phosphorus and high potassium gave the legume a competitive advantage. Anderson (1946) reported that under low copper, high zinc levels *Phalaris tuberosa* had an advantage over lucerne, while under high copper, low zinc it was reversed.

Symbiotic nitrogen fixation can be considered to be a key factor in confering competitive advantage on legume plants, because nitrogen is the major important nutrient affecting plant growth and it is known that legume plants can compete poorly with grasses for soil nitrogen. de Wit et al. (1966) showed clear evidence of a positive correlation between the level of nitrogen fixation and the competitive ability of legume plants. They showed that *Glycine javanica* cv.Tinaroo was severely suppressed by *P. maximum* in the non-rhizobium innoculation treatment, while in the rhizobium innoculation treatment the situation was reversed. Thus, any soil factors which enhance nitrogen fixation in legumes would confer competitive advantage to the legumes.

2.3.2.2 Management

Cutting or grazing management can be an important tool to change pasture species dominance, because pasture species respond differently to cutting or grazing. The shorter species are likely to benefit from defoliation because the shading effect the taller associate(s) is reduced or removed. Twining legume species such as *Centrosema pubescens*, *Neonotonia wightii*, *Macroptilium artropurpureum*; and scrambling species eg.*Desmodium intortum*, *D. uncinatum*; may not prefer frequent close cutting or severe grazing, whereas prostrate legume species, eg. *D. heterophyllum* and *S. humilis* may have an advantage under such management.

Cutting (Jones, 1967) and grazing trials (Whiteman, 1969; Partridge, 1979) in M. atropurpureum cv.Siratro showed clearly that siratro can compete very well or even suppress the associated grasses under less-frequent defoliation or leniently grazed situations. But under severe grazing conditions it cannot compete. This was attributed to the small number of growing points originating at ground level and their slow regrowth. A similar response to severe grazing has been reported in Glycine javanica cv. Cooper, D. uncinatum cv.Silverleaf (Whiteman, 1969), Centrosema pubescens, Pueraria phaseoloides (Eng et al., 1978). In contrast, species having a prostrate growth habit such as S. humilis and D. heterophyllum can compete better under moderate to severe grazing conditions. Ritson et al (1971) investigated the effects of stocking rate on the botanical composition of a Townsville stylo (S. humilis) and spear grass (Heteropogon centortus) pasture. He found that after three years grazing the S. humilis content changed from 35 % to 54 % in a high stocking rate treatment(1 cow / 1.2 ha) and from 30 % to 23 % in a low stocking rate treatment (1 cow / 2.4 ha). A similar response has been reported by Winks et al (1974), Shaw (1978), and Akinola (1981).

The response of erect or semi-erect growth habit, such as S. guianensis and S. hamata, respectively, to cutting or grazing may vary depending on their relative plant stature compared with the associated grasses. When they are grown with a grass species having a more rapid growth rate or a greater stature they may prefer moderate to severe grazing, but when they are grown with a grass of similar or lower stature and lower growth rate they may prefer lenient grazing. For example, when S. guianensis was grown with P. maximum, a greater stature grass, after three years grazing the legume content was 8, 18, and 10 percent, while the grass content was 78, 64 and 39 percent in a stocking rate of 2, 4, and 6 hd(cattle)/ha, respectively (Eng et al., 1978). In contrast, Gutteridge (1978) showed that the S. guianensis cv.endeavour content increased when grown with a similar stature native grass Arundinaria pusilla at a stocking rate of 2.5 AU/ha (1 AU = 300 kg animal), but the legume content decreased at the higher stocking rate of 2.5 AU/ha. Similarly, in a S. hamata and A. pusila mixture,the S. hamata content increased at a stocking rate lower than 5.5 AU/ha, while at a stocking rate of 5.5 AU/ha and higher the legume content decreased. Torssel et al (1976) also reported that the relative competitive ability of S. hamata to Urochloa mosambicensis (a similar stature species) was greater in undefoliated than defoliated treatments. Thomas (1976) compared the performance of the different growth habits of tropical legume species when grown with Rhodes grass (Chloris gayana) under frequent close cutting and grazing. The results agreed with those Eng et al (1978), Gutteridge (1978), and Torssell et al (1976). The legumes were D. uncinatum cv.Silverleaf, D. intortum cv.Greenleaf, M. atropurpureum cv. Siratro, Macrotyloma axillare cv.Archer, S. guianensis cv.Schofield, and S. guianensis cv.Endeavour.

When comparing the effect of grazing system between continuous grazing and rotational grazing on competition between grass and legume, there is general agreement that continuous grazing at a moderate stocking rate should be of advanteous to the legumes (Stobbs, 1969; Jones, 1972; Roberts, 1974; Holmes,1980) This is because the legume under continuous grazing would not receive the sudden and drastic reduction in leaf area and numbers of growing points experienced under close rotational grazing. However, there is the exceptional case when the legume is highly palatable. Jones (1972) reported that continuous grazing has led to a reduction in vigor of *Leucaena leucocephala* due to heavy selective grazing under a fairly heavy stocking rate of 1.9 cattle/ha

The type of grazing animal has been reported to affect competition between grass and legume. Boswell (1979) working on Ryegrass/White clover pastures in New Zealand reported that grazing by cattle favours clovers while grazing by sheep favours grasses. The aggressivity of the grass is decreased when grazed by cattle, because cattle uproot ryegrass tillers in the summer-early autumn period when the ryegrass rooting system is least vigorous. Another effect is the more uneven return of nitrogen to pasture via cattle compared with sheep.

At the DSIR Ballantree hill country reseach station, Palmerston North, it has also been observed that the population of clover increased in a pasture grazed by goats (Lambert, 1984, personal communication). This may be due to in part the grazing habit of the goat which clipped only the top of the canopy. Thus, the top of the taller grass was removed and allowed the legume grow better under lower competition from grass. In part it is also due to goats preferentially grazing fibrous material and actively avoiding clover species. In the tropical pasture situation however, there is no available data on the affect of type of animal on competitive ability between grass and legume.

2.4 The study and measurement of plant competition

Plant competition has been studied for more than half a century. Many methods of experimentation and analysis have been developed to study competitive relationships between plants. Two major types of competition experiment have been used to study competition in crops and pastures (Harper, 1977; Jolliffe *et al*., 1984); namely "additive" and "replacement" types of experiments.

2.4.1 The additive type of experiment

In additive experiments two species are grown together, the density of one is maintained constant and that of the other is varied. This kind of experimental design is suitable to determine the effect of invading species on crop species, for example, to answer the question " to what extent is the yield of a crop reduced by the presence of weeds?". In the pasture situation, an additive experiment may be designed to determine how the establishment of a species from seed is affected when it is grown with different seeding rates of other species. For example, Jones (1975) investigated the affects of *M. atropurpureum* (cv.Siratro) and *D. intortum* (cv.Greenleaf) at different seeding rates on the establishment and growth of *Setaria anceps* (CPI 33453). The similar experiment was also carried out by Jones (1966), Tow (1967) and Middleton (1970, 1973).

2.4.2 The replacement type of experiment

The replacement experiment was introduced by de Wit (1960). It has been used widely in studies of mixed populatons because it seems to offer a clear cut method for interpreting the interactions between species

(Hall, 1974; Trenbath, 1974; Snaydon, 1979; Willey, 1979). The main characteristic of the replacement experiment is that the proportion of two species I and J in mixture are varied while the overall density I + J is maintained constant. The interaction between species in the mixture is analyzed graphically in replacement diagrams, and mathematically through indices such as the the relative crowding coefficient, relative replacement rate (de Wit, 1960), relative yield total (de Wit and van den Bergh, 1965) and aggressivity (McGilchrist, 1965). Thus, at a given total plant population this kind of experimental design is appropiate to study competitive relationship between grass and legume and to answer the question 'what proportion of grass and legume produce the highest yield'. The replacement series may be more effective if the total plant population is added as a treatment.

The competitive relationship between pasture species in a mixture can be measured by the following parameters : relative crowding coefficient (de Wit, 1960), aggressivity (McGilchist, 1965), and relative yield total (de Wit and van den Bergh, 1965). The products from these parameters have been compared by Willey (1979). He found that the values were similar. The products indicated which was the dominant and which the dominated species. Also, both the crowding coefficient products and the relative yield total values showed which combinations did, or did not give a yield advantage; the aggressivity values were not able to do that. In some situations where the yield of a component in the mixture is higher than its monoculture, the relative crowding coefficient can not be used (becomes a negative value). Thus, the relative yield total is more versatile than the other two parameters, and it will be used to interpret the results of this experiment. The relative yield total is expressed as:

$$RYT = Y_{ij}/Y_{ii} + Y_{ji}/Y_{jj}$$

where Y_{ij} = Mixture yield of species i in combination with species j
Y_{ji} = Mixture yield of species j in combination with species i
Y_{ii} = Yield of species i in monoculture
Y_{jj} = Yield of species j in monoculture

When RYT = 1, it indicates either overlapping ecological niches with competition for the same environmental resources or an absence of competition. In such a situation when competition is seen, the reduction in the relative yield of one species is compensated by the increase in the relative yield of the another. A RYT less than 1 represents a situation of inhibitary effects where the resources of the environment are used less efficiently, and the reduction in the relative yield of one species is not compensated by an increase in the other. A RYT greater than one is indicative of the opposite situation when the species together exploit the environment more efficiently than either of the monocultures.

The results of experiments based on the replacement series can, in theory, take any of four basic forms (Figure. 2.2.a-d)(Harper, 1977).

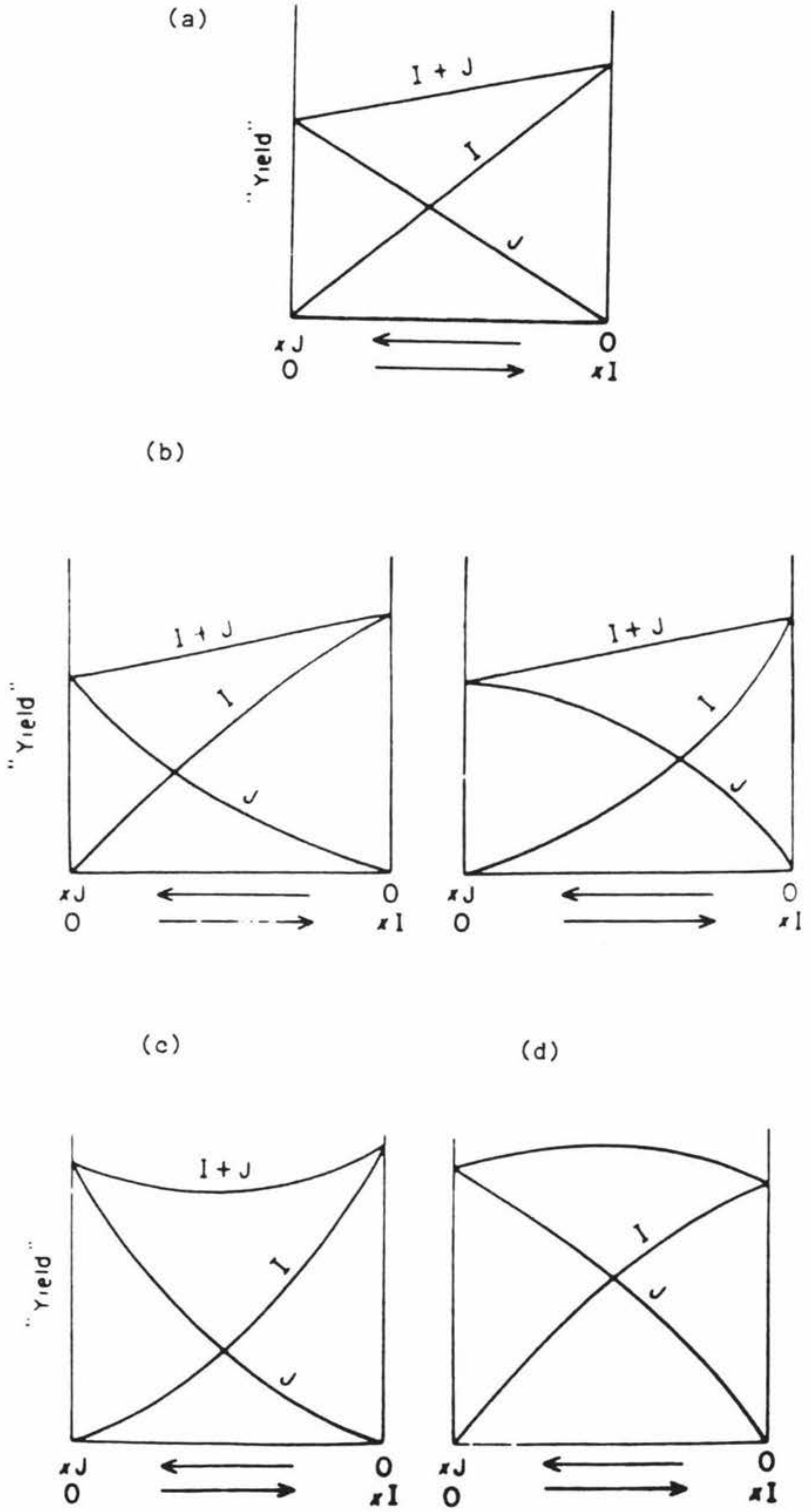
The growth of two species in a mixture (measured as dry weight, seed number or some other parameter) results in each contributing to the total yield in direct ratio to the proportion of seed sown (Figure.2.2 a). This can happen in two ways. Either there is no interference between plants due to the density of the mixed population being too low, or the density is great enough for plants to interfere with each other but the two species have equal competitive ability. Figure.2.2.(b) represents a situation, where one species has a suppressing efect on the other, and both species utilize the same environmental resources. Figure.2.2.(c) represents a situation, where the effect of one on another is greater than that of its own species. This is a model of mutual antagonism in which neither species contributes its expected share to the yield of a mixture. The last form (Figure. 2.2.d) is where interspecific competition is less than intraspecific competition. The species in mixture escape some measure of competition with each other.

de Wit <u>et al</u>.,(1966) proposed a relative replacement rate model, to measure the relative competitive ability in respect to change with time. The relative replacement rate of species i with respect to the species j at the $n^{\underline{th}}$ harvest with respect to the $m^{\underline{th}}$ harvest is expressed as:-

$$ {}^{nm}\rho_{ij} = \frac{{}^{nm}R_i/{}^{nm}R_j}{{}^{m}R_i/{}^{m}R_j} $$

where ${}^{n}R_i$ is the relative yield of species i in the mixture at the $n^{\underline{th}}$ harvest, and the other symbols have a similar meaning. When ${}^{nm}R_{ij}$ is greater than 1,it indicates that species i gains in relative competition, at the $n^{\underline{th}}$ harvest compared to the $m^{\underline{th}}$ harvest, with respect to species j.

Figure 2.2 Diagram illustrating the basic forms of competition situations according to the replacement series (adapted from Harper, 1977)



CHAPTER 3

EXPERIMENTAL MATERIALS AND METHODS

3.1 The site

The experiment was conducted in a glasshouse at the Plant Growth Unit, Massey University, during the period November 1983 to April 1984.

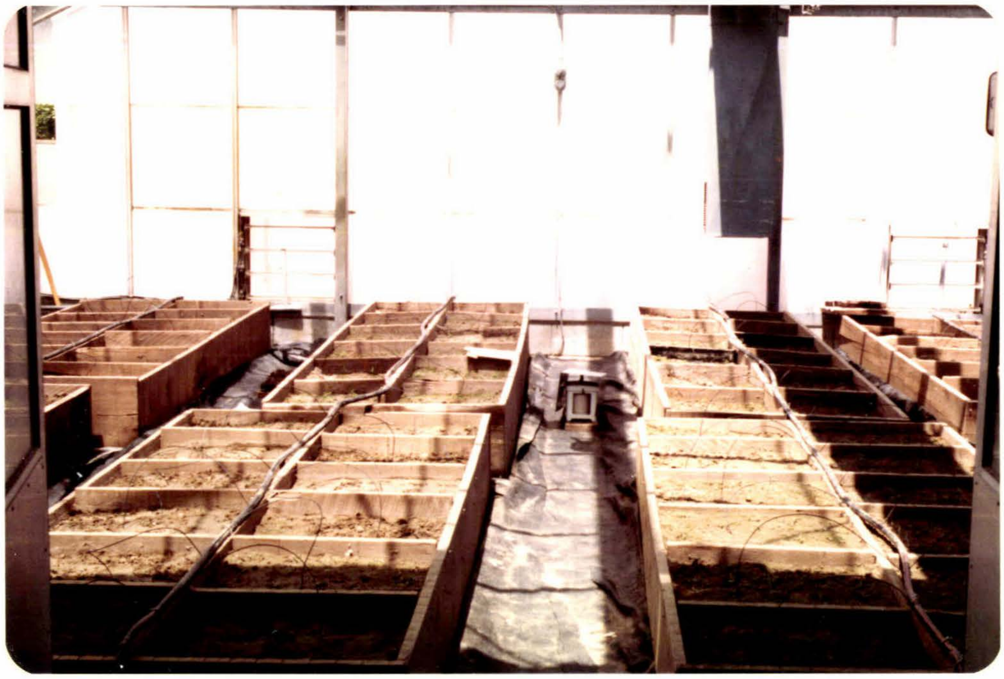
3.2 The boxes

Miniswards were estabished in 4 boxes of dimension 100x240x30 cm and 4 boxes of dimension 80x300x30 cm. It was necessary to have two different box sizes to fit into the glasshouse. Each of these boxes was further sub-divided by partitions into 12 units measuring 40x50x30 cm. (Plate.3.1). The boxes were insulated below by means of a 10 cm. deep layer of sand enclosed within plastic sheeting. The boxes were filled with a sandy silt soil with pH 5.7, Ca 6 ppm, K 3 ppm, P 6 ppm.

3.3 Grass and legume mixtures

The grass used for the study was Panicum maximum (cv. Coloniao). The seed came from the Seed Technology Centre, Palmerston North. The Legume species was Stylosanthes hamata (cv. verano) which was obtained from the Seed Technology Centre, Massey University. Grass and legume were combined in mixtures according to the replacement series principle of de Wit (1960), in

Plate 3.1: The boxes



the proportions of 100L (L=legume), 75L:25G (G=grass), 50L:50G, 25L:75G, and 100G.

