EFFECTS OF INTENSITY AND FREQUENCY

OF DEFOLIATION ON A MIXTURE OF

GUINEA GRASS (PANICUM MAXIMUM CV. COLONIAO) AND

VERANO STYLO (STYLOSANTHES HAMATA CV. VERANO)

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Abstract

A study was conducted in a glasshouse to determine the effect of defoliation treatments comprising combinations of two intensities (7.5 cm and 15.0 cm cutting height) and three frequencies (2, 3 and 6 weeks) on production, botanical composition and crude protein of a Guinea grass (Panicum maximum cv. Coloniao) / Verano stylo (Stylosanthes hamata cv. Verano) sward.

Total cumulative yield was reduced with more intense defoliation and decreased as the sward was defoliated more frequently. A similar response was observed for cumulative grass yield. In legume, cumulative yield was reduced at hard intensity but was not influenced by defoliation frequency.

The proportion of the legume component in the sward was not influenced by defoliation intensity but increased with increasing defoliation frequency due more to depressed grass growth rather than a promotion in legume growth.

Defoliation intensity and defoliation frequency had no effect on legume branch number. Similarly, branch size was not influenced by defoliation frequency but increased with less intense defoliation.

Both defoliation intensity and defoliation frequency influenced grass tiller number. It was increased with more intense defoliation. The sward defoliated at moderate frequency resulted in the highest tiller number. Tiller number was not different between very frequent and infrequent defoliation. Intensity and frequency of defoliation also influenced average tiller size. It was reduced with more intense defoliation and decreased with increasing defoliation frequency.

Percent crude protein content of both grass and legume was not influenced by defoliation intensity but was reduced with less frequent defoliation. The percent crude protein content in the legume which was more than double that in the grass indicates that Verano stylo has important contributions in the development and management of a legume-based tropical pasture.

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Chapter 1

Introduction

Pastures in the tropics commonly consist of grasses such as Guinea grass (*Panicum maximum*), Paragrass (*Brachiaria mutica*), and Napier grass (*Pennisetum purpureum*) which mature very quickly with a corresponding decline in digestibility (Milford and Minson, 1966), voluntary intake (Milford and Minson, 1968; Minson and Milford, 1968) and especially that of protein content (Vicente-Chandler *et al*, 1974). The higher intake of digestible energy and protein of tropical legumes at all but the early growth stages will increase the quality of the mixed sward when they are incorporated into pastures (Whiteman, 1980).

Since yield of dry mater, crude protein (Horrel, 1964, Vicente-Chandler *et al*, 1953), digestible dry matter intake (Minson and Milford, 1967) and animal live weight gain (Evans, 1970; Norman, 1970) are linearly related to legume content in the mixture, the legume/grass mixed pasture should be managed such that a high and stable proportion of legume is maintained. Legumes will be reduced in the sward when competition from the grass component is strong. Therefore frequent and intense removal of the grass component by defoliation should be favourable to the legume component in a mixed sward.

However, little information is available on the effects of different defoliation intensities and frequencies on tropical grass/legume mixtures. Such studies are urgently needed in assisting grazing management decisions of tropical pastures.

This experiment was designed to study the effects of different intensities and frequencies of defoliation on the production, composition and protein content of a Guinea grass (*Panicum maximum* cv. Coloniao)/Verano stylo (*Stylosanthes hamata* cv. Verano) sward.

Chapter 2

Review of the Literature

2.1 Introduction

The first requirement of permanent pastures is the capacity to regrow after repeated defoliation. However, the frequency, intensity and timing of each defoliation either by cutting or grazing are important in determining long term production and survival of the pasture. The extent of the effects is also conditioned by the developmental stage of the plants and climatic conditions at and immediately prior to defoliation. In mixed pastures, defoliation is even more important in influencing production because pasture species differ in their growth characteristics and respond differently to defoliation.

2.2 Response of pastures to defoliation

Defoliation is defined as the removal of the above ground portion of the plant either by cutting or grazing (Humphreys, 1981). It is also described in terms of (1) Frequency - the time interval between successive defoliations; (2) Intensity - the degree of defoliation or the proportion of herbage removed at each defoliation; and (3) Timing - the stage of plant development and season of the year (Harris, 1978; Humphreys, 1981).

Defoliation not only reduces leaf area, with the concomitant effects on carbohydrate storage, tiller development, leaf and root growth, but also alters the microenvironment of light intensity, soil temperature and moisture, which in turn affects plant growth (Watkin and Clements, 1978).

In grazed pastures, animal treading can reduce the growth and persistence of pastures. Direct injury occurs to stem and bud tissue, and the indirect effects of treading operate through soil compaction and pudding, especially if treading occurs when the soil is wet. The magnitude of the effect depends on plant species, animal species, sward height, soil type and management (Edmond, 1966).