3.4 Experimental lay-out

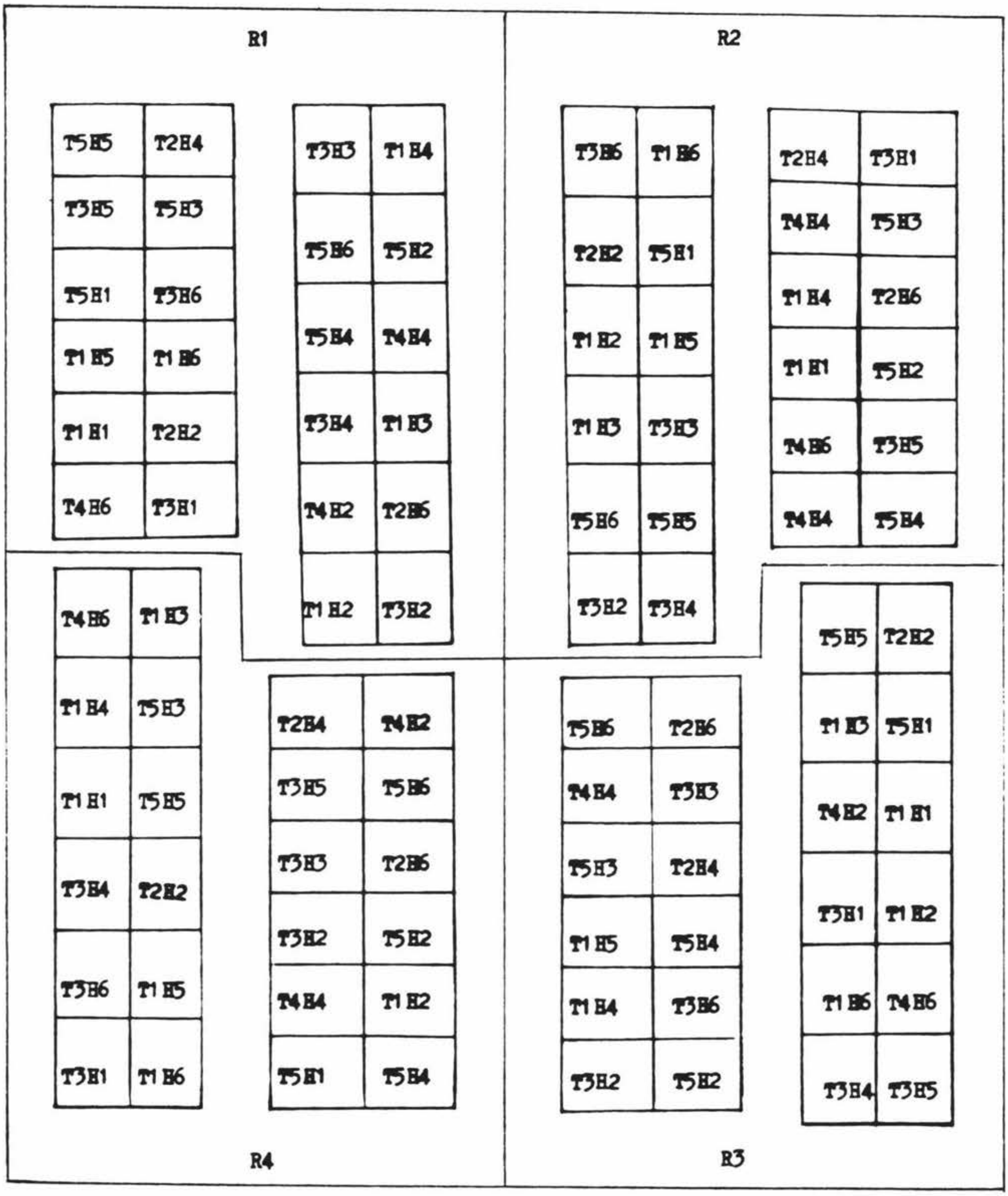
A randomized complete block design with 4 replicates was used for this study, with each box containing 20 plants making up one experimental unit.

Because of the limited room in the glasshouse the experiment was designed to allow for increased harvests (ie. number of plots) for the 100L, 50L:50G, and 100G compared to the 75L:25G and 25L:75G treatment. Treatment and sampling time was randomly allocated (Figure 3.1). Date of samplings is presented in Appendix 3.1.

3.5 Sward establishment

Grass and legume seed was germinated in a growth cabinet at 30 °C. It took 40 hours to germinate. The seedlings were kept in the cabinet for almost two days before they were transplanted. In order to spread the work load, replicates were germinated in successive days. The seedlings of Replicate 1 were germinated on November 24, and were transplanted three days later. Seedlings were transplanted, according to the planting arrangement as shown in Figure 3.2 in order to allow the two species to compete with each other as much as possible. Three seedlings were transplanted at each intersect on a 10 cm grid. The 10 cm spacing between plants (100 plants/m^2) was used in order to ensure that competition between plants occurred within the 19 week period. That population is also in the range of recommended plant population for both species

Figure 3.1 Lay-out



T1 = 100L T2 = 75L:25G T3 = 50L:50G

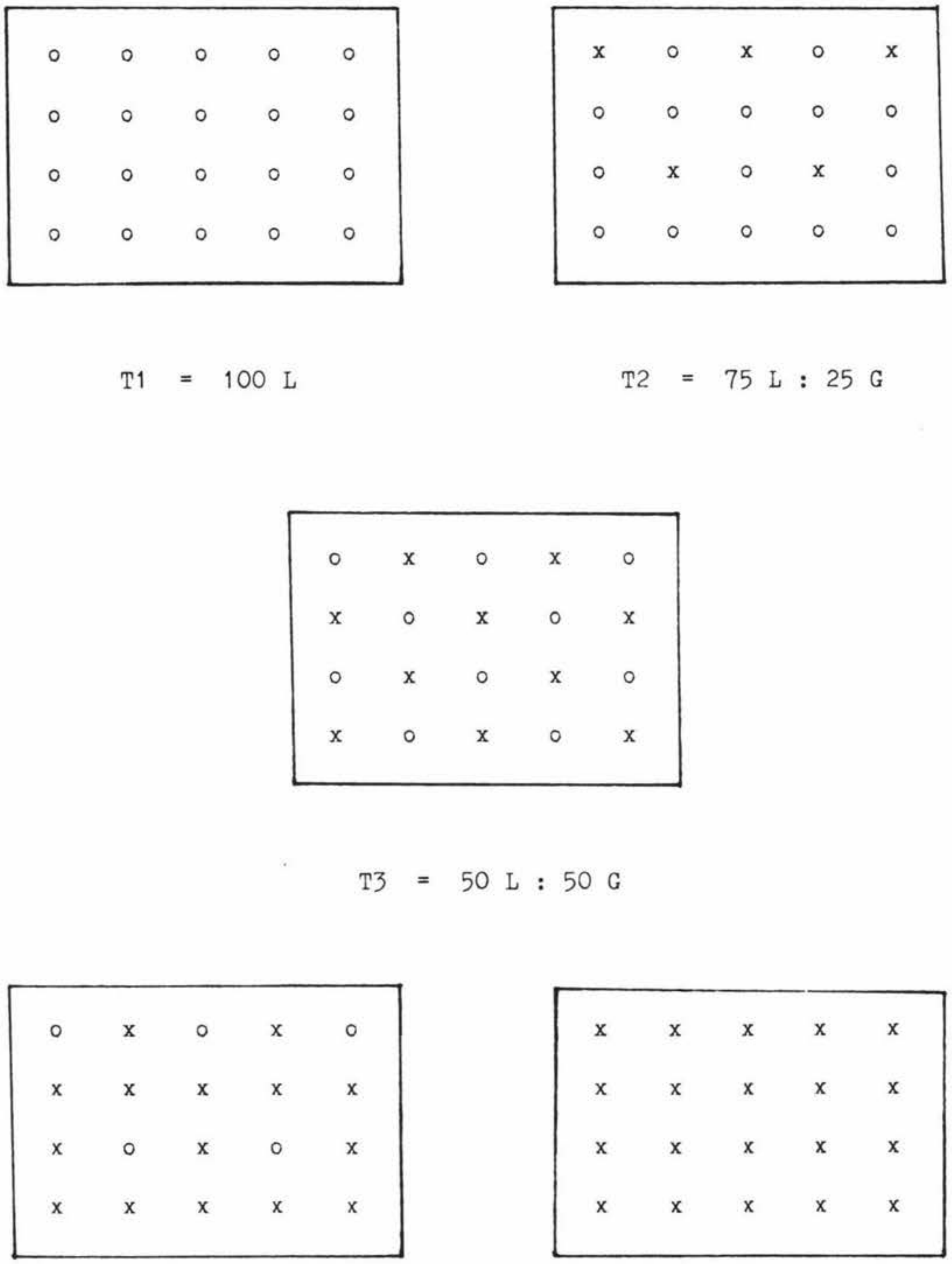
T4 = 25L:75G T5 = 100G R = REPLICATE.

H = HARVESTING TIME.

Figure 3.2 Planting arrangement according to the replacement series.

Legume (L) = o

Grass (G) = x



T1 = 100 L

T2 = 75 L : 25 G

T3 = 50 L : 50 G

T4 = 25 L : 75 G

T5 = 100 G

(Humphreys, 1980a). The populations calculated from the recommended seeding rate was 32-210 plants /m^2 for verano stylo and 30-180 plants/m^2 for guinea grass.

Seedlings were thinned to one plant per position two weeks after transplanting.

3.6 Management

3.6.1 Environmental conditions

It was attempted to maintain the temperature in the glasshouse in the range of $30/20 \pm 5$ °C (day/night) to simulate the tropical climate. This was acheived by the use of a automatic heating and cooling system which included fan heating and ventilation cooling. Daily-maximum and minimum temperatures were recorded (Appendix 3.2) by a thermohydrograph placed on the floor in the middle of the glasshouse.

In order to prevent light entering into the canopies laterally the top of each plot was surrounded by aluminized matterial "sisalkraft" shields. The shields were installed in week 4 after transplanting when the grass plants started to shade the legume plants. Height of the shields was always adjusted to be the same and approximately 10 cm above legume canopies for the legume monoculture and mixtures, respectively. A stake was put at each corner of each plot and string was strung around about 20 cm apart, to firm a barrier and contain the grass within each plot.

3.6.2 Watering.

The plants were watered 2-3 times a day to keep the soil always moist. Water was manually sprayed after an Automated Capillary Tube irrigation was used for two weeks. This was due to the difficulty in controlling the amount of water applied under the automated system.

3.6.3 Fertilizing

The very low soil phosphorus and potassium condition was improved by the application of super phosphate and potassium nitrate respectively. Nitrogen was applied in the forms of potassium nitrate and urea.

As it is well known that soil nutrient conditions affects grass and legume competition (see Section 2.3.2.1) a moderate rate of the fertilizer was applied The total fertilizer applied was 60 kg/ha for phosphorus, 66 kg/ha for sulphur, 90 kg/ha for potassium and 78 kg/ha for nitrogen. The nitrogen fertilizer was split into 4 applications in order to prevent nitrogen loss. Potassium nitrate at a rate of 77 kg/ha and slow release super phosphate fertilizer 600 kg/ha were applied a day before transplanting. The fertilizers were mixed with the top 10 cm soil after broadcast application. In week 5 and 7 when the grass plants showed symptoms of nitrogen deficiency potassium nitrate at 77 kg/ha was applied as a solution. Again in week 9 when the grass plants again showed symptoms of nitrogen deficiency nitrogen fertilizer in form of urea was applied at a rate of 100 kg/ha as a solution.

3.6.4 Rhizobium innoculation

Rhizobium solution, strain NZ P 5390, at a concentration of $2\text{-}3\times10^9/\text{cm}^3$ was sprayed, at a rate of approximately 8 cm^3/legume position, twice around legume plants. The solution was applied one week and three weeks after transplanting.

3.7 Measurement

3.7.1 Non-destructive sampling

The following data were collected from the last harvest plot of each treatment. Five plants of each species were sampled per plot. Plant height data were collected from every plant.

(i).Plant height (the height from the soil level to the tip of the highest leaf)

(ii).Number of branches and tillers.

(iii).Number of leaves per plant.

(iv).The site of branching or tillering. This was recorded as the basis of subtending leaf position.

(v) .Light interception at the "bottom", "middle", and "top" of the canopy. This was measured by using a "Li-Cor"light meter (Model Li-185), with a quantum sensor (Lamba Instrument Corporation, Nebraska, USA). The sensor was placed at random throughout the canopies in 25 points at the ground level, vertically mid- and top-canopy. Light interception in the legume canopy was estimated from the mean of light interception at the mid and bottom of the canopy of the mixtures.

Data were collected weekly till week 10 and then again at week 12, 15, and 19.

3.7.2 Destructive sampling

Because of the limited room in the glasshouse, the monoculture of both species and 50L:50G mixture were harvested in week 3,5,8,12,15,and 19,while that of 25L:75G and 75L:25G mixtures were harvested only in week 5,12,and 19. Data for all the mixtures in week 1 were collected from the thinned seedlings.

The following data were collected for each harvesting.

(i) Shoot characters.

The canopy was divided into equal layers (top, middle, and bottom). Herbage in each layer was divided as shown below:

(a).Grass.
- Lamina
- Non-lamina
- Dead material

(b).Legume.
- Lamina
- Non-lamina
- Dead material
- Inforescense

Every plant was harvested. The area of lamina was measured with an area meter (model Li-3100) and all components were weighed after drying at 80 °C for 24 hours in a forced - air dry oven.

(ii) Root characters.

Each treatment contained 5 rows of 4 plants. Root studies were conducted on 2 adjacent rows at one end of the plot only due to time constraints. This block of soil and roots was washed on a sieve to remove soil and then seperated into grass root and legume root. Samples were weighted following drying at 80 ^{o}C for 24 hours. The number of nodules present on legume roots were counted at the last harvest only.

3.8 Statistical analysis.

3.8.1 Analysis of variance

The homogeneity of variance of all variables was tested as outlined by Gomez and Gomez (1976). Results showed that the variance of leaf number, branch number, shoot, root, and total plant dry weight of verano stylo depended on the mean, therefore, the data required a transformation. Log10 was used for the transformtion.

Analyses of variance were done by using the statistical computer programme ''Genstat '' (Alvey et al,1977 - Rothamstead Experimental Station), available at Massey University. The performance of each species in a mixture was compared with its monoculture.

Test of significance between all means at each harvest were caried out for all variables using the least significant difference test as outlined by Snedecor and Cochran (1967). Differences among means were tested for statistical significance at the 5 percent of probability using Student's t-test (Snedecor and Cochran, 1967).

The following symbol was used:-

* = Significant at 5 percent level of probability.

NS = Non significance at 5 percent level of probability.

3.8.2 Regression analysis

A simple regression analysis was used to examine the relationship between shoot dry matter yield and branch number of verano stylo. The dependent variables are predicted from a linear function of the form (Gomez and Gomez, 1976),

$$\hat{Y} = a + bX$$

where $\hat{Y}$= estimated value of the dependent variable Y.

a = the intercept.

b = regression coeficient.

X = independent variable.

The homogeneity of the two regression coefficients of the regression lines, $\hat{Y}_1 = a_1 + b_1X_1$ and $\hat{Y}_2 = a_2 + b_2X_2$' were analysed using the t-test formular (Gomez and Gomez, 1976).

$$t = \frac{b_1 - b_2}{\sqrt{[\,Sp^2(\frac{1}{Ex_1^2} + \frac{1}{Ex_2^2})\,]}}$$

where b_1 and b_2 are the two estimated regresssion coeficients

Sp^2 = pooled residual mean square

$$= \frac{(n_1 - 2)Sy.x(1)^2 + (n_2 - 2)Sy.x(2)^2}{n_1 + n_2 - 4}$$

$Sy.x(1)^2$ and $Sy.x(2)^2$ = the residual mean squares.

Ex_1^2 and Ex_2^2 = the corrected sums of square.

This is equivalent to testing that $b_1 = b_2$, that is the slope of regression lines are the same.

3.8.3. Competitive indices.

Competitive interactions and the nature of competition between species were analysed using the Relative Yield Total (RYT) (de Wit and van den Bergh, 1965); and Relative Replacement Rate (RRR) (de Wit, 1960). Relative yield totals were calculated based on the model of de Wit and van den Bergh (1965), which can be expressed as:

$$RYT = Y_{ij}/Y_{ii} + Y_{ji}/Y_{jj}$$

wher Y_{ii} and Y_{ij} are the yields of guinea grass in monoculture and mixtures respectively. Y_{jj} and Y_{ji} have a similar meaning for verano stylo. Relative yield totals were calculated for shoot, root dry weight and crude protein yield.

Change in relative competitive ability over time was calculated using the Relative Replacement Rate (RRR) (de Wit, 1960). The relative replacement rate (ρ) of guinea grass with respect to verano stylo at the n^{th} harvest with respect to the m^{th} harvest can be defined as:-

$$^{nm}\rho_{ji} = \frac{^{n}r_i/^{n}r_j}{^{m}r_i/^{m}r_j}$$

where $^{m}r_i$ and $^{n}r_i$ are the relative leaf number of guinea grass in the mixtures at the m<u>th</u> and the n<u>th</u> harvest, respectively. ^{m}rj and ^{n}rj have a similar meaning for verano stylo. RRR was calculated only for leaf number as adequate data was available only for this character.

CHAPTER 4

EXPERIMENTAL RESULTS

4.1 Herbage dry matter yield per box

Total plant dry matter yield (final harvest) per box is shown in Table 4.1. The legume monoculture produced significantly less than all other treatments. Production was less than 20 percent of the total dry matter yield of the grass monocultures. Total dry matter yield in the 50L:50G combination was significantly higher than that of the 75L:25G and both monocultures.

4.2 Plant growth and development

4.2.1 Legume

4.2.1.1 Total dry matter yield per plant

The patterns of total plant, shoot, and root growth are shown in Figure 4.1. At week 5, the significant differences in shoot and total plant dry weight already occured between monoculture and the 50L:50G and 25L:75G, but there was no significant difference between treatments in root dry weight (Table 4.2). Total dry matter yield per plant of legume (final harvest) decreased markedly when grown in mixtures with grass (Figure 4.2) with legume yield decreasing 73, 83 and 86 percent in the 75L:25G, 50L:50G and 25L:75G, respectively. The yield reductions were not proportional to the increase in grass proportion.

TABLE 4.1. Dry matter yield at the final harvest (week 19).

	TOTAL DRY MATTER YIELD (g/box)
100L	87.06 a
75L:25G	456.04 b
50L:50G	524.61 c
25L:75G	496.11 bc
100G	467.0 b
CV(%)	10.0
SIGN.	*

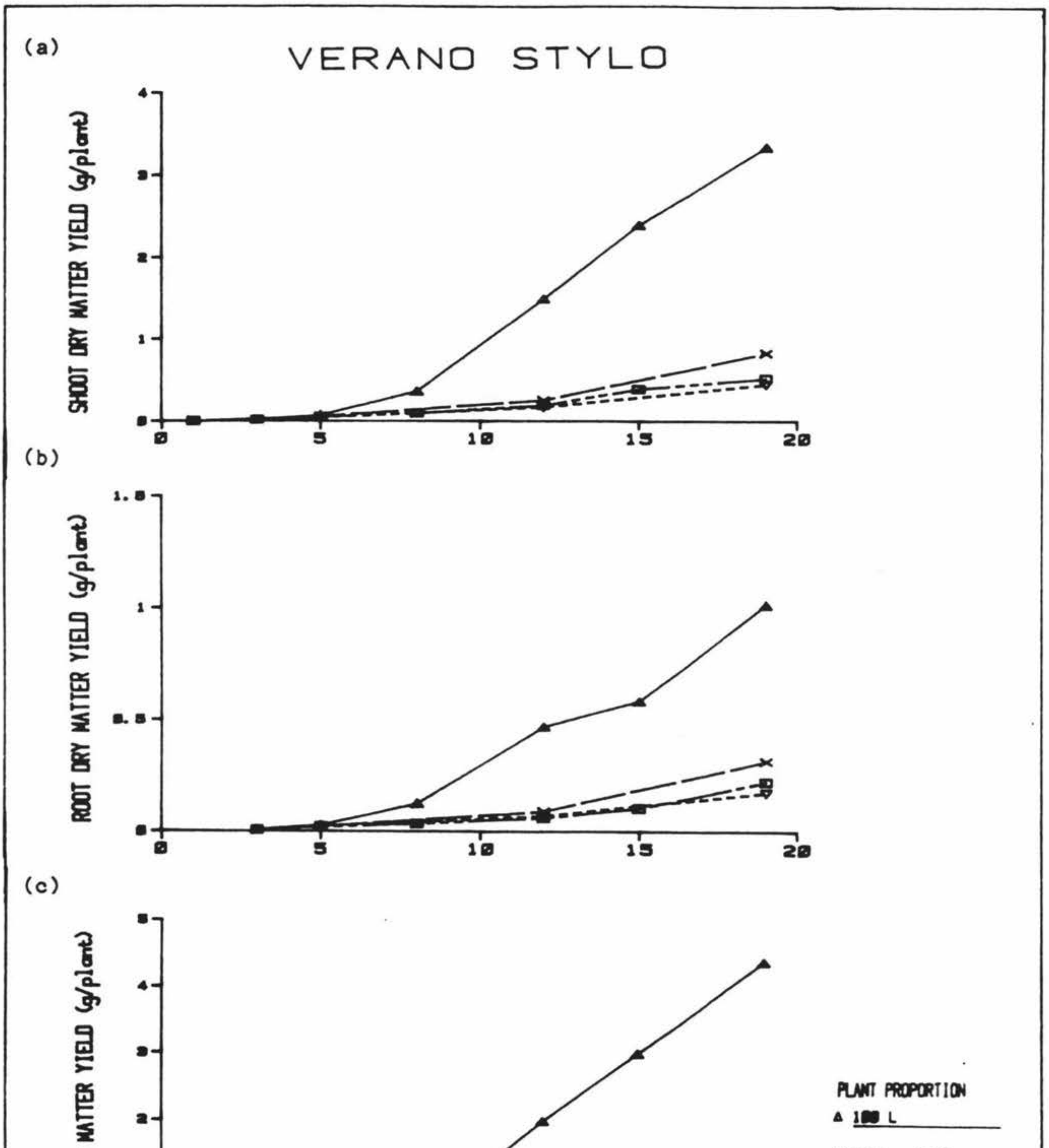
Note: Means not sharing a common letter differ significantly at P<0.05

Table 4.2. Transformed (log10) treatment means of plant dry weight of verano stylo.

	WEEK 5			WEEK 12			WEEK 19		
	SHOOT	ROOT	TOTAL	SHOOT	ROOT	TOTAL	SHOOT	ROOT	TOTAL
100L	1.85 a	1.45	2.00 a	3.17 a	2.67 a	3.29 a	3.51 a	2.99 a	3.63 a
75L:25G	1.78 ab	1.40	1.93 ab	2.39 b	1.94 b	2.52 b	2.89 b	2.47 b	3.03 b
50L:50G	1.68 b	1.31	1.84 b	2.27 c	1.78 c	2.39 c	2.69 c	2.29 c	2.83 c
25L:75G	1.64 b	1.39	1.84 b	2.22 c	1.85 c	2.37 c	2.62 c	2.20 c	2.76 c
CV(%)	4.4	5.8	3.8	2.5	2.4	2.0	3.0	3.6	2.7
SIGN	*	NS	*	*	*	*	*	*	*

Note: Means not sharing a common letter differ significantly at p<0.05

Figure 4.1: **Dry matter yield of verano stylo (g/plant).**
(a) Shoot dry matter yield.
(b) Root dry matter yield.
(c) Total dry matter yield.



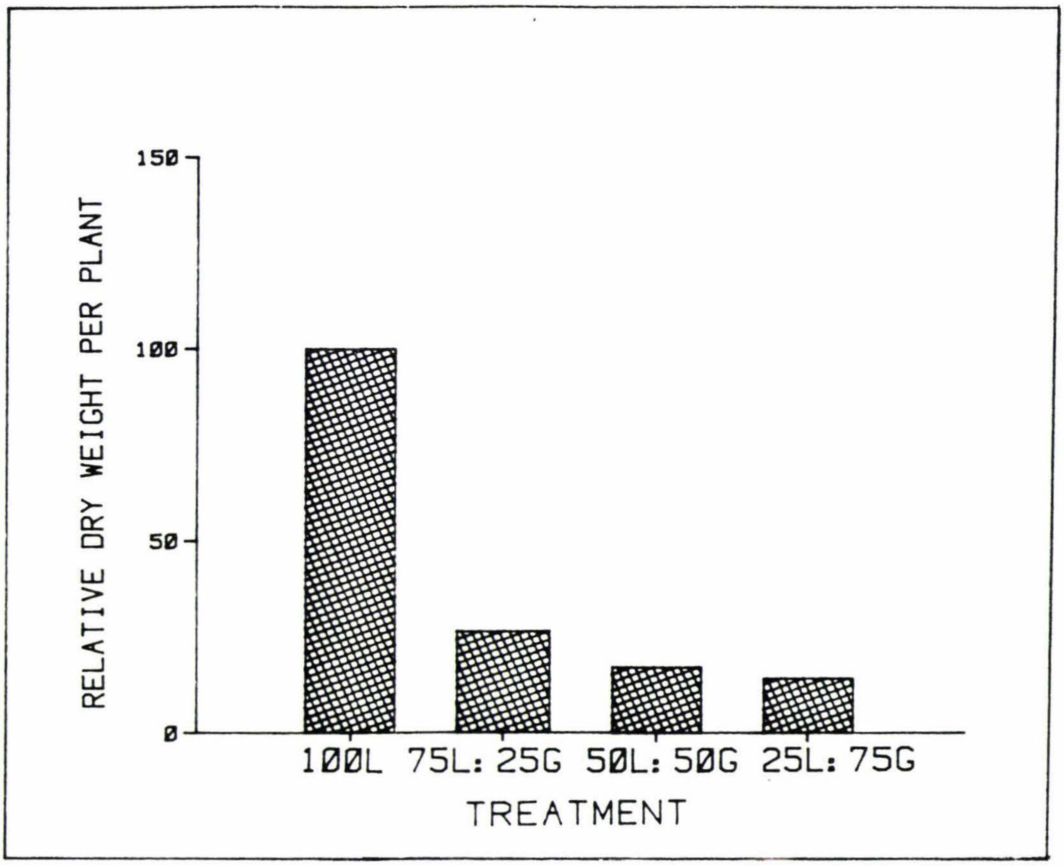


Figure 4.2: Relative dry weight per plant of Verano stylo at the final harvest (week 19)

Plate 4.1: Verano stylo at the final harvest.

4.2.1.2 Relative growth rate (RGR)

The patterns of relative growth rate in relation to shoot dry weight of legume in mixtures were similar (Figure 4.3). They decreased sharply in the early stage and then decreased slowly. At shoot dry weight per plant 300 mg. RGR of legume in mixtures were approximately 23 percent of that of legume in monoculture.

4.2.1.3 Shoot/root ratio

Shoot/root ratio of the legume in the 25L:75G was significantly lower than the other treatments in week 5-12 (Figure 4.4). No significant difference was observed in shoot/root ratio between other treatments but it is interesting to note that by week 19 both the 75L:25G and 50L:50G mixtures produced very similar shoot/root ratios to the 25L:75G mixture.

4.2.1.4 Leaf/non-leaf ratio

The leaf/non-leaf ratio decreased curve-linearly as legume shoot dry weight increases (Figure 4.5). It decreased more rapidly in the mixtures than in monoculture. At shoot dry weight 0.5 g per plant, leaf/non-leaf ratios of the legume in mixtures were around half of legume in monoculture. As can be seen from Figure 4.5 once the leaf non-leaf ratio reached 1 further decrease was very slow by comparison with the rapid decline previously observed.

Figure 4.3: Relative growth rate (mg/mg/week) in relation to shoot dry matter yield of verano stylo.

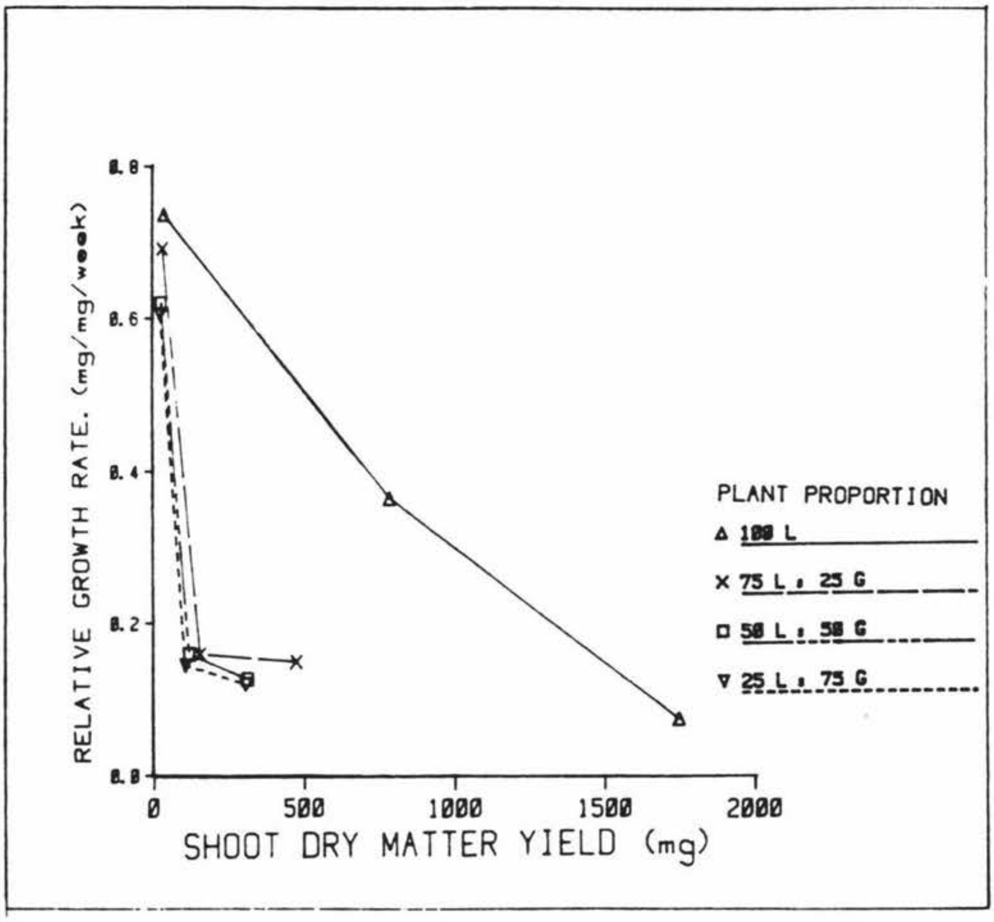


Figure 4.4: Shoot/root ratio of verano stylo.

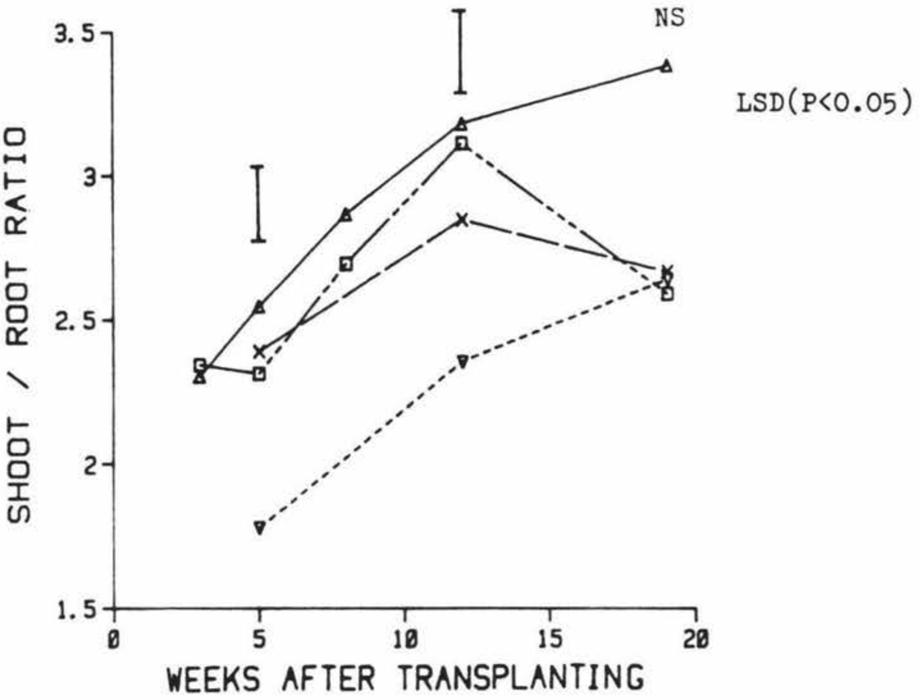
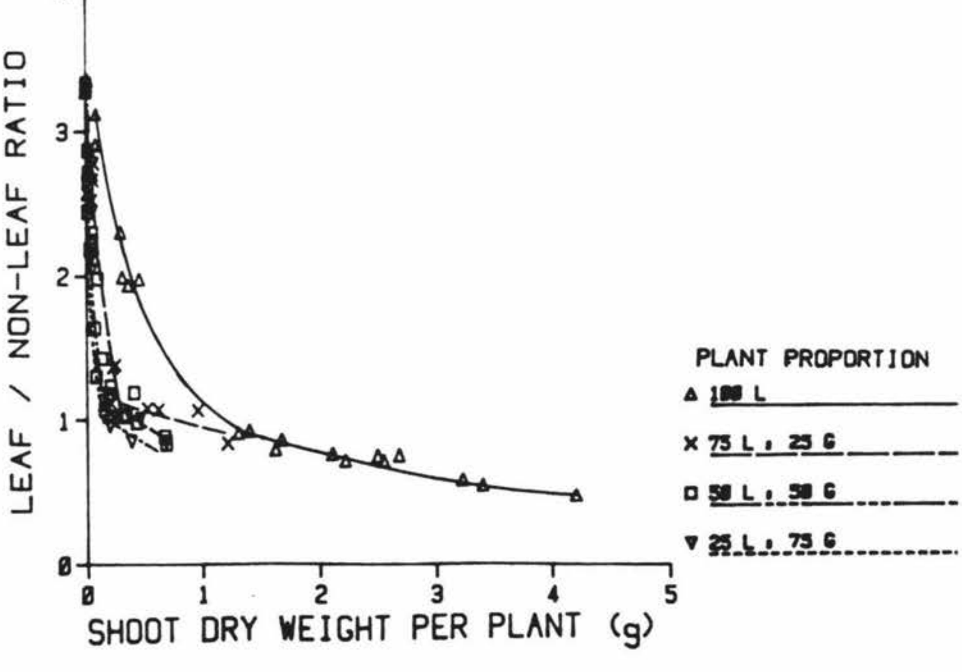


Figure 4.5: Leaf/non-leaf ratio in relation to shoot dry matter yield of verano stylo.



4.2.1.5 Days to flowering

Legumes in the monoculture started to flower in week 7, while legumes in mixtures started to flower in week 17 for the 75L:25G and week 19 for the 50L:50G combination. Legume plants in 25L:75G combination remained vegetative throughout the trial.

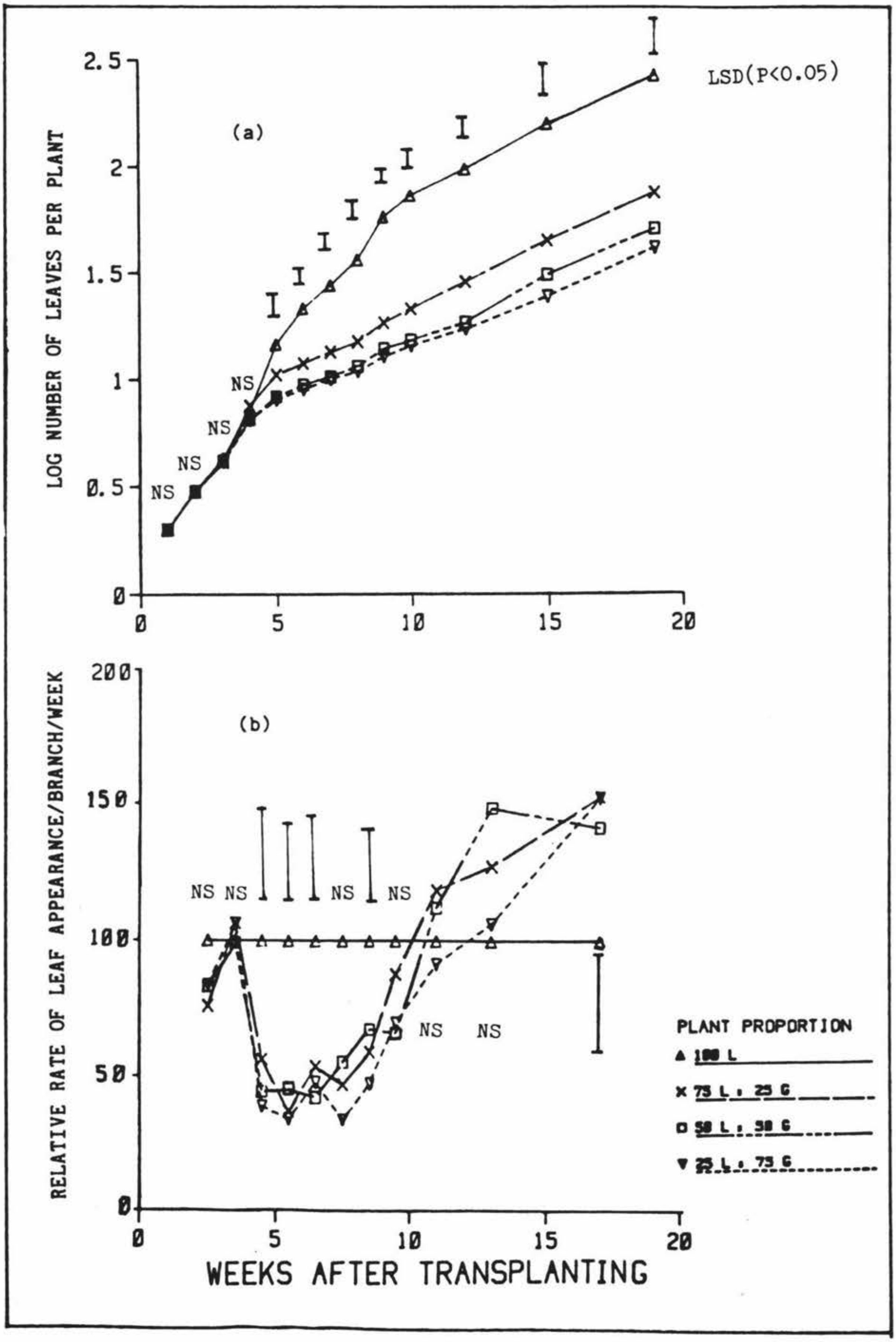
4.2.1.6 Leaf number and the rate of leaf appearance

The number of leaves per plant of verano stylo in mixtures was significantly lower in all mixtures relative to the monoculture from week 5 (Figure 4.6.a). From week 5 to week 19 the three mixtures produced additional leaves at approximately the same rate. During week 5 the 75L:25G produced more leaves than the other two combinations and this gain then persisted throughout the trial. This difference led to significantly more leaves per plant on the 75L:25G than the 25L:75G treatment.