The grazing animal removes only a small quantity of nutrients from the pasture, the remainder being returned as dung and urine (Davies et al, 1962). Dung and urine are potentially significant sources of nutrients for the pasture because they contain elements, of which N, P, K, S, Mg, and Ca are the most important, though most of the micronutrients are present (Dale, 1963, cited by Watkin and Clements, 1978). However, their effects on pasture productivity and composition, while frequently striking, will depend on many plant, animal, soil and climate factors (Watkin and Clements, 1978).

The grazing animal can disperse seeds through its hooves, hides, wool, dung and medic burrs in sheep fleeces. This can lead to the colonization of new sites by some pasture species (Watkin and Clements, 1978). However, in this review, only defoliation effects on pasture will be considered.

2.2.1 Cutting vs grazing

Although no cutting experiment can satisfactorily reproduce the defoliation effects of a grazed pasture (Watkin and Clements, 1978), much of the research work has been done using cutting experiments because of high requirements of land, labour and finance in grazing trials.

Whereas in cutting experiments, herbage above cutting height is instantly and uniformly removed, the grazing animals selectively graze and trample pasture, return dung and urine to the pasture and disperse seeds (Watkin and Clements, 1978). Both the botanical composition and the herbage production of grazed pasture are often different from that of a cut sward (Korte, 1981).

Selective grazing leads to unevenness in the severity of defoliation. Stobbs (1975a) has shown that when cattle intensively graze a pasture, they graze from the top to the bottom and select leaf in preference to stem. Selective consumption of Panicum maximum in preference to Stylosanthes guianensis during the wet season has been demonstrated in Thailand (Humphreys, 1978). However, utilization of species within a pasture may change with time. With Macroptilium atropurpureum, selection and intake are higher at the end of the growing season (Stobbs, 1975b) because of the higher palatability of the legume. Selection of plant parts or one species in preference to another is attributed to relative palatability or edibility, accessibility, and availability of pasture and its components (Watkin and Clements, 1978).

The intensity of defoliation by grazing animals is primarily a function of the stocking rate. At low stocking rates, the differences between cut and grazed pastures are largely due to higher selective grazing. A tiller or plant may be defoliated several times during a grazing period, while others may not be defoliated at all. As grazing pressure is increased, relative acceptability between species will be reduced, but in the extreme, animals may prefer to starve rather than eat a really disliked species (Watkin and Clements, 1978). In a temperate, perennial mixed pasture heavily grazed by sheep, Lynch (1966) found the botanical composition to be different from the same pasture which was closely and frequently cut with nutrients returned in the form of clippings or excreta.

The difficulty in extrapolating the results from cutting experiments to grazing systems has been illustrated by Jones (1959). With three varieties of Cocksfoot (Dactylis glomerata), he showed that the herbage production and the order of production under rotational grazing by sheep with 5 grazings per season differed from those under mowing of herbage 5 times per season. However, with caution, information gained from cutting trials can be useful in helping to explain responses obtained under grazing (Korte, 1981) especially those conducted under a short duration.

2.2.2 Factors influencing regrowth after defoliation

2.2.2.1 Residual characteristics

(1) Residual shoots

a) Tiller density

Regrowth of the sward after defoliation is dependent on tiller density. At very low tiller densities, not all the light is intercepted by tillers and regrowth is positively correlated with tiller density. In *Lolium rigidium* cv. Wimmera, Cocks (1974) found that the rate of regrowth in terms of increase in leaf area index (LAI) after defoliation rose with the number of tillers up to about 10,000 tillers per m^2, after which it remained constant. Davies (1966) also found that regrowth of S24 perennial ryegrass was related to tiller density between 5,400 and 8,700 tillers per m^2. Korte (1981) showed that the critical tiller density, below which growth is positively correlated with density, in autumn was at least 8,000 tillers per m^2 for infrequently grazed ryegrass (*Lolium perenne*) dominant pasture. At high density, regrowth is insensitive to tiller density because of the negative relationship between tiller density and tiller size (Cocks, 1974).

b) Growing point

The rate of recovery of the sward depends on the number of sites remaining for regrowth after defoliation. This has been demonstrated by Gutteridge and Whiteman (1975) who showed that regrowth of *Psoralea eriantha* was markedly reduced under frequent defoliation caused by the reduction of growing points remaining after frequent defoliation.

Species and cultivars with a high density of growing points recover more quickly after defoliation than those with few growing points. Under close and frequent defoliation of three ecotypes of Stylosanthes guianensis, Grof et al (1970) found that regrowth was lower in the erect ecotypes than in the decumbent ecotypes due to the presence of a smaller number of growing points below cutting height.