During the first 10 weeks, generally, the rates of leaf appearance per branch per week of legume in monoculture were higher than that of the legume in mixtures, and significantly higher during week 4-7 and 8-9 (Figure 4.6.b). After week 10, the rate of leaf appearance per branch per week of legume in mixtures was higher than the monoculture and by the end of the experiment the mixtures were significantly higher than monoculture. The rate of leaf appearance between the mixtures was not significantly different but a trend was observed that in the higher legume proportion higher rates of leaf appearance were observed than the mixtures with lower legume proportion.

Figure 4.6: (a) The number of leaves per plant of verano stylo.

(b) Relative rate of leaf appearance of verano stylo in mixtures to monoculture (monoculture equals 100).



4.2.1.7 Branch number

The number of branches carried by the legume in monoculture was significantly higher than that of legume in mixtures from weeks 5 (Figure 4.7). The number of branches of the legume in the 75L:25G was higher than the other two mixtures from the beginning, and significantly higher than legume in the 25L:75G from week 8. Relative branching rate of the legume in monoculture was higher than that in mixtures after week 4 and significantly higher during week 4-9 (Table 4.3). Relative branching rate of legume in the 75L:25G was significantly higher than that of the other mixtures during week 3-4.

Shoot dry matter yield per plant was linearly related to the number of branches (Figure 4.8). The rates of shoot dry matter yield increase per unit branch numbers increase were similar in all treatments (Figure 4.8, Appendix 4.1). Shoot dry matter yield can be estimated from the equation,

$$\hat{Y} = 0.0824 + 0.0385X$$

when X is the number of branches.

4.2.1.8 Nodule number

The number of nodules per plant was severely suppressed by the presence of the grass in the mixture. Increasing the proportion of grass significantly decreased the number of nodules per plant (Table 4.4). The number of nodules decreased 81, 88 and 96 percent in the 75L:25G, 50L:50G and 25L:75G, respectively.

Figure 4.7: The number of branches per plant of verano stylo.

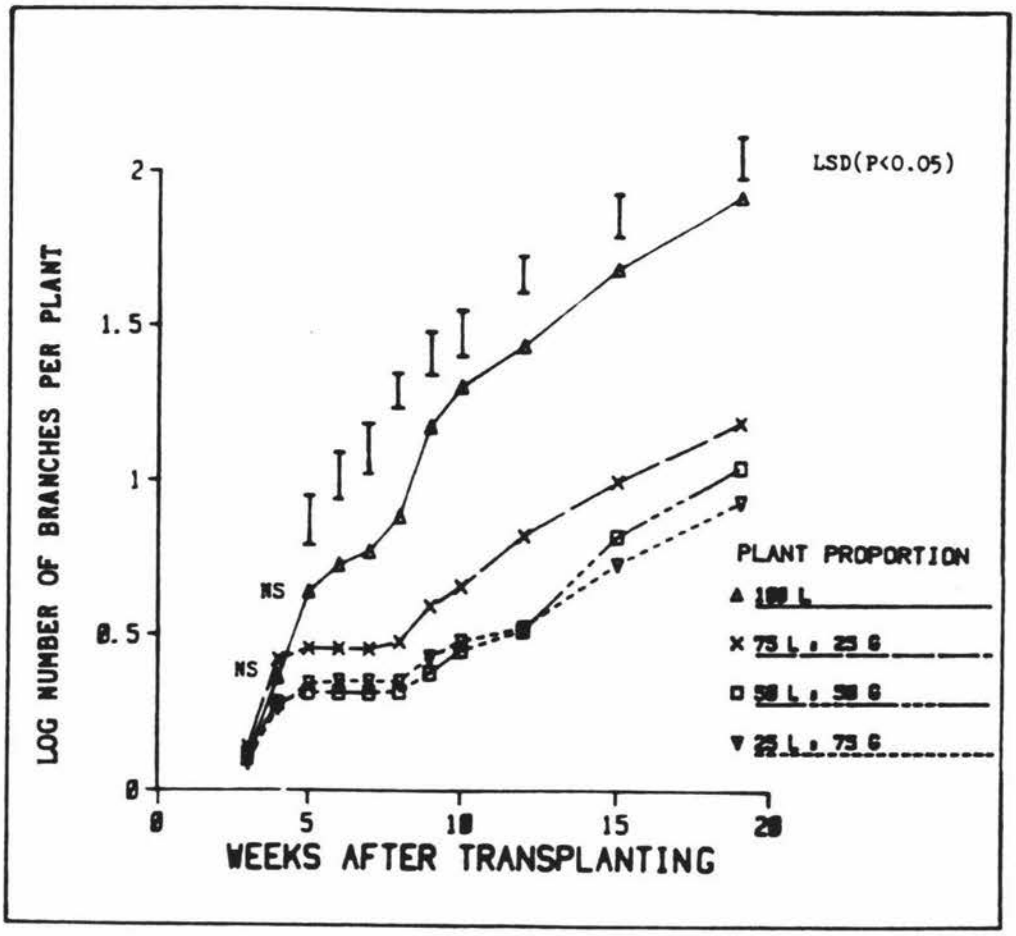


TABLE 4.3. Relative branching rate of verano stylo in different combination.

	RELATIVE BRANCHING RATE (branch/branch/week)		
	WEEK		
	3-4	4-9	9-19
100L	0.366 a	0.163 a	0.0741
75L:25G	0.423 a	0.0352 b	0.0591
50L:50G	0.282 b	0.0203 b	0.0662
25L:75G	0.267 b	0.0339 b	0.0499
CV(%)	23.6	25.3	20.6
SIGN.	*	*	NS.

Note: Means not sharing a common letter differ significantly at P<0.05

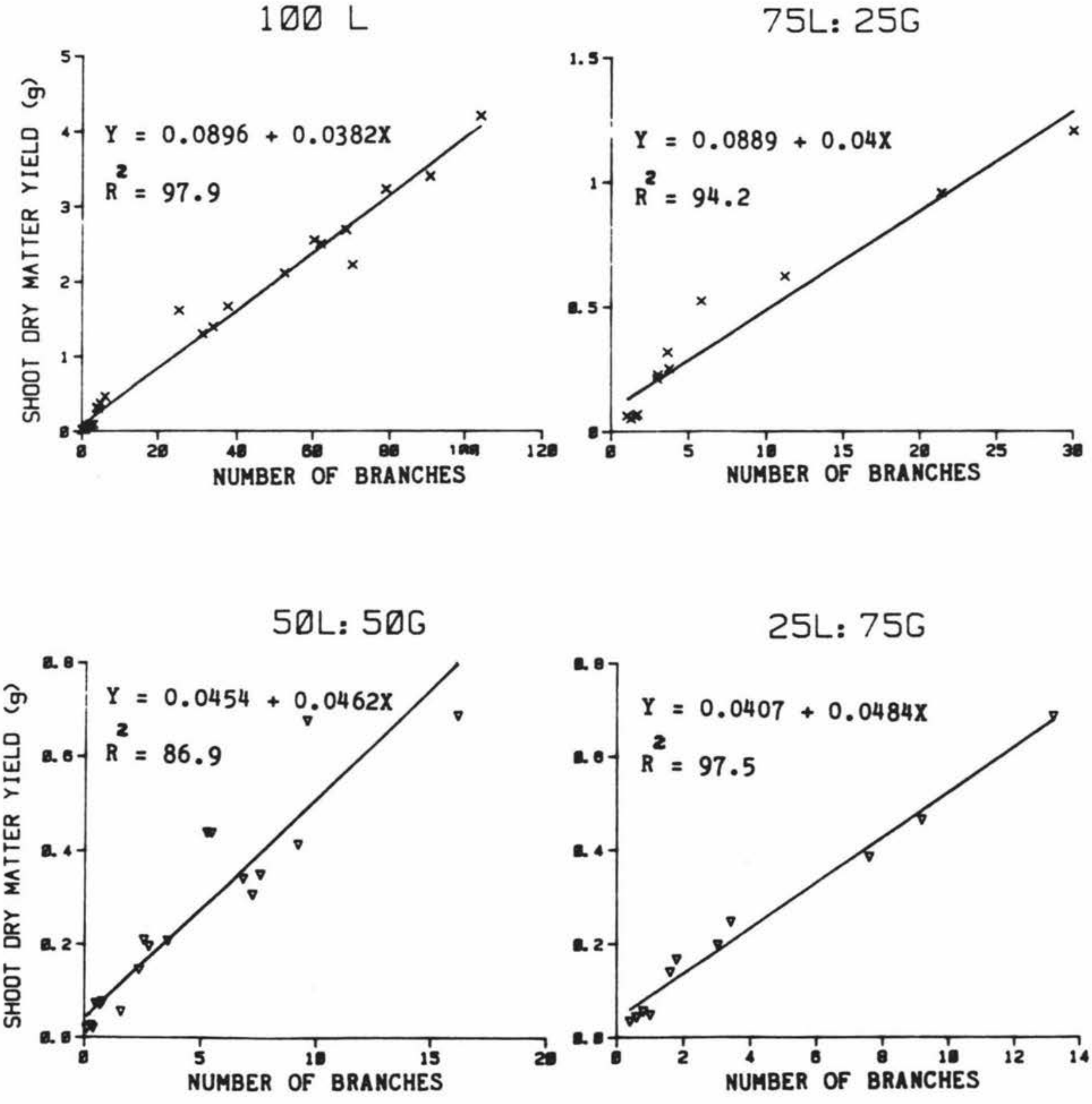


Figure 4.8: **Shoot dry matter yield (g/plant) in relation to the number of branches of verano stylo in different grass-legume proportion.**

TABLE 4.4. Nodule number of verano stylo (week 19).

	NODULE NUMBER PER PLANT
100L	362.1 a
75L:25G	68.1 b
50L:50G	42.8 c
25L:75G	15.1 d
CV(%)	12.8
SIGN.	*

Note: Means not sharing a common letter differ significantly at $P<0.05$

4.2.2 Grass

4.2.2.1 Total dry matter yield

The patterns of total plant growth, shoot and root growth are shown in Figure 4.9. The rapid growth phase of the grass plants began around week 5. At week 5, the significant differences in shoot, root, and total plant dry weight between treatments already occured, particularly between the 75L:25G and the other treatments (Table 4.5).

Total shoot dry matter yield per plant (final harvest) decreased markedly with an increase in grass proportions (Figure 4.10). The yield reductions were not proportional to the increase in grass proportion. As the grass proportion increased from 25 to 50, 75, and 100 percent the grass dry matter yield per plant declined 41, 62 and 73 percent respectively.

4.2.2.2 Relative growth rate

At the same plant shoot dry weight, relative growth rates of grass in the lower grass proportions were higher than that of grass in the higher grass proportions (Figure 4.11). On a time basis, the differences in relative growth rate between treatments occurred only during the first 12 weeks (Table 4.6).

Figure 4.9: **Dry matter yield of guinea grass (g/plant)**
(a) Shoot dry matter yield.
(b) Root dry matter yield.
(c) Total dry matter yield.

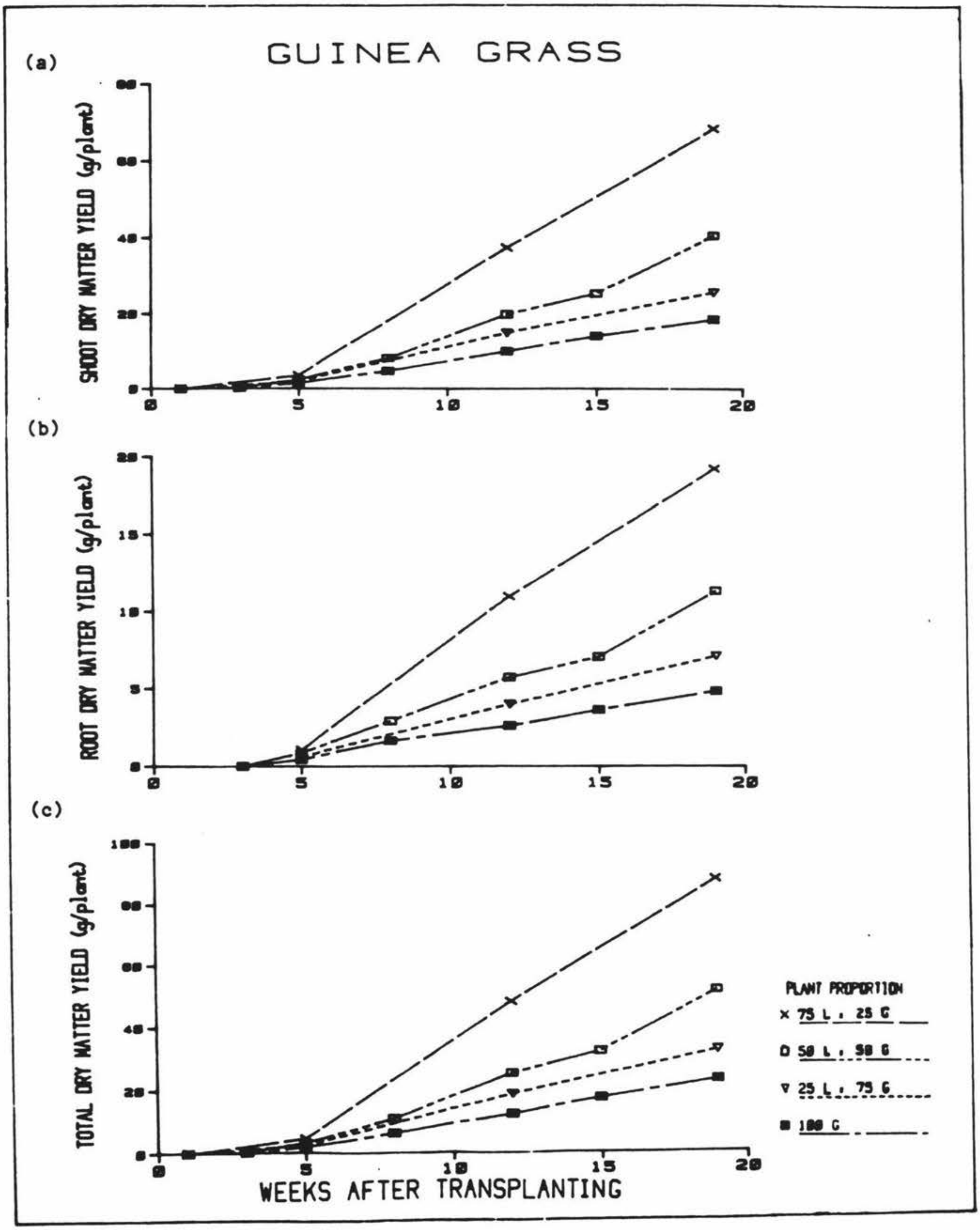


Table 4.5. Treatment mean of plant dry weight (g/plant) of guinea grass.

	WEEK 5			WEEK 12			WEEK 19		
	SHOOT	ROOT	TOTAL	SHOOT	ROOT	TOTAL	SHOOT	ROOT	TOTAL
75L:25G	3.5 a	1.06 a	4.57 a	37.46 a	10.94 a	48.41 a	68.60 a	19.16 a	87.76 a
50L:50G	2.42 b	0.86 b	3.29 b	19.77 b	5.73 b	25.5 b	40.68 b	11.29 b	51.97 b
25L:75G	1.89 c	0.63 c	2.52 c	14.88 bc	3.98 bc	18.87 bc	25.77 c	7.09 c	32.86 c
100G	1.47 c	0.44 d	1.91 c	9.97 c	2.6 c	12.57 c	18.53 d	4.82 d	23.35 d
CV(%)	13.5	13.5	13.2	22.0	32.1	23.1	8.5	10.6	8.7
SIGN	*	*	*	*	*	*	*	*	*

Note: Means not sharing a common letter differ significantly at P<0.05

TABLE 4.6. Relative growth rate of guinea grass.

	RELATIVE GROWTH RATE(g/g/week)		
	WEEK		
	1-5	5-12	12-19
75L:25G	1.8339 a	0.3349 a	0.088
50L:50G	1.7522 b	0.2931 ab	0.1015
25L:75G	1.6841 c	0.2884 b	0.0787
100G	1.6173 d	0.2682 b	0.0893
CV(%)	1.9	9	37.3
SIGN.	*	*	NS.

Note: Means not sharing a common letter differ significantly at P<0.05

Figure 4.10: Relative dry weight per plant of guinea grass at the final harvest (week 19).

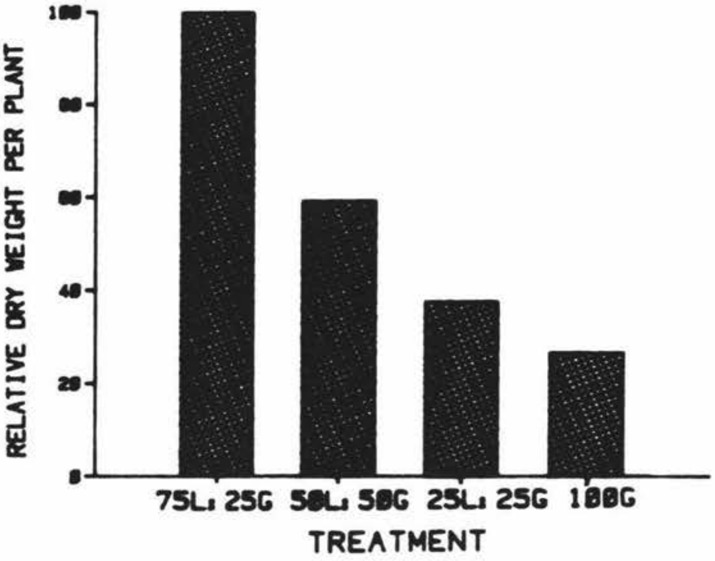
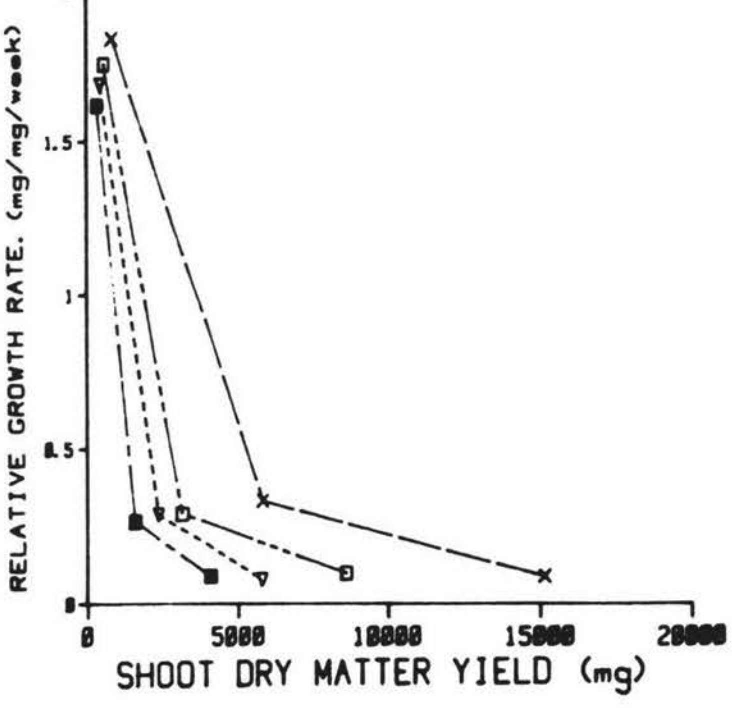


Figure 4.11: Relative growth rate (mg/mg/week) in relation to shoot dry matter yield of guinea grass.