Similarly, the position of the growing point is also important in influencing regrowth. For example, regrowth rate is greater in Paspalum dilatatum than in Panicum coloratum because the aerial shoots of Panicum coloratum are more vulnerable to defoliation than Paspalum dilatatum which has more basal shoots (Holt and McDaniel, 1963).

(2) Residual leaf area

Leaf area is of great importance in pasture growth because it plays the principal role in intercepting light for photosynthesis. Watson (1947) introduced the concept of leaf area index (LAI), defined as the ratio of leaf area to the area of ground it occupies. The relationship between residual LAI and the rate of subsequent growth of defoliated swards has been well demonstrated (Humphreys and Robinson, 1966; Jones, 1974a; Ludlow and Charles-Edwards, 1980; Jones and Carabaly, 1981). Brown and Blaser (1968) concluded that in general increased LAI provided greater light interception and hence accelerated growth rate, other environmental factors being favourable. Once all the incident light energy is intercepted, there is no further increase in growth rate with increased LAI, and eventually growth rate declines until a point is reached, called ceiling yield, when respiratory and death losses equal photosynthetic gains.

Brougham (1958) used the term "Critical LAI" to describe the LAI required to intercept 95% of the incident light at noon. Brougham (1956) showed that pasture growth after defoliation was exponential in form until this critical LAI value was reached. Thereafter a relative constant rate of growth was recorded over LAI values of 5 to 9. Some workers used a different term, "Optimum LAI", to describe the LAI when maximum growth rate was reached, further increase in LAI resulting in reduced growth rate (Davidson and Donald, 1958; Stern and Donald, 1961; 1962; Black, 1963). However, McCree and Troughton (1966) concluded that the declining growth rate above the optimum LAI observed in the field experiments was partly attributed to the failure to include material which died between harvests.

For maximum yield, a sward should be so managed as to maintain it as closely as possible to the optimum LAI (Donald and Black, 1958). Harris (1978) concluded that maximum dry matter yield should be expected if defoliation frequency was such that the regrowth interval was extended until pasture growth rate began to decline from its maximum. Intensity of defoliation should be to the level that left the amount of herbage at which maximum growth rate was first attained. However, there are many factors affecting the simple application of the LAI concept to defoliation practice. This is because the critical LAI or optimal LAI appears to vary with leaf angle, latitude and time of the year (Brougham, 1958; Davidson and Donald, 1958; Stern and Donald, 1962; Black, 1963; Brown and Blaser, 1968). Defoliation intervals to leave sufficient residual herbage to intercept 90 - 95% incident light at noon resulted in low photosynthetic efficiency of the stubble and decreased tiller density (Hunt and Brougham, 1967). Low LAI values may be desirable at times because they reduce the old leaf and favour tiller production. Whereas LAI above the optimum may be desirable at other times when regrowth may be dependent on stored reserves. Tainton (1974) determined grazing interval and height of Lolium perenne dominant pastures by reference to 95% light interception. He showed that different grazing treatments had little influence on dry matter production during the main reproductive growth period in late spring and early summer. Lax and infrequent grazing at this time, however, reduced tiller density. During the dry summer period lax infrequent grazing increased production by 20%, while in the vegetative growth period in autumn, alternate lax and hard grazing outyielded hard-grazed pasture by 63%.

(3) Carbohydrate reserves

The fluctuations in the level of carbohydrate reserves following defoliation has lead to the belief that carbohydrates have an important role in influencing pasture regrowth (Graber et al, 1927; Sullivan and Sprague, 1943; Smith and Graber, 1948; Sprague and Sullivan, 1950). However, May (1960) has questioned the importance of carbohydrate in regrowth. Subsequent works have provided evidence that both photosynthesis by residual leaf and carbohydrate reserves contribute energy to regrowth after defoliation (Davidson and Milthorpe, 1966a; 1966b; Booysen and Nelson, 1975).

The major areas of carbohydrate reserve storage in grasses are usually in the lower regions of stem, e.g. stem bases, corms, rhizomes or stolons (White, 1973). In legumes, the major storage areas are roots, corms, stolons and stems (Weinmann, 1961; Hunter et al, 1970). The concentration of carbohydrate within plants fluctuates diurnally (Holt and Hilst, 1969; Melvin, 1965) and also depends on season (Humphreys and Robinson, 1966). This has also been found to relate to pasture species (Barnes, 1960; Barnes and Hova, 1963), stage of growth (Humphreys and Robinson, 1966), climatic factors (Mitchell, 1953; Blaser et al, 1966; Brown and Blaser, 1970), nitrogen fertilizer (Hojjati et al, 1968) and defoliation regimes (Sullivan and Sprague, 1943; Evans, 1972).