4.2.2.3 Shoot/root ratio

The pattern of shoot/root ratio is presented only for the 50L:50G and monoculture due to no data collection in the 75L:25G and 25L:75G in weeks 3, 8 and 15 (Figure 4.12). The pattern of shoot/root ratio of the first two treatments similar. An initial ratio of 4.5 declined to approximately 3 by week 5. Between week 8-12 the ratio increased and then remained constant at around 3.5.

4.2.2.4 Leaf/non-leaf ratio

The leaf/non-leaf ratio decreased in a curvelinear manner with increased shoot dry weight (Figure 4.13). The rate of decline in leaf/non-leaf ratio was greater in the higher grass proportion combinations than in the lower grass proportion combinations. The rate of decrease did not appear to be proportional to the increase in grass proportions.

Figure 4.12 Shoot/root ratio of guinea grass

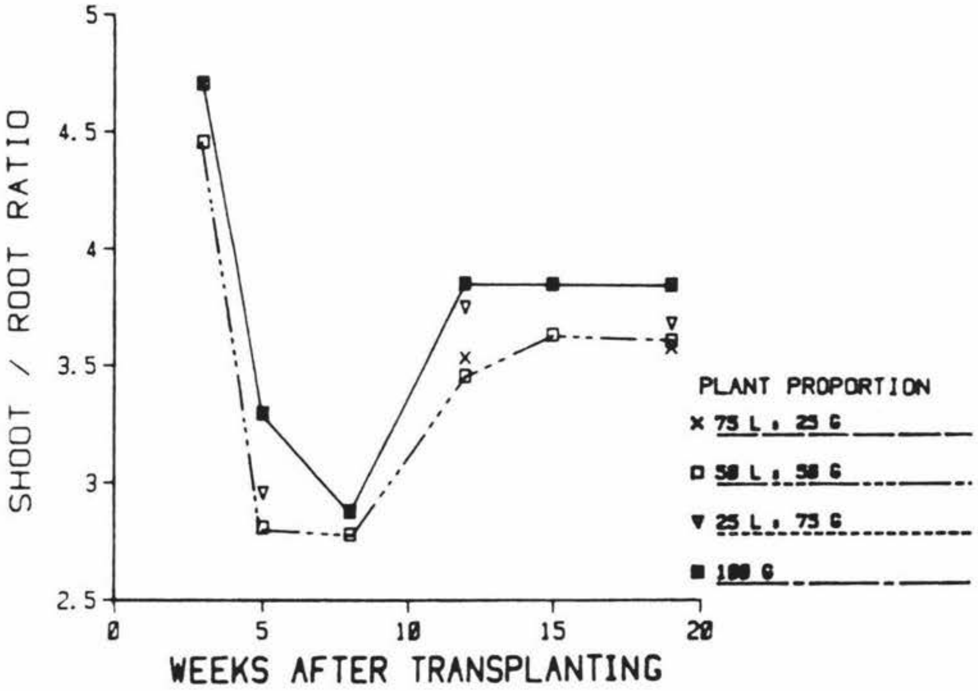
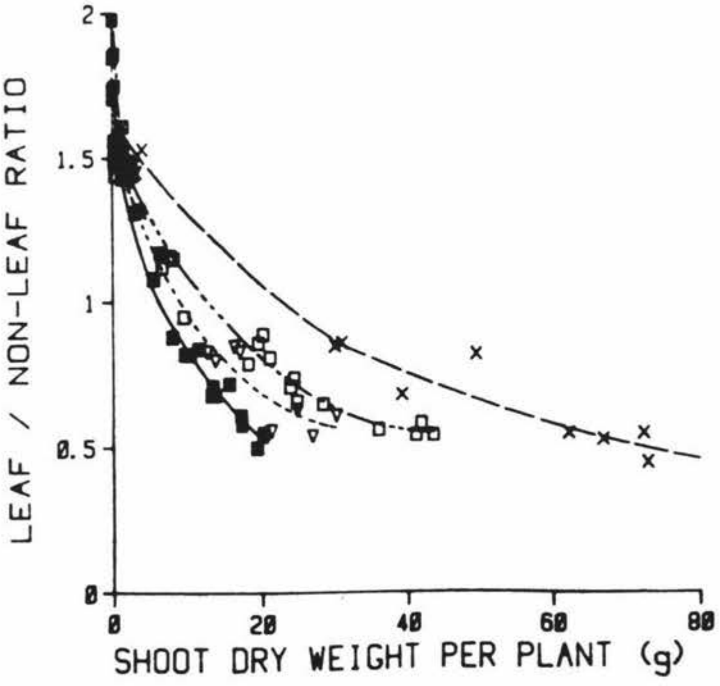


Figure 4.13 Leaf/non-leaf ratio in relation to shoot dry matter yield of guinea grass.



4.2.2.5 Leaf number and the rate of leaf appearance

The average rate of leaf appearance per tiller per week was high (more than 1) during the period of week 1-4 and 8-9 relative to other periods (Figure 4.14.a). From week 11, the average rate of leaf appearance per tiller per week was less than 0.4. During week 3-12, the rate of leaf appearance in the 75L:25G and 50L:50G were significantly higher than in the 25L:75G and monoculture (Figure 4.14.b). However, the average rate of leaf appearance per tiller per week of the grass throughout the experimental period was slightly higher, but not significantly, in the higher legume proportions than in the lower legume proportions. This resulted in a significantly higher number of leaves on the primary plant (tiller) of the grass in the higher than in the lower legume proportions during week 5-12 (Figure 4.15).

4.2.2.6 Leaf length

The length of leaves on the primary stem were similar in all treatments up until leaf eleven. After that the average leaf length of grasses in the 75L:25G and 50L:50G was significantly longer than that of grass in the 25L:75G and monoculture (Figure 4.16).

4.2.2.7 Tillering

In all treatments the grass started tillering in week 3 when the primary plant had at least 5 leaves (Apendix 4). Increasing the grass proportion from 50 to 75 percent suppressed tillering more than an increase in grass proportion from 25 to 50 percent and from 75 to 100 percent in the final harvest (Figure 4.17).

Figure 4.14: (a) Rate of leaf appearance of guinea grass
(b) Relative rate of leaf appearance of guinea grass (75L:25G mixture equals 100).

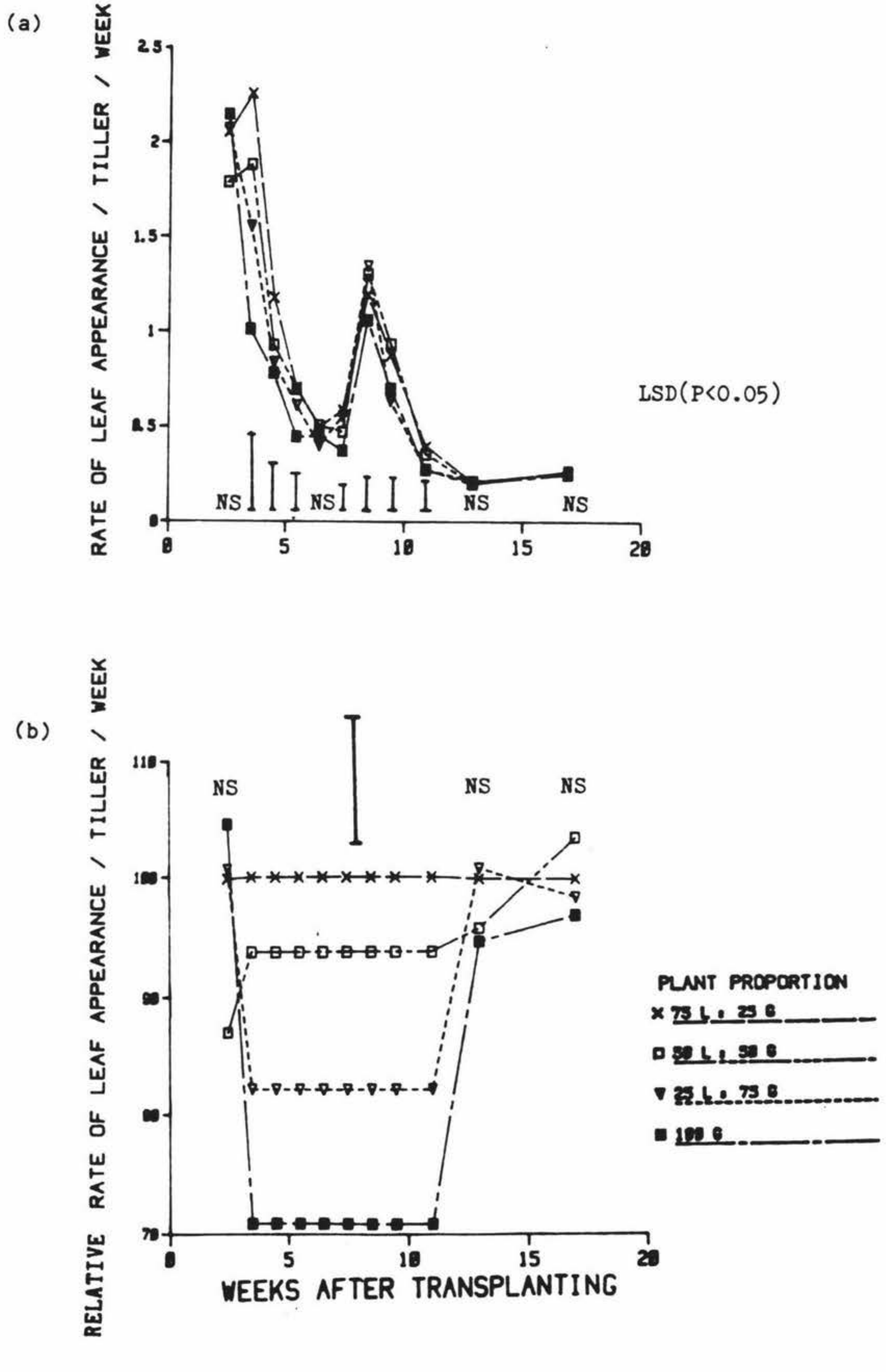


Figure 4.15: The number of leaves on a primary plant of guinea grass.

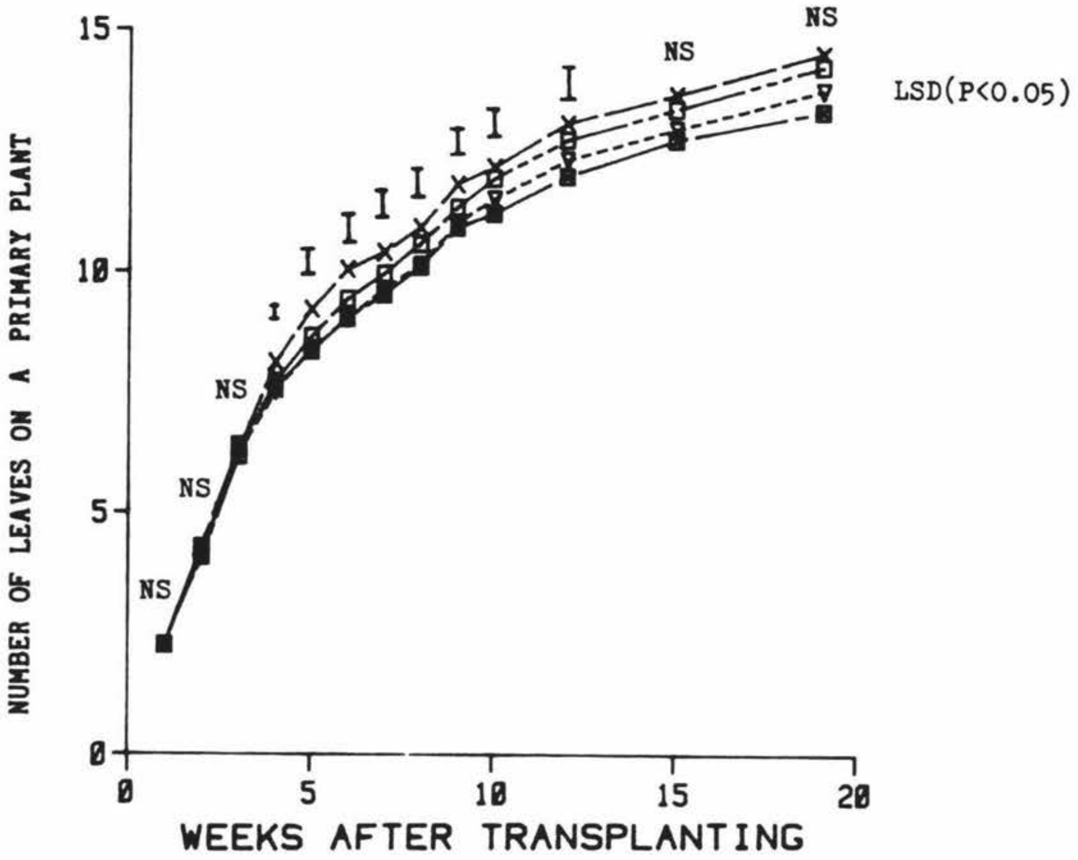


Figure 4.16: The length of fully expanded leaves on a primary plant of guinea grass.

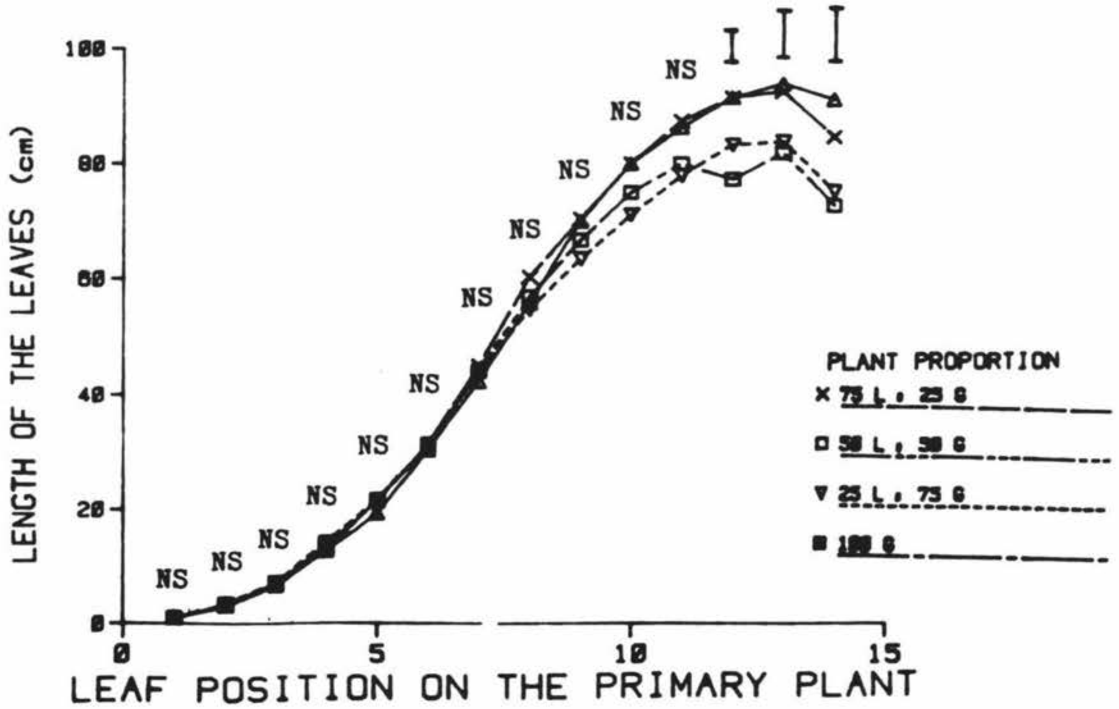
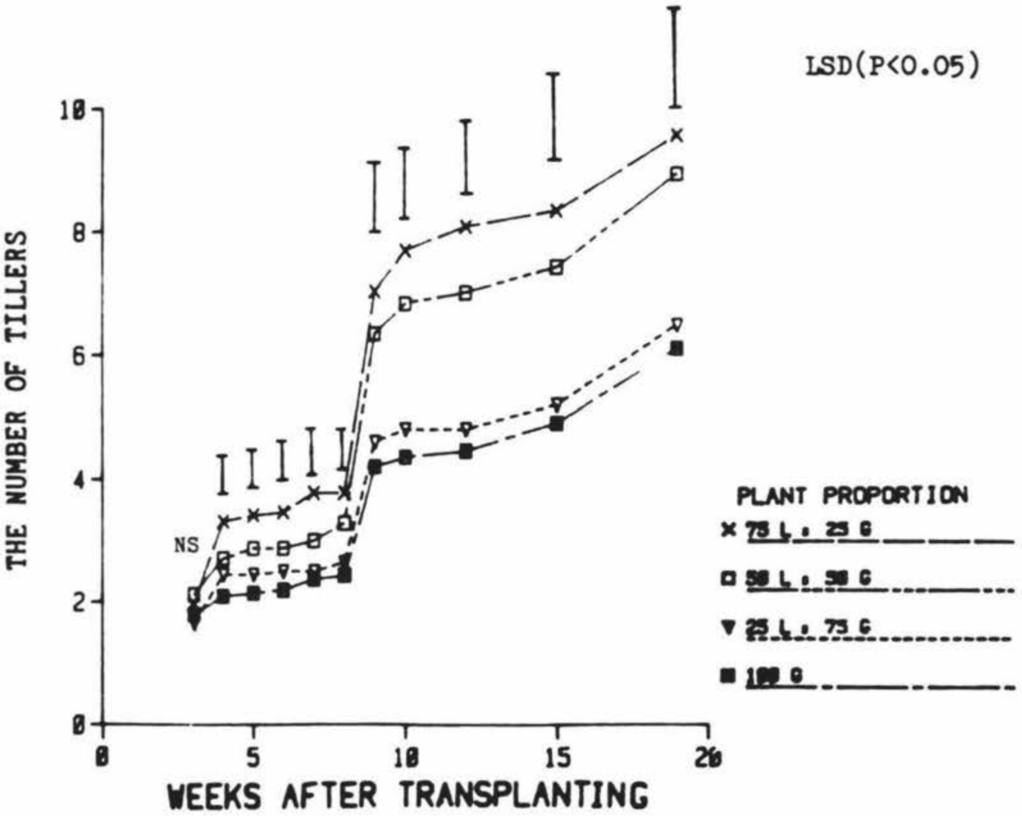


Figure 4.17: The number of tillers per plant of guinea grass.



4.3 Canopy morphology and light interception.

4.3.1. Plant height

The average height of the legume at the final harvest was similar in all mixtures (Figure 4.18.a). Although plants grown in mixtures were apparently slightly shorter than those in the legume monoculture the differnce was not significant (Table 4.7). In contrast, grasses in the 75L:25G and 50L:50G were significantly taller than those grasses in the 25L:75G and monoculture (Figure 4.18.b).

4.3.2 Light interception

In the mixtures, the grass was already taller than the legume in the first week. By week 4, about 41-48 percent of full day light was intercepted at the legume canopy in the mixtures (Figure 4.19). After week 12, the percent light interception was fairly constant in all treatments. Light interception by grasses in the 50L:50G and 25L:75G was significantly higher than that by grasses in the 75L:25G during week 6-8 and 19.

4.3.3 Leaf area distribution

Leaf area distribution in the legume was affected by inter-specific competition. The proportion of leaf area at the bottom of the canopy decreased as grass proportion increased and vice versa for the top (Figure 4.20.a). In the case of guinea grass, leaf area distribution through the canopy was similar in all treatments (Figure 4.20.b).

Figure 4.18: Plant height
(a) Verano stylo
(b) Guinea grass

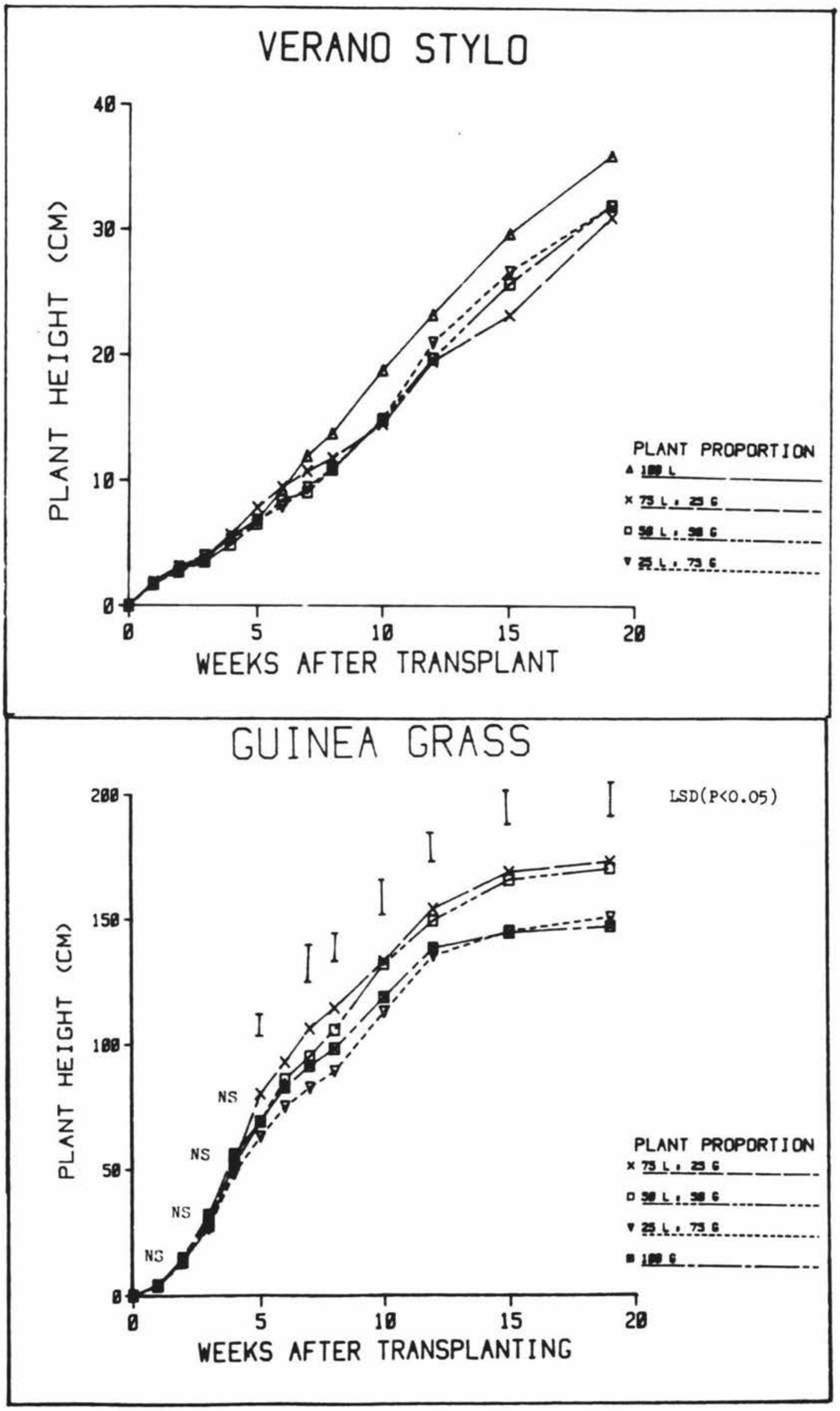


Table 4.7. Mean plant height of verano stylo.

WEEK	TREATMENT				CV(%)	SIGN
	100L	75L:25G	50L:50G	25L:75G		
1	1.84	1.90	1.71	1.69	7.5	NS
2	2.81	3.12	2.70	3.05	9.4	NS
3	3.68 ab	3.81 ab	3.50 a	3.97 c	4.2	*
4	5.49 a	5.65 a	4.84 b	5.25 ab	6.5	*
5	6.86	7.84	6.25	6.78	8.5	NS
6	9.23	9.45	8.45	7.89	11.3	NS
7	11.98 a	10.73 ac	9.05 bc	9.41 c	9.5	*
8	13.74	11.77	10.88	10.91	11.7	NS
10	18.8	14.46	14.79	14.88	16.6	NS
12	23.21	19.48	19.69	20.98	14.7	NS
15	29.7	23.2	25.7	26.6	16.4	NS
19	36.0	31.0	32.0	31.9	15.9	NS

Note: Means not sharing a common letter differ significantly at $P<0.05$

Figure 4.19: Light interception at the legume canopy.

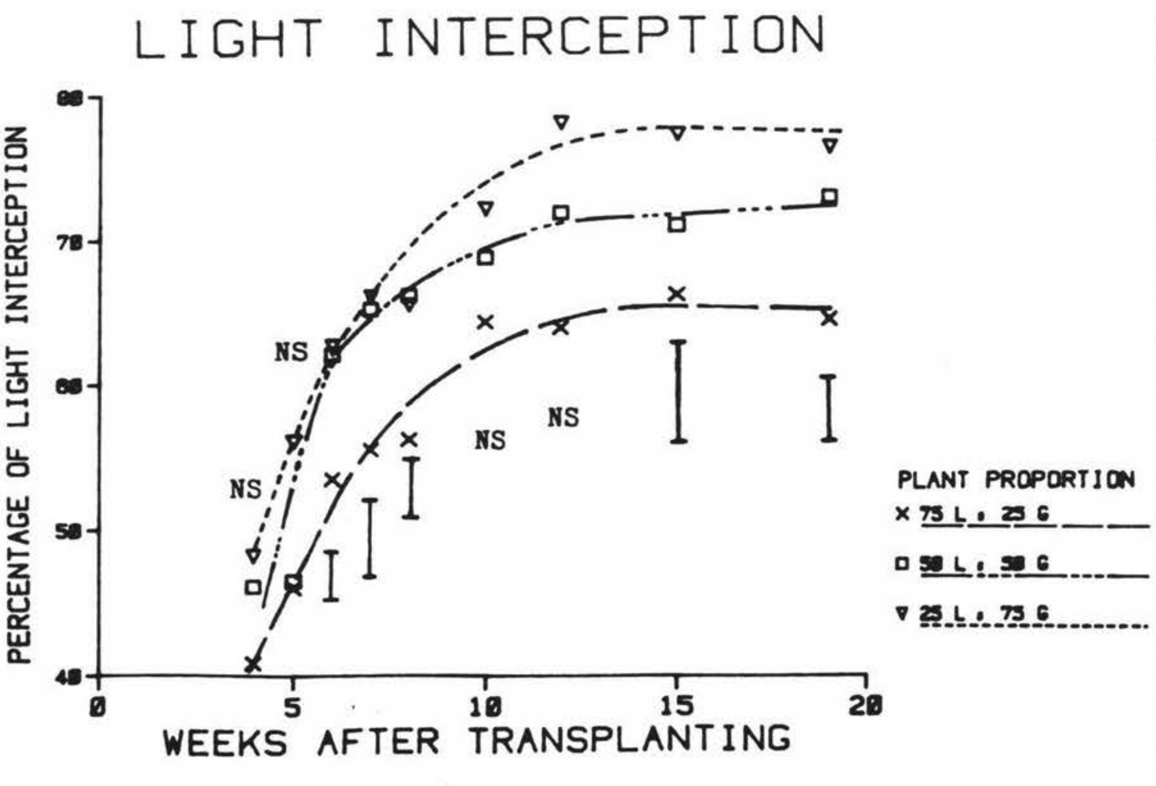
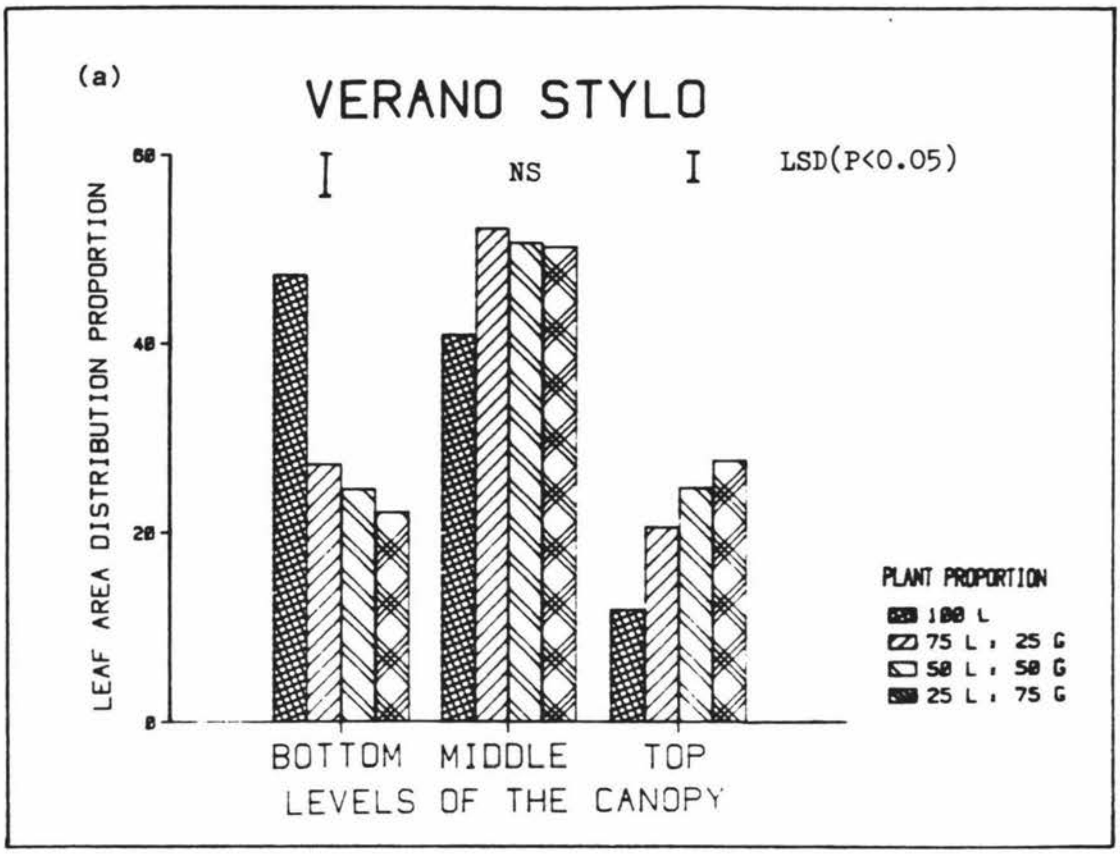
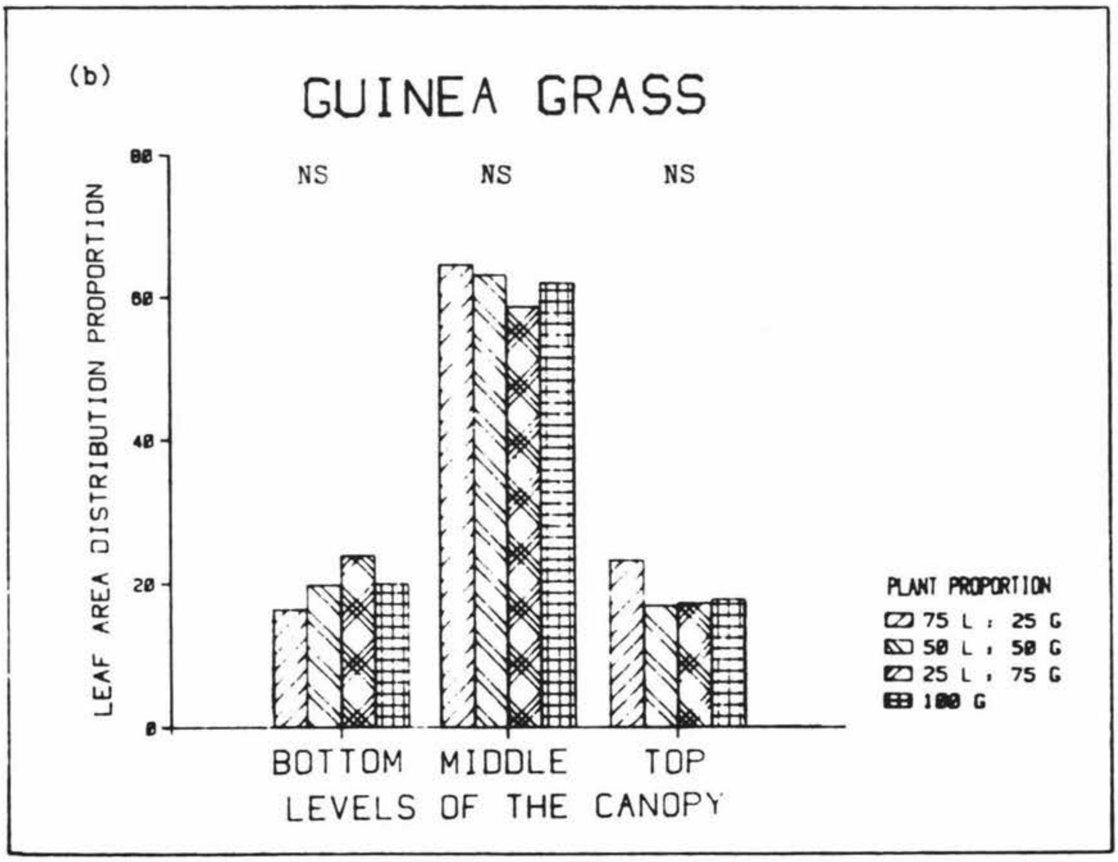


Figure 4.20: Leaf area distribution in the canopy.
(a) Verano stylo
(b) Guinea grass





4.4 Plant Nitrogen

4.4.1 Crude protein yield per box

Although crude protein yield per box in the 50L:50G was higher and in the grass monoculture lower than other treatments, (Table 4.8), there was no significant difference between treatments. Most of the crude protein yield in mixtures was contributed by the grass component. Even in the 75 percent legume combination, legume contributed only 19 percent of the total crude protein yield.

4.4.2 Percent nitrogen in plants

The percentage of nitrogen in grass leaf, non-leaf and dead material was similar in all treatments (Table 4.9). In the case of legume, percent leaf nitrogen in the 25L:75G was significantly lower than that in monoculture and in the 75L:25G, but percent nitrogen in stem was similar in all treatments.

TABLE 4.8. Crude protein yield(mg/box)

	CRUDE PROTEIN YIELD (mg/box)		
	LEGUME	GRASS	TOTAL
100L	8.44 a	-	8.44
75L:25G	1.55 b	6.57	8.13
50L:50G	0.58 c	8.02	8.60
25L:75G	0.25 d	7.67	7.91
100G	-	7.14	7.14
CV(%)	9.3	14.9	11.1
SIGN.	*	NS.	NS.

Note: Means not sharing a common letter differ significantly at P<0.05

TABLE 4.9. Percent nitrogen in plant components of guinea grass and verano stylo.

	PERCENT NITROGEN					
	GUINEA GRASS			VERANO STYLO		
	LEAF	NON-LEAF	DEAD MATERIAL	LEAF	NON-LEAF	SEED HEAD
100L	-	-	-	2.941 a	1.107	2.83
75L:25G	0.528	0.215	0.214	2.967 a	1.053	-
50L:50G	0.53	0.218	0.199	2.760 ab	0.892	-
25L:75G	0.521	0.218	0.222	2.647 b	0.951	-
100G	0.51	0.213	0.226	-	-	-
CV(%)	6.0	10.8	7.6	5.0	11.3	-
SIGN.	NS	NS	NS	*	NS	-

Note: Means not sharing a common letter differ significantly at P<0.05

4.5 Competitive indices

4.5.1 Relative yield total (RYT).

Relative yield total (RYT) values of shoot, root dry matter yield and of crude protein content are shown in Figure 4.21,4.22 and 4.23, respectively. The RYT patterns in both shoot and root dry matter yield were similar at each harvest. The RYTs of the two components at week 5 demonstrated a minor affect on legume by the grass. In contrast, it reflected a severe affect at week 12 and week 19.

The relative total values in the mixtures of shoot dry matter yield in week 1,5,12 and 19 (Figure 4.21), of crude protien yield in week 19 (Figure 4.23), and of root dry matter yield in week 12 and 19 (Figure 4.22) were closed to unity. While RYT of root dry matter yield in week 5 was significantly greater than 1.

4.5.2 Relative replacement rate (RRR)

The relative replacement rate of guinea grass with respect to verano stylo changed with time (Figure 4.24). It appeared that guinea grass in the 25L:75G and 50L:50G gained on verano stylo when verano stylo was younger and gained at a faster rate than that in the 75L:25G. When verano stylo had approximately 20 leaves the RRRs were fairly constant in all treatments.

Figure 4.21: Relative yield total of shoot dry matter yield.

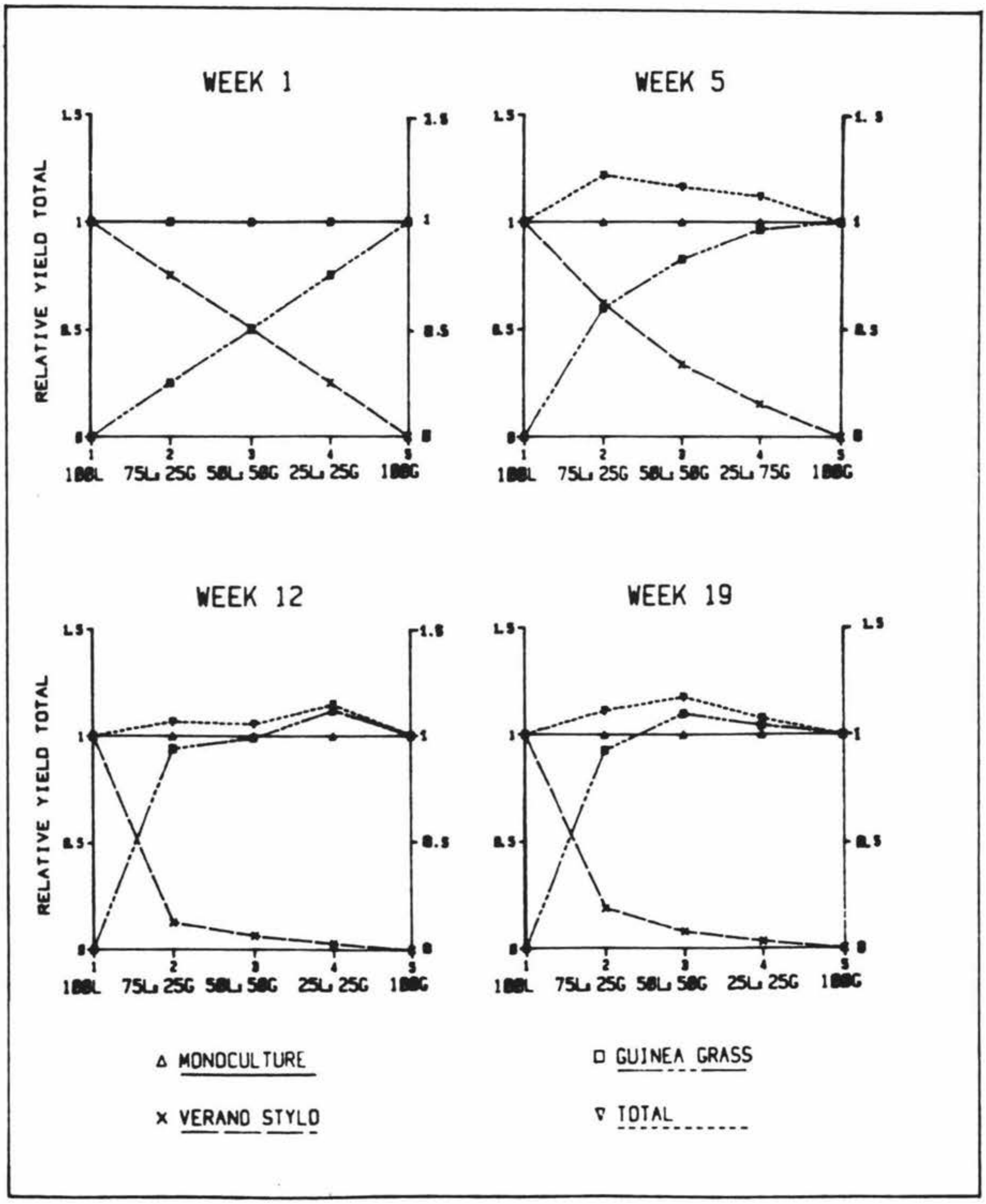


Figure 4.22: Relative yield total of root dry matter yield.