In intact plants, carbohydrate reserves are accumulated when photosynthates are in excess of requirements for growth and respiration (Harris, 1978). Defoliation causes reduction in carbohydrate reserves (Humphreys, 1966a) because they are used for respiration and providing substrates for new growth until sufficient photosynthetic capacity has developed to meet the demands of respiration and growth (Harris, 1978). The supply of carbohydrate is also reduced as a result of reduced photosynthetically active tissues. Thus the reserve levels immediately prior to defoliation affect the regrowth rate. Adequate carbohydrate reserves are therefore important in regrowth initiation after defoliation, when the photosynthesis is insufficient to meet the growth and respiration demands (Adegbola, 1966; Humphreys and Robinson, 1966).

The significant involvement of carbohydrate reserves in regrowth is dependent on the amount and capacity of photosynthetic tissue remaining after defoliation (Ward and Blaser, 1961; Humphreys and Robinson, 1966; Langer and Keoghan, 1970). Intensive defoliation will be compatible with high production provided that the frequency of defoliation is such that reserve levels and adequate root growth can be maintained or that adequate leaf capable of photosynthesis remains to supply the energy requirement after defoliation.

2.2.2.2 Stage of growth

During the vegetative phase, internode extension does not normally occur so that regrowth after defoliation can come from both terminal and axillary meristems (Jewiss, 1972). In contrast, in the reproductive phase, internode extension occurs in reproductive tillers hence meristems are easily removed by hard cutting or grazing. If defoliation removes the meristems of the reproductive tillers, the stubble will not grow and will ultimately lose weight and die (Davies, 1977). Regrowth must therefore occur from new tillers which subsequently arise from hitherto dormant tiller buds (Ryle, 1974) or existing vegetative tillers in the sward. New growth from vegetative tillers at the base of the decapitated stem is a slow process (Davies, 1956, cited by Matthews, 1971).

Defoliated reproductive tillers with intact meristems can continue to develop, although if the apex is close to the cutting level, the tiller will develop in a virtually leafless condition (Davies, 1976). Thus it will grow into a stemmy sward with a corresponding decline in nutritive value (Raymond, 1969). Tillering is reduced due to the flowering axis exerting an inhibitory effect on the growth of tiller buds (Jewiss, 1972). In Panicum maximum var. trichoglum cv. Petrie, developing inflorescences will suppress axillary bud development, but not at the anthesis stage (Humphreys, 1966b). The survival of vegetative tillers is also poor. This is caused by the failure of larger tillers (mainly reproductive tillers) to supply assimilate to small heavily shaded vegetative tillers (Ong et al, 1978).

Dovrat et al (1980) have shown that the initial regrowth of a Rhodes grass (Chloris gayana) sward after a long (28 days) pre-cutting period is slower than after a short (7 days) pre-cutting period. When the sward of younger age is cut, approximately 90% of the tillers can regrow whereas in the sward of older age, approximately 20% of the tillers will regrow. This is because the sward of younger age comprises a relatively small number of reproductive tillers, but there is a relatively large number of reproductive tillers in the sward of older age. The slower regrowth after defoliation of the sward of older age is attributed to the lack of tillers capable of regrowing caused by the removal of the apical meristems with defoliation. Similarly, Milthorpe and Davidson (1966) showed that regrowth of Lolium perenne was greater when defoliated at flower initiation than at ear emergence and during seed development. The main factor contributing to the greater amount of new growth when plants were defoliated at flower initiation than later was the presence of a number of intact secondary flowering tillers which had a much faster rate of growth than non-elongating vegetative tillers.

However, some plants, particularly range grasses, behave differently with regard to the time and duration of the elevation of the growing point above cutting height. In species within the Natal Tall Grassveld, Booysen et al (1963) showed that Themeda triandra was less useful than other grasses (Hyparrhemia hirta and Tristachya hispida) because elongation of the stem carried the apex above cutting height while still in the vegetative condition. Therefore, grasses with culmed vegetative tillers, whose apices are elevated by internode elongation will be more prone to removal of the apices by cutting or grazing than grasses with culmless vegetative tillers (Hyder, 1972).

2.2.2.3 Environmental factors and nutritional factors

(1) Water and nutrient uptake

Defoliation has been observed to affect root growth (Davidson, 1978). Crider (1955) removed top growth of several grass species (viz. Rhodes grass (Chloris gayana), Kentucky bluegrass (Poa pratensis) and Smooth bromegrass (Bromus inermis)) in increments of 10% from 0 - 90%. He showed that a single clipping stopped root elongation of all species when more than 40% of tops were removed. The larger the percentage removed, the longer the period of root growth stoppage. Numerous studies on many species reviewed by Troughton (1957) show that the more frequent the cutting interval, the greater is the reduction in root weight. Although increasing intensity and frequency of defoliation reduce root growth, the magnitude of the effect depends on plant structure. Species with a low growth habit, and particularly those which have underground stems (rhizomes), e.g. Cynodon spp., are more resistant than the upright species e.g. Eragrostis curvula, partly because harvesting to any particular height will remove a lower proportion of the plant tops and partly because these underground stems act as storage organs (Tainton, 1981).