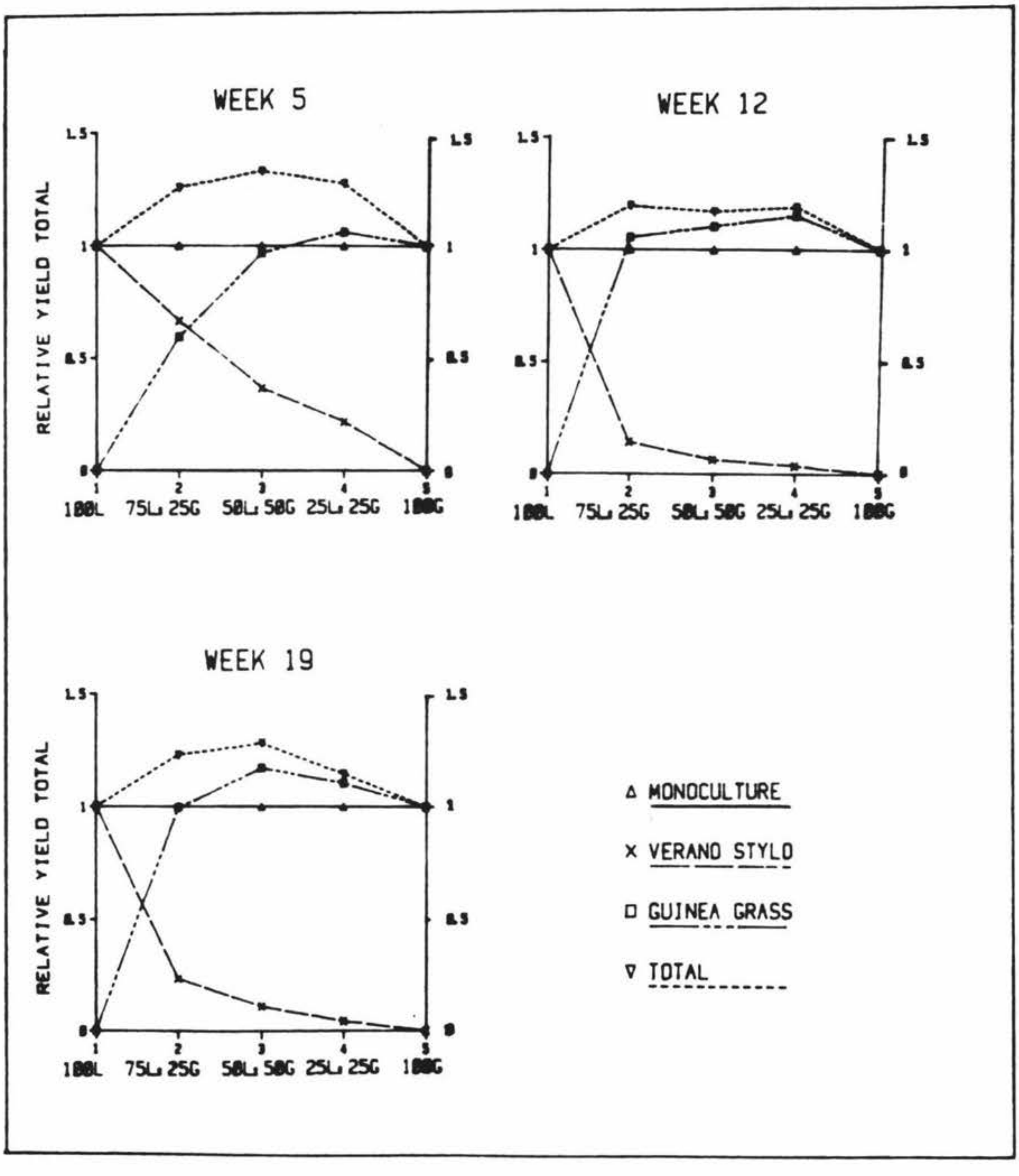


Figure 4.23: Relative yield total of crude protien yield.

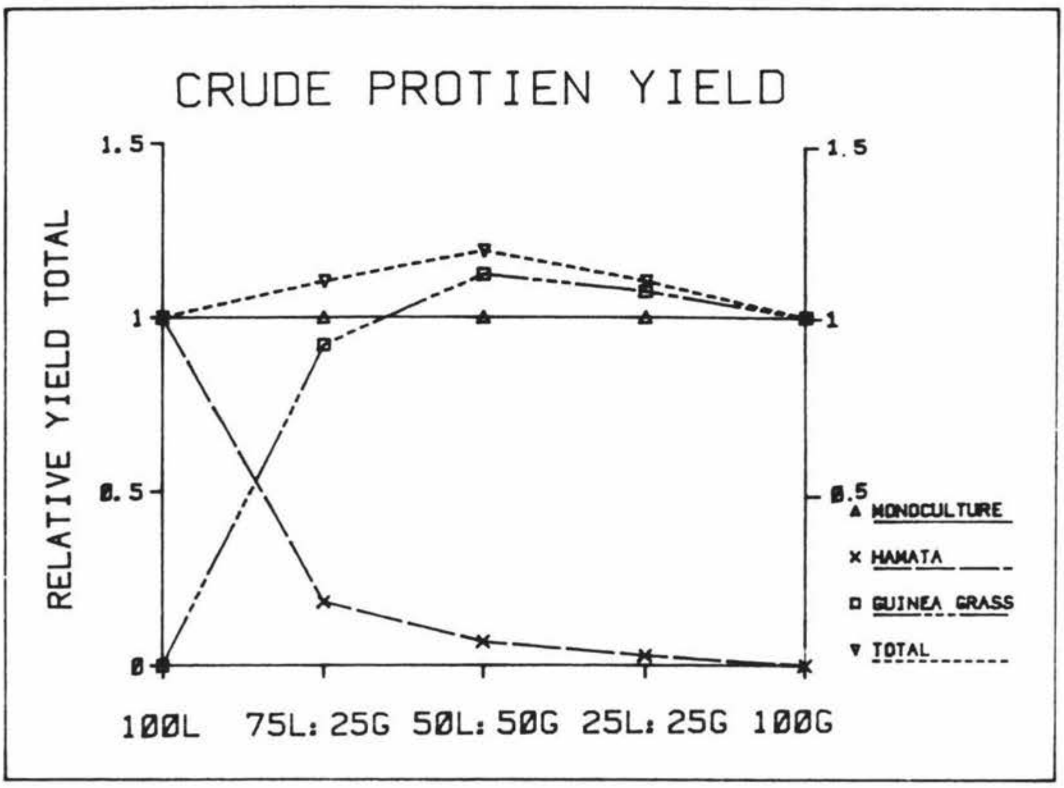
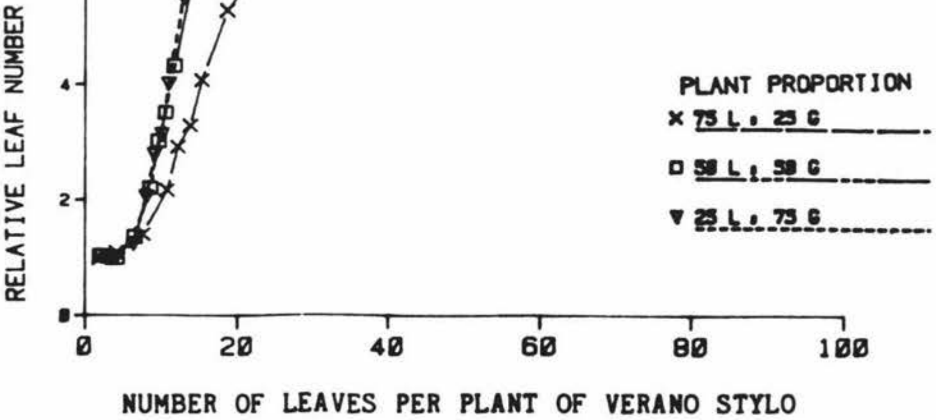


Figure 4.24: Relative leaf number of guinea grass to relative leaf number of verano stylo in relation to growth stage of verano stylo.



CHAPTER 5.

DISCUSSION.

5.1 The effect of plant competition on dry matter yield

Total dry matter yield per box of verano stylo in a monoculture was less than 20 percent of that of guinea grass in monoculture after 19 weeks (Table 4.1). This is due to the difference in yield potential of C_3 and C_4 plants. Guinea grass (a C_4 plant) has a much higher yield potential than verano stylo (a C_3 plant) under adequate nutrient status (Cooper, 1970; Ludlow and Wilson, 1970; Humphreys, 1981). However, in terms of crude protein yield per box there was no significant difference between combinations (Table 4.8). In spite of crude protein yields not being significantly different there is an apparent trend towards increasing crude protein yield per box as the proportion of verano stylo is increased. The result for the 50L:50G mixture can be explained by the exploitation of the adjoining box by the roots of guinea grass (in two replicates) in this mixture. This is also reflected in the unusual patterns of plant dry weight and leaf area of guinea grass in the 50L:50G from week 15-19 (Figure 4.9.,Appendix 4.3). In addition, Padilla et al (1984) showed that (redrawing from Table 3) plant dry matter yield per unit area of common guinea grass demonstrates an asymptotic relationship with plant density. This type of relationship also has been reported in other species by many workers e.g. Donald (1954); Haynes and Sayre (1956) and Holiday (1960), while this study showed a parabolic relationship with maximum yield being acheived in the 50L:50G treatment (Appendix 4.4). This again reflects the additional soil resources being utilised by plants in this treatment.

In terms of improving or maintaining soil fertility, the legume monoculture is likely to do better than legume in mixtures. Nodule numbers per plant of the legume in monoculture were significantly higher than legume in mixtures, being 531, 846 and 2398 percent higher than the legume in the 75L:25G, 50L:50G and 25L:75G, treatments respectively. This indicated the greater capacity of legume in monoculture to fix nitrogen. Many workers (e.g. Henzell, 1962; Jones et al., 1967; Whitney et al, 1967; and Humphreys, 1981) also reported that the amount of nitrogen fixation in effectively nodulated plants is positively related to plant growth. In this study, legume plants in monoculture were much bigger than legume plants in mixtures (Figure 4.2). Thus, under infertile soil conditions, legume monoculture would be more suitable, in order to build up soil fertility. After the soil becomes more fertile grass-legume mixtures may be imposed.

Most of the RYTs, except that of root dry matter yield in week 5, were not significantly different from 1 which aggrees with most results previosly reported by a number of workers(Harper, 1977). In his review, Trenbath (1974) found that 82.7 percent of mixtures (572) showed the relative yield totals (RYTs) were in the range of 0.9 - 1.3. With one exception relative yield totals in this study were also in this range. The RYT of root dry matter yield in the 50L:50G combination in week 5 was 1.34 (Figure 4.21).

Relative yield total of root dry matter yield at week 5 was significantly greater than 1. This is possibly due to the supra-optimal density of the grass monoculture under such low soil fertility condition. Root growth of the grass in monoculture at week 5 may be already affected by intra-specific competition, while root growth of the grass in mixtures was still not affected. Thus resulting in a relatively high root dry matter yield of the grass in mixtures. In addition, competition from grass had only little affect on root growth of the legume component at this stage.

RYTs of dry matter yield and crude protien yield in the final harvest closed to unity indicating that both species used the supply factors from the same resouces. In other words, there was no advantage for the mixture under the conditions of this study. This may be due to the severely suppressed growth of the legume plants from competition with the companion grasses. The suppressed growth of the legume plant would therefore limit its capacity to fix nitrogen. The yield advantage from a mixed pasture would be expected from a mixture with management that ensured that legume plants are not severely supressed by the grasses.

5.2 The effects of plant competition on plant growth

Torssell et al (1976) reported that verano stylo competed successfully with Digitaria ciliaris and Urochloa mosambicensis. Its yield contributed 80 and 35 percent of total dry matter yield when grown with D. ciliaris and U. mosambicensis, respectively, at 25 percent of grass proportion. However, when grown with an aggressive grass species such as the guinea grass in this study, it was severely suppressed. Relative growth rates of verano stylo in mixtures at shoot dry weight 300 mg was only 23 percent of that verano in monoculture (Figure 4.3). It contributed less than 4 percent to the total dry matter yield (Appendix 4.4) and plant dry weight decreased by 73 percent in the 25 percent grass proportion (Figure 4.2). The further increase in grass proportions to 50 and 75 percent decrease the legume yield per plant by a further 10 percent (83 percent) and 3 percent (86 percent), respectively. The results, however, indicated that all the proportions are not suitable for verano stylo grown in association with guinea grass under the conditions of this study. This reflected that an assumtion of one verano stylo plant equivalent to one guinea grass plant is not appropiate. One guinea grass plant may be equivalent to 5 or more verano stylo plants as indicated from the dry matter yield per box of verano stylo in monoculture was less than 20 percent of that guinea grass in monoculture. This area, however, requires further investigation.

The severe suppression of verano stylo growth from the guinea grass can be attributed to the differences in seedling growth rate, plant height, and the size and morphology of the root system. The relative growth rate during the first 5 weeks of verano stylo in monoculture was only 45 percent of that guinea grass (Appendix 4.6). One week after transplanting guinea grass plants were already taller than verano stylo plants (Figure 4.18.a,b). The root system of guinea grass is larger and appeared to ramify more than that of verano stylo. The difference in competitive ability due to differences in these characteristics have been discussed in Section 2.3.1.

It has been shown clearly that seed size is an important factor affecting seedling growth rate during establishment phase (e.g Ludlow and Wilson, 1970a, 1972; Gardener, 1978, and Sangakkara, 1983). Thus, selection or breeding for larger seed of verano stylo would improve its competitive ability during the early establishment phase.

Grazing or defoliation is another way to reduce competitive effect from grass. Grazing animals would have better prehension of the taller grass plants. The taller grass plants, therefore, would be grazed more than legume plants. This would not only reduce the shading effect on the legume plants, but also reduce the grass root activity (Harris, 1978). This in turn would enhance the legume plants. This is supported by Wilaipol and Humphreys (1983) who found early defoliation to be favourable to legume growth in a guinea grass-verano stylo mixed pasture.

By using branch numbers which were linearly related to plant dry weight (Figure 4.8) as a growth parameter it can be clearly seen that verano stylo plants in mixtures were severely suppressed during week 4-8 rather than other periods (Figure 4.7). Verano stylo in the 75L:25G started to be suppressed from week 4 while competition in the other two mixtures started ealier. At week 4 grass plants in the 75L:25G mixture had approximately 82 tillers/m^2, and a leaf area index of 0.75 (Appendix 4.3). This demonstrates that guinea grass with 82 tillers/m^2 or leaf area index 0.75 was sufficient to suppress verano growth at 4 weeks or 1.7 branches stage (Figure 4.7). The severe growth suppression of verano stylo during week 4-8 could possibly be due to two main factors. Firstly, verano stylo and guinea grass were in different stages of growth. The guinea grass was in rapid growth phase while verano stylo was still in lagged growth phase. The lagged growth phase period of guinea grass was only 4–5 weeks (Figure 4.9) while that of verano stylo in monoculture was 8 weeks (Figure 4.1). The differences in lagged growth phase period, or in other words, the differences in seedling growth rate between pasture species have been attributed to be the important factors affecting the severe suppressive growth of one species by another (Blaser et al, 1953,1956; Dalrymple and Dwyer, 1967; Cock and Donald, 1973 a; and Laskey and Wakefiled, 1978; Sangakkara, 1983). Under field conditions, Torssell et al, (1976) showed that the rapid growth phase of verano stylo began around week 6. Thus, establishing the legume component two to four weeks before the grass would allow it to reach the rapid growth phase at the same time or before grass, thus minimizing the competitive effect from the grass.

Secondly, application of fertilizers which included nitrogen during the first 8 weeks would provide a competetive advantage to the grass. This has been shown clearly by previous workers (eg.de Wit et al., 1966; Chestnut and Lowe, 1970; Blunt and Humphreys, 1970; Bruce, 1972; Lambert et al, 1982).

Total dry matter yield per plant of guinea grass also decreased markedly with an increased grass proportion (Figure 4.9). Relative growth rate with respect to shoot dry weight of guinea grass in the higher grass proportions decreased more sharply than in the lower grass proportions (Figure 4.11). The differences in plant dry weight at the last harvest were due to the difference in relative growth rate during the first 12 weeks (Table 4.6). Previous studies (e.g. Holliday, 1960; Donald, 1963) have shown that the reciprocal of yield per plant is linearly related to plant density. However, in this study there was no such relationship. This was due to the average yield per plant of grass in the 50L:50G and 25L:75G being high, probably as a result of the grass roots in some boxes of those mixtures penetrating into the harvested boxes alongside.

The most sensitive yield components affecting plant competition were branch number in the legume (Figure 4.7) and tiller number in the grass (Figure 4.17). Rates of leaf appearance, per branch in legume (Figure 4.6.b) or per tiller in grass (Fig 14.14.a,b), and leaf size (Figure 4.16) were relatively insensitive to branch number or tiller number. This supports the finding of Rhodes (1968). The higher branch numbers of legume in the 75L:50G, the lowest grass proportion, than the other two mixtures at the final harvest (Figure 4.7) was due to the higher relative branching rate during week 3-4 (Table 4.3). Thus, decreasing the grass proportion would be another way to minimize competitive effect of the grass, particularly during early stages of growth.

The relative replacement rate results also support the idea of decreasing the proportion of grass in the mixture. Decreasing the proportion of grass would delay the competition betweeen grass and legume allowing legume plants to grow until at least the 20 leaf stage without severe competition. It appears that when the legume plants reach this stage they would be able to compete more successfully with grass.