Regrowth after defoliation may be limited by reduced nutrient and water uptake. Harris (1978) has concluded that the three possible ways in which nutrient uptake is reduced by defoliation are, firstly, the cessation or slowing down of root extension by defoliation may limit the exploitation of nutrients and water from the soil. Secondly, defoliation reduces transpiration. This could restrict absorption of nutrients because there appears to be a positive relationship between transpiration and the absorption of inorganic ions by intact plants - at least when soil nutrient status is high. Thirdly, defoliation, by restricting the flow of synthates and hence, respiratory substrate, to the roots, could limit active ion uptake. Similarly, Davidson (1963, cited by Humphreys, 1966a) noted that the uptake of P^{32} in Cocksfoot was proportional to the rate of root extension and considered that some of the responses to severe defoliation which had been ascribed to carbohydrate shortage might in fact be due to the limitation of mineral uptake.

(2) Nodulation and nitrogen fixation

Defoliation by cutting or grazing affects the legume /Rhizobium symbiosis through influencing host plants and altering the micro-environment of the plant. Very frequent defoliation impairs nodulation and nitrogen fixation and can lead to poor regrowth of legumes in low-fertility soils due to simple nitrogen deficiency (Humphreys, 1981).

Whiteman and Lulham (1970) and Whiteman (1970) reported reduction in the nodule weight and number following defoliation of Macroptilium atropurpureum, Desmodium uncinatum and Desmodium intortum. Nodulation of Centrosema pubescens was also decreased by defoliation in a field study by Bowen (1959). The loss of nodules is due to the insufficient photosynthate supply caused by defoliation. In Desmodium intortum and Macroptilium atropurpureum, Whiteman (1970) found that nodule loss was greater with more severe defoliation, and was greater when young photosynthetically active leaves were removed than when older less active leaves were removed.

Defoliation has been shown to cause loss of older nodules and lateral roots in red clover (Trifolium pratense) and Lotus corniculatus (Butler and Bathurst, 1956). This is followed by regrowth of laterals and new nodule formation, so that with cycles of grazing, there is a turnover of nodules. The strength of the cycle of further nodule initiation and the size to which these nodules grow is determined by the severity of the defoliation regime (Whiteman, 1970).

Defoliation causes the reduction of nitrogen fixation by legumes. Using the acetylene reduction technique, Moustafa et al (1969) and Chu (1971) demonstrated the markedly reduced rate of fixation caused by defoliation. The reduction of nitrogen fixation corresponded to a change in nodule colour from pink to green or brown upon defoliation (Wilson, 1942; Butler et al, 1959; Chu and Robertson, 1974). A change in nodule colour signified the degradation of the pink pigment leghaemoglobin which was correlated with fixation activities (Schwinghamer et al, 1970).

(3) Light and temperature

Regrowth of grasses and legumes following defoliation shows a marked temperature dependence. Ferraris and Norman (1976) found that regrowth of Pennisetum americanum under frequent defoliation was positively related to temperature. McWilliam (1978) concluded that regrowth of subtropical and tropical grasses was increased with temperature over the range 15 - 30^{o}C. A similar response was reported for Desmodium intortum and Macroptilium atropurpureum (Jones, 1971, cited by McWilliam, 1978). The temperature response was associated with an increase in the rate of tillering, rate of leaf appearance and expansion of individual leaves (Muldoon and Pearson, 1979a; Whiteman, 1980). Furthermore, using tropical tallgrass hybrid pennisetum (Pennisetum americanum x Pennisetum purpureum), Muldoon and Pearson (1979b) found that rapid regrowth was associated with the breakdown of organic reserves and that the speed of mobilization increased markedly with temperature.

In temperate grasses, Sullivan and Sprague (1949) studied the recovery of Lolium perenne following clipping under different temperature regimes. They found that new shoot growth was most rapid at 15 - 20°C and least at 26 - 30°C. The dry weight of both the roots and the stubble decreased throughout the 40 days after clipping during which they were studied, the losses being most rapid and extensive at the higher temperature. The roots and stubble also underwent rapid losses of sucrose and fructosan during the early part of the experiment but these losses were, under low temperature conditions, partially replaced later. Under high temperatures, especially in the roots, the losses continued almost to the point of exhaustion and in some cases until the death of the roots. High temperature leading to rapid dissipation of reserve carbohydrates, slowed down the production of new leaf growth, and, in general, inhibited the recovery from defoliation.

Similarly, light intensity can influence regrowth after defoliation by means of its influence on the carbohydrate reserves. Without light under otherwise normal conditions a plant is unable to grow. Following partial defoliation the percentage of water soluble carbohydrate in the roots and stubble of Lolium perenne plants was found by Sullivan and Sprague (1943) to decrease rapidly for several days. After approximately 11 days, carbohydrates started to accumulate in the root and stubble of plants in the light, but not in those plants placed in the dark. Marked reduction occurred in those plants placed in the dark. There was also hydrolysis of protein, and an accumulation of nitrates which disappeared when the plant was dying.

2.3 Effects of defoliation on dry matter yield

Defoliation of grass/legume mixtures generally gives higher yields as the frequency of defoliation decreases (Moores, 1965; Whitney, 1970; Olson, 1973; Jones, 1974b; Siewerdt and Holt, 1974; Dradu and Nabusiu-Napulu, 1977; Murphy et al, 1977).

The effects of frequency of defoliation on dry matter yield of grasses in the mixtures depends on growth habit. For erect grass species, increased yields with decreasing cutting interval have been demonstrated in Panicum maximum (McIvor, 1978), Setaria anceps (Jones, 1974b). For Brachiaria decumbens (Signal grass) which is stoloniferous, McIvor (1978) found that yield was higher with more frequent defoliation. He attributed the decrease in yield of Brachiaria decumbens with longer cutting interval to lodging of herbage below cutting height and subsequent decay, whereas with more frequent cutting all herbage was harvested.

Increased frequency of cutting reduces legume yield in mixed swards. The reduced Siratro (Macroptilium atropurpureum) yield in mixed swards with increasing frequency of cutting has been reported by many workers (Jones, 1967; 1974b; Whiteman, 1969; Siewerdt and Holt, 1974). Jones (1974b) found that every week of extension of the cutting interval increased Siratro yield by an average of 225 kg/ha/yr. Siratro density increased linearly with cutting interval, which was attributed to greater development of new plants from stolon or rhizomes as none of the original plant survived. The reduced yield was also related to the lower residual leaf area index and the slow increase in leaf area index after cutting (Jones, 1974a). Both aspects are related to the lack of active or potential growing points and functional leaves on the twining stem caused by frequent cutting (Jones and Jones, 1978). The increased total yield of twining legume grown with grass as cutting interval increases is attributed to both increased grass and legume yield as shown in the Setaria anceps /Siratro mixture (Jones, 1974b). In contrast to twining legumes, cutting frequency has much less effect on prostrate legumes in the mixtures. At Samford, S.E. Queensland, Trifolium semipilosum growing with Paspalum dilatatum was cut to 3.8 cm or 7.5 cm every 4 or 8 weeks over a four year period (Jones, 1973a). There was no significant effect of cutting interval on Trifolium semipilosum yields but total dry matter yields were 16% greater for the 8 week cutting interval than the 4 weekly cuts. The greater total yield was due to the increased grass yield as the cutting interval increased.

There are several reports where less intensive defoliation has given higher yield than more intensive defoliation, for example, Jones (1974b) with Nandi setaria (Setaria anceps) /Siratro pastures and with Cynodon dactylon/Desmodium intortum (Jones, 1973b). In contrast, Moores (1965) found that increased height of cutting resulted in decreased dry matter yields of a Giant stargrass (Cynodon plectostachyus)/Centro (Centrosema pubescens) mixture. Whitney (1970) found no yield differences with Pangola (Digitaria decumbens)/Desmodium intortum pastures cut either at 5 or 13 cm. Riveros and Wilson (1970) and Olson (1973) also found no yield differences with Setaria sphacelata/Desmodium intortum mixtures cut at 7.5 or 15.0 cm height.

The response of legume components in the mixtures to defoliation intensity depends on plant structure. The more prostrate types such as Trifolium semipilosum (Kenya white clover) and Stylosanthes humilis are favoured by a more intense defoliation. Jones (1973a) showed that yields of Trifolium semipilosum were greater at 3.8 cm than at 7.5 cm cutting height. In contrast, the erect types and twining climbing types of legume yield better at higher cutting height. Yields of Siratro and Desmodium intortum were shown to decline when cut frequently to a low stubble height (Imrie, 1971; Jones, 1974b). The higher yield of the prostrate types under a more intensive defoliation is the result of the presence of a greater number of growing points below cutting height (Grof et al, 1970).