5.3 The effect of plant competition on shoot/root ratio.

An increase in grass proportion had no affect on the shoot/root ratios of grass (Figure 4.12), but significantly decreased shoot/root ratio of verano stylo (Figure 4.4) in the 25L:75G mixture during week 5-12. In Panicum maximum, Taerum (1970),(quoted by Crowder and Chheda, 1982) showed that from an early but unspecified growth stage, shoot/root ratios increased with plant age up until 6 months and then only fluctuated slightly. Shoot/root ratios of guinea grass in this study also increased with plant age during week 8-12. During this period soil nitrogen is presummed to be sufficient for the grass growth because of an application of 46 kg nitrogen/ha. However, during week 3-5 and 12-19 where the grass leaves showed symptoms of nitrogen defficiency suggesting more intense competition for nitrogen, shoot/root ratios were fairly constant. This indicated that the affect of competition was greater on shoot growth than on root growth. In verano stylo, the lower shoot/root ratios of the legume in the severe competition (75L:25G) also reflected the greater affect of competition on shoot rather than root growth. The dramatic decline in shoot/root ratio in this mixture at week 5 (Figure 4.4) can be attributed almost completely to the decline in shoot dry matter yield (Table 4.2).

Previous studies showed that competition for light and competition for nutrients have a contrasting affect on shoot/root ratio. Generally, root growth was suppressed more than shoot growth under low light intensities (Troughton, 1960; Beard and Daniel, 1966; Cooper and Tainton, 1968; and Ludlow et al., 1974), and vice versa under nutrient deficiency (Troughton, 1960; Robinson and Jones, 1972 (re calculation data from Fig 1); Welbank et al., 1974). Troughton (1960) suggested that the change in shoot/root ratio with environment serves to maintain a balance between the photosynthetic activities of the shoot and the absorptive activities of the root. If it is assumed that a given weight of root would extract less nutrients from a low than a high nutrient condition soil, then the development of the larger root system in the soil of low nutrient status would tend to maintain the same balance between photosynthesis and nutrient absorption. The development of a large shoot system (relative to root system) when the plant was shaded would tend to maintain a similar balance.

The results of this experiment showed greater suppression of shoot growth than root growth in both grasses and legumes, therefore, suggesting that the effect of competition on shoot/root ratio due to competition for nutrients was more important than competition for light.

5.4 The effect of plant competition on plant morphology

Plant height is a function of internode length and node number for legumes, and includes leaf length for grasses. Yamada and Horiuchi (1960) reported that in their investigations, characters associated with the elongation of plant tissue, such as leaf length, were unaffected by competitive stress, whilst other characters of a multiplicative nature, such as shoot and leaf number were affected. The results of this study, however, do not agree with such generalized conclusions, because while plant height in the legume (Table 4.7) was unaffected both plant height (Figure

4.18.b) and leaf length (leaf 12-14) in grass (Figure 4.16) were significantly decreased as competition stress increased (increased grass proportion). The decrease in plant height with a plant population increase in common guinea grass has been reported by Padilla _et al_ (1984). Work by Rhodes (1968) also found, in some situations, the effect of competitive stress on leaf length and plant height in the pasture species studied.

An increase in grass proportions had no affect on the leaf area distribution of grass (Figure 4.20.b) but decreased leaf area distribution of legume (Figure 4.20.a) at the bottom and increased it at the top of the canopy. The effect on legume plants was due to the suspension of branching at the lower node resulting from competitive affects during the early growth stage (Plate 4.1). When conditions became more favourable to legume growth, most of the new shoots developed from the younger shoot priomodia in the upper leaf axils, which was similar to that reported by many workers (e.g. Mitchell, 1953; and Langer, 1963) in other pasture species.

5.5 The effect of competition on plant quality

Quality in pasture species is a reflection both of leaf production and nitrogen content. The quality of verano stylo and guinea grass decreased with increased competitive stress, by decreasing leaf nitrogen concentration in verano stylo under high competitive stress (Table 4.9) and decreasing leaf/non -leaf ratio in both the grass (Figure 4.13) and the legume (Figure 4.5). There is no doubt that changes in grass-legume proportions will over time alter soil nitrogen status, which in turn influences plant nitrogen concentrations

(Little et al, 1984). The response of plant nitrogen concentration to soil nutritional status varies between plant species. Ball (1979) found that in 11 out of 12 cases plant nitrogen concentration in grass increased with an application of 448 kg/ha nitrogen fertilizer, while only 3 out of 12 cases were found in clover plants. Similarly, the degree of effect of phosphorus and sulphur application on nitrogen concentration in legume plants varies between plant species (e.g. Robinson and Jones, 1972; Andrew and Robins, 1969b; Robertson et al. 1976; Andrew, 1977; and Gilbert and Shaw, 1980). In this study it was possible that the availability of some nutrients (e.g. phosphorus and sulphur) for verano stylo in the 25L:75G were less than was available to verano stylo in the other mixtures,because of the high proportion of guinea grass and this could have indirectly led to the lower level of leaf nitrogen observed in verano stylo in this mixture. Such nutrient conditions, however, had no influence on nitrogen concentration in the guinea grass.

Previous studies (e.g. Burt, 1968; Robinson and Jones, 1972) have shown that pasture species grown under competitive stress for some nutrients had a lower leaf/non-leaf ratio. The results in this study agree with those reports. Leaf/non-leaf ratio of both guinea grass and verano stylo decreased with increasing competitive stress (increased grass proportions), by 24 to 44 and 50 percent respectively (Figure 4.13, 4.5). The reduction in leaf/non-leaf ratio was attributed to the reduction in rate of leaf appearance per plant (Burt, 1968). The greater reduction of leaf/non-leaf ratio in legume plants may be due to the additional shading affect (Fig 4.19) which reduces the rate of leaf appearance in pasture plants (Mitchell, 1955;

Mitchell and Coles, 1955; Forde, 1966). Shading may also decrease leaf/non leaf ratio by promoting stem growth. Holmes and Smith (1975) reported that under relatively high far-red light condition stem growth as promoted (increased 75 - 100 percent), but decreased leaf growth by only 4-9 percent.

5.6 The effect of plant competition on flowering of verano stylo

In a growth cabinet with optimum growing conditions, verano stylo started flowering 5 weeks after germination (Argel and Humphreys, 1983). Under field conditions, at Khon Kaen, Thailand, it started flowering 9.5 weeks after sowing (Waikakul, 1984), which was similar to that reported by Mackay (1975) in Australia. In this study it started flowering in week 7 for the monoculture, week 17 for the 75L:25G, week 19 for the 50L:50G, while legumes in the 25L:75G treatment were still vegetative at the conclusion of the trial. Gardener (1981) reported that verano stylo plants started flowering when they reached a certain minimum size; small plants remained vegetative throughout the season. Under the conditions of this experiment, verano stylo in monoculture started flowering when it had acheived a shoot dry weight of approximately 0.417 g. while in the 75L:25G and 50L:50G mixtures dry matter at flowering was approximately 1, and 1.47 g, respectively (Figure 4.1).

The results of this study indicated that not only the size of the plant influenced flowering but also environmental factors eg. (light condition) may have an effect. The larger size of verano stylo in mixtures with guinea grass at the start of flowering may be due to the affect of the lower quantity and quality of light under shading from the grass. The relatively high proportion of far-red light under shade conditions tends to convert most of the phytochrome present to the P_r form (Jones, 1983), which influences flowering (Vince-Prue, 1976). The relatively low net photosynthetic rate under shade conditions, (Ludlow, 1978) would also retard plant development.

Such late flowering of verano stylo in mixtures would affect seed production in the field situation. Flowering at this time almost at the end of the growing season for the tropical climate could mean the plants may be facing water stress. Severe water stress has been shown to greatly reduce inflorescence density and seed setting of verano stylo (Argel and Humphreys, 1983), and hence seed production. Lower light intensity, due to shading effects from grass, also reduces seed production (Argel and Humphreys, 1983). Thus, seed production of verano stylo in the mixtures would be low.

Gardener (1981) has reported that verano stylo population is almost entirely dependant on the readily germinated seed production from the previous year. He found that only 6 percent of established plants of verano stylo were still alive through the next season. Thus, the population of verano stylo in the following year after such a late flowering would be dramatically decreased. In addition, verano stylo may disappear from the pasture if its seed germination is inhibited by alleopathic substance produced by guinea grass as has been reported by Chou and Young (1975) on latuce's seed (Lactuca sativa var. Great Lakes). Thus, minimizing the competitive effect from grass is neccessary to maintain the population of legume in the pasture.

CHAPTER 6

CONCLUSIONS

- There was no yield advantage from the mixtures over the monocultures of these two species under the conditions of this study. This may be due to the amount of nitrogen fixed by the legume not being large enough to affect herbage yield. The low level of nitrogen fixation may have been due to severe growth suppression of legume from the grass and also to the short experimental period. Under such the conditions the legume monoculture is likely to produce a higher crude protien yield than the other combinations.

- Herbage yield per plant of both species decreased markedly, in particular legume, as the grass population increased. The severe suppression of legume growth can be attributed to:- its lower seedling growth rate, plant height, and the size and morphology of the root system. The options to minimize the competitive effect, therefore, are:- establishing the legume before the grass, earlier defoliation, decreasing grass population relative to legume, decreasing total population, and/or the strategic application of fertilizers.

- Branch number in the legume and tiller number in the grass are the yield components most sensitive to competition. The number of branches is also a good parameter to estimate plant dry matter yield.

- Plant competition did not affect shoot/root ratio of the guinea grass but decreased shoot/root ratio of verano stylo in the high grass proportion (25L:75G) during week 5-12.

- An increase in plant competition decreased leaf/non-leaf ratio of both species.

- In creasing the proportion of grass delayed flowering in legume in the 75L:25G and 50L:50G by approximately 11 weeks while legume in the 25L:75G remained vegetative throughout the trial. Under field condition, this would lead to a severe reduction seed reserve in soil which is the important factor on its population in subsequent growing season.

- Plant morphology of both species is affected by increasing plant competition. Plant height in grass and leaf area distribution at the bottom level of legume canopy was decreased.

- Plant competition did not affected nitrogen concentration in the grass plant but decreased leaf nitrogen concentration of verano stylo in the high grass treatment.

- It is also evident that the two species studied should not be compared on a 1:1 replacement basis. On a plant number basis more legume plants should be sown relative to the number of grass plants.

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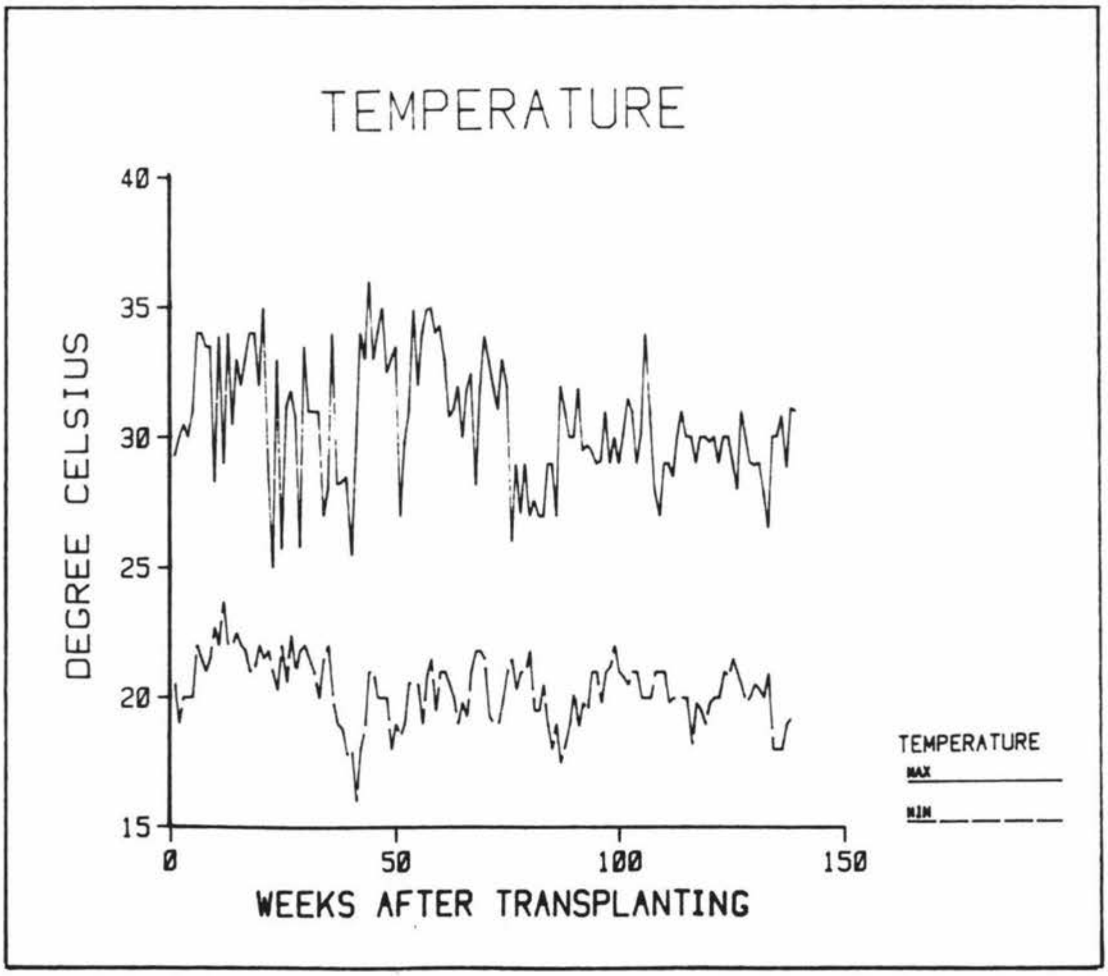
Appendix 3.1 Harvesting date.

HARVEST	DATE OF HARVESTING				
	REP.1	REP.2	REP.3	REP.4	
1	19	20	21	22	DECEMBER 1983
2	2	3	4	5	JANUARY 1984
3	23	24	25	26	JANUARY 1984
4	20	21	22	23	FEBRUARY 1984
5	12	13	14	15	MARCH 1984
6	9	10	11	12	APRIL 1984

Appendix 3.2 Daily-minimum and maximum temperature during the experimental period.



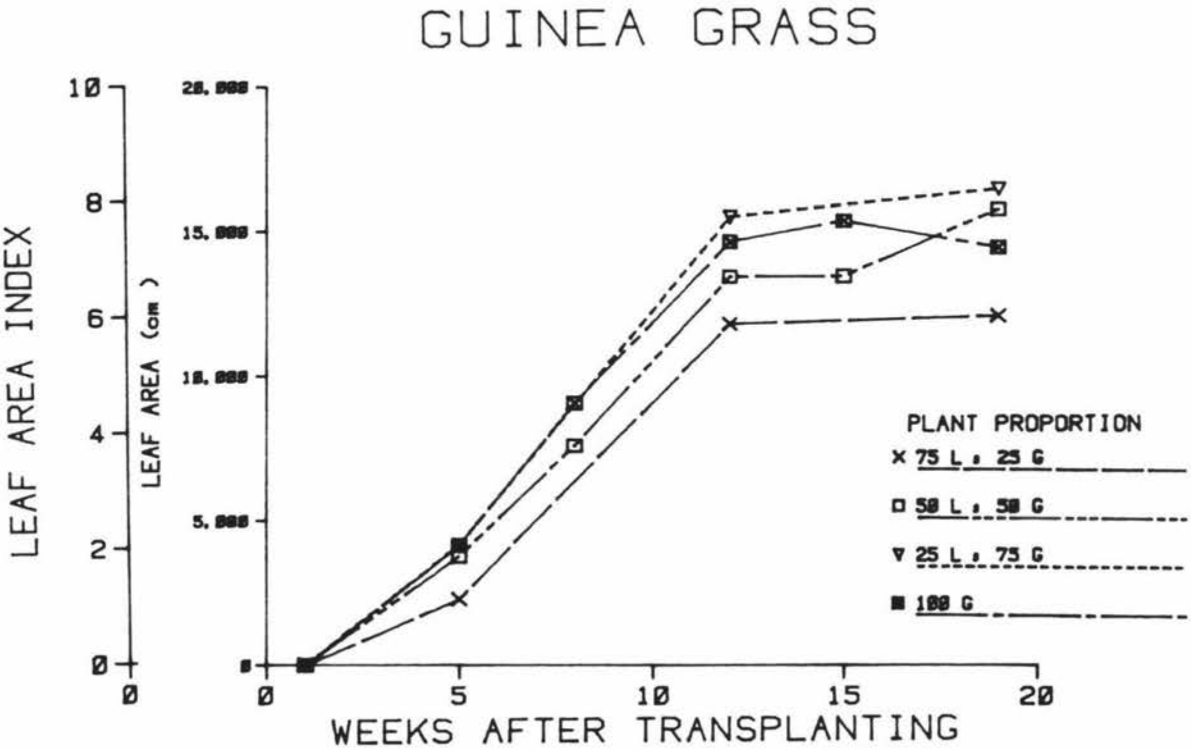
Appendix 4.1 A comparison of t-values between the t-values from tabular ($P<0.05$) and estimated values from equations in figure 4.8

			T-VALUES	
			ESTIMATED	TABULAR($P<0.05$)
100L	vs	75L:25G	0.007	2.042
100L	vs	50L:50G	0.011	2.021
100L	vs	25L:75G	0.01	2.042
75L:25G	vs	50L:50G	0.03	2.042
75L:25G	vs	25L:75G	0.047	2.086
50L:50G	vs	25L:75G	0.024	2.042

Appendix 4.2 The number of leaves when guinea grass started tillering.

The number of leaves on the primary plant.			
75L:25G	50L:50G	25L:75G	100L
5.75	5.75	5.75	5.75
5.75	5.25	6.5	5.75
5.75	5.75	5.75	5.75
6.25	5.75	6.25	5.75
5.75	6.25	6.25	6.25
6.75	5.75	6.75	5.75
6.75	6.25	6.75	6.75
6.25	6.75	6.75	6.75
6.5	5.75	6.25	6.75
5.25	6.25	6.75	6.25
5.75	5.75	6.75	6.25
7.5	7.25	7.50	6.25
5.75	6.25	6.25	6.25
6.50	6.75	6.75	6.25
7.50	6.25	5.75	6.25
5.25	5.75	6.75	6.75
5.25	5.75	5.25	5.25
5.75	5.75	5.75	6.25
5.75	5.75	5.25	5.75
5.25	6.25	6.5	5.75

Appendix 4.3 Leaf area and leaf area index of guinea grass over time.



Appendix 4.4 Dry matter yield at the final harvest (week 19).

	DRY MATTER YIELD (g/box)					
	LEGUME			GRASS		
	SHOOT	ROOT	TOTAL	SHOOT	ROOT	TOTAL
100L	66.68	20.38	87.06	-	-	-
75L:25G	12.42	4.78	17.20	343.01	95.83	438.84
50L:50G	5.2	2.24	7.44	406.88	110.29	517.17
25L:75G	2.23	0.86	3.09	386.61	106.41	493.02
100G	-	-	-	370.6	96.40	467.0
CV(%)						10.0
SIGN.						NS.

Appendix 4.5 Method of estimating light interception at the legume canopy.

$A = (B + C)/2$

where A = Light interception at the legume canopy.

B = Light interception at the middle of the mixture's canopy.

C = Light interception at the bottom of the mixture's canopy.

Appendix 4.6 Relative growth rate of guinea grass and verano stylo in monoculture during week 1-5.

	RELATIVE GROWTH RATE (mg/mg/week)	
	GUINEA GRASS	VERANO STYLO
100L	-	0.74
75L:25G	1.83	0.69
50L:50G	1.75	0.62
25L:75G	1.61	-