Intensity of defoliation also influences grass yields in the mixtures. Jones (1974b) showed that yield of Setaria anceps grown with Siratro cut at 7.5 cm was 29% higher than at 15.0 cm. Jones (1973a) found that Paspalum dilatatum grown with Trifolium semipilosum yielded higher at 3.8 cm than at 7.5 cm cutting height. For the grass/twining climbing legume mixtures, the increased total yields as the height of cutting decreases are mainly due to the increased grass yields as demonstrated in Setaria anceps/Siratro (Jones, 1974b) and Cynodon dactylon /Desmodium intortum (Jones, 1973b), while the increased total yields with decreasing height of cutting for the grass/prostrate legume mixtures are attributed to increases of both grass and legume yields as shown in Paspalum dilatatum/Trifolium semipilosum mixtures (Jones, 1973a).

There is a negative interaction between defoliation intensity and defoliation frequency. This indicates that the adverse effects of intense defoliation can be reduced by decreasing the frequency of defoliation as demonstrated for the mixed pastures of Cynodon dactylon/Desmodium intortum (Jones, 1973b) and for the Panicum maximum/Stylosanthes guianensis (Dradu and Nabusiu-Napulu, 1977).

The interaction effect between height and frequency on legume yields has also been reported (Jones, 1973b; 1974b). At 4 weekly cutting interval, a cutting height of 3.8 cm gave the lowest Desmodium intortum yield whereas at the 12 weekly cutting interval, a cutting height of 3.8 cm gave the highest yield. At the 8 weekly cutting interval, the cutting height treatments had little effect on Desmodium intortum yield (Jones, 1973b). A similar result occurred in Siratro (Jones, 1974b).

It is assumed that the positive relationships between growth and both cutting interval and cutting height are due to their effects on the size of the sward canopy (Humphreys, 1981). Working with a pasture mixture of Setaria anceps/Desmodium intortum cut every 3 and 5 weeks at 7.5 cm and 15.0 cm height above ground levels, Ludlow and Charles-Edward (1980) found that total dry matter production increased with cutting height and with interval between defoliations. The main effects of height and frequency of defoliation on dry matter production were through their effects on leaf area index and light interception. There was little effect on leaf photosynthetic characteristics. After defoliation more light was intercepted by the more lenient regimes because of their greater residual leaf area. Pastures cut to a height of 7.5 cm intercepted less light than those cut to 15.0 cm because of lower residual leaf area. Lower production was recorded when pastures were cut more frequently (every 3 weeks) and more intensively (7.5 cm) due to minimal opportunity for leaf area to increase.

2.4 Effects of defoliation on botanical composition

To be successful a grass/legume pasture is required to maintain an adequate proportion of legume in the sward since yields of dry matter and crude protein (Vicente-Chandler et al, 1953; Horrel, 1964), digestible dry matter intake (Minson and Milford, 1967) and animal live weight gains (Evans, 1970; Norman, 1970) are linearly related to legume content in the mixtures.

The effect of defoliation intensity and frequency on percent legume content in the mixtures has been shown to be dependent on growth habit. The erect types of tropical legumes, such as Stylosanthes guianensis and the twining climbing types of tropical legumes, such as Macroptilium atropurpureum, Desmodium intortum and Glycine wightii are sensitive to the frequency and height of defoliation. Severe defoliation can lead to rapid depletion of the legume content (Jones, 1967; Whiteman, 1969). Olson (1973) showed that frequent close cutting had a deleterious effect on the percent of Desmodium intortum in the Setaria sphacelata/Desmodium intortum mixture. The amount of legume was enhanced as the length of the harvesting interval increased and as the cutting height changed from 8 to 20 cm. In order to maintain the legume in the mixture, long cutting intervals (6 to 9 weeks) at 20 cm height were essential to keep Desmodium intortum in adequate amounts when grown in association with Setaria sphacelata. Similarly, Jones (1973b) studied the effect of three cutting intervals - 4.8 and 12 weeks and three cutting heights - 3.8, 7.5 and 15.0 cm - on the yield of Desmodium intortum over a three year period. He found that the legume percentage increased with cutting height and with cutting interval. Jones (1974b) found an increase in the percentage of Siratro (Macroptilium atropurpureum) with an extension of cutting interval for the plots of Siratro plus Setaria anceps cut every 4, 8, 12 or 16 weeks at either 7.5 cm or 15.0 cm above ground over three years. Siratro percentage was higher at the 15 cm cutting height with 4 and 8 week cutting intervals but not with 12 or 16 week. This indicated that cutting height was important in modifying the effect of cutting interval. To maintain Siratro with frequent cutting a tall stubble was necessary, whereas with long intervals a low cutting height was necessary. Working with Stylosanthes guianensis and Centrosema pubescens, McIvor (1978) found that the legume content of Stylosanthes guianensis plots cut every 12 or 16 weeks was higher than that of those cut every 4 or 8 weeks. The proportion of Centrosema pubescens in the swards increased linearly as cutting interval increased. The legume contents grown with Brachiaria decumbens were lower than those grown with Panicum maximum for all cutting intervals. The higher legume content with Panicum maximum compared with Brachiaria decumbens was attributed to the superior yielding ability of Brachiaria decumbens over Panicum maximum (Grof and Harding, 1970; Winter, 1976).

The twining climbing tropical legumes have ascending stems capable of attaining heights of 2 m or more. Thus the leaf canopy can rise above competing vegetation and gain an advantage in intercepting light under lax cutting. The continued dry weight increase over prolonged periods is associated with increasing height and increasing stem percentage. With short cutting intervals, particularly at low stubble height, yield is low because of the slow increase in LAI after cutting (Jones, 1974b).

Unlike the erect types and twining climbing types of tropical legumes, the more prostrate legume types such as Trifolium semipilosum (Kenya white clover) and Stylosanthes humilis are favoured by a more intensive defoliation. Jones (1973a) showed that the percent content of Trifolium semipilosum grown with Paspalum dilatatum was reduced from 36% at 3.8 cm cutting height to 24% at 7.5 cm cutting height over a four year period. Gillard and Fisher (1978) reported that the highest proportion of Townsville stylo (Stylosanthes humilis) was obtained in heavily grazed treatments. These were attributed to the reduced shading effect of the associated grasses (Jones, 1973a) and the presence of a greater number of growing points below cutting height under a more intensive defoliation (Grof et al, 1970).

Selective grazing can lead to the reduction of the selected species. Rotational grazing of Lucerne (Medicago sativa)/grass swards is necessary to maintain the proportion of Lucerne (Moore et al, 1946, cited by Humphreys, 1966a). More Stylosanthes guianensis plants survive (Bowen and Rickert, 1979) and a higher Stylosanthes humilis content of the pasture is obtained (Norman and Phillips, 1970; Ritson et al, 1971; Winks et al, 1974) because grasses which have a particularly high protein content when they are young are preferentially grazed by cattle early in the wet season during the main growth phase of the pasture. Heavy grazing during this period continually removes photosynthetic tissue and nutrient reserves from the grasses, while letting Stylo growth proceed unhindered. From the end of the wet season onwards, although Stylosanthes hamata and Stylosanthes humilis are preferentially grazed by cattle (Gardener, 1980; Hunter et al, 1976), heavy defoliation of the

Stylo has little adverse effect since growth has largely ceased due to inadequate soil moisture and low temperatures (McCown, 1980) and grasses can gain little competitive advantage. Considerable quantities of Stylo seed may be ingested if seed yields are high (Playne, 1974; Gardener, 1980) but any such partial reduction in seed input is unlikely to have any effect on future plant populations under normal stocking rates with cattle (Winkworth and Miller, 1972).

2.5 Effects of defoliation on persistency.

Superior survival of pasture species under defoliation stress is more important than high yielding ability and competitive capacity (Humphreys, 1981). Four accessions of the semi-arid shrub legume *Psoralea eriantha* were evaluated under 3, 6 and 9 week cutting regimes for 72 weeks in pots in the glasshouse (Gutteridge and Whiteman, 1975) and showed that one erect accession, though giving the highest average yield, also suffered the highest mortality under the frequent defoliation. The other accessions suffered little mortality.

Old and dying tillers must be continually replaced by new tillers to ensure the survival of perennial grasses (Davidson and Milthorpe, 1965). A high rate of shoot replacement is a favourable factor for plant persistence in many stress situations. Cutting at too frequent intervals leads to depletion of reserves and to ultimate exhaustion of the plants as described by Weinmann (1948) in the subtropical species *Hyparrhenia hirta* and *Themeda triandra*. Repeated defoliation causes plant death by reducing the level of energy substrate required for tissue respiration and maintenance of root activity in the uptake of minerals (Davidson and Milthorpe, 1966b).

Defoliation also influences legume persistency in the grass/legume mixtures. For example, Jones (1967) found that *Macroptilium atropurpureum* cv. Siratro did not persist when cut to a height of 3.8 cm every 4 weeks. Whiteman (1969) reported reduced survival of Macroptilium atropurpureum, Desmodium uncinatum and Glycine javanica in legume/Chloris gayana mixtures under close and frequent cutting or grazing. The survival of plants under close grazing after 2 years was 0.2, 1.7 and 12.6% for Desmodium uncinatum, Macroptilium atropurpureum and Glycine javanica respectively. Survival of the same species when undefoliated was 67.4, 59.1 and 81.5% and grazing was shown to reduce survival more than cutting. Jones (1973b) studied the effect of three cutting heights - 3.8, 7.5 and 15.0 cm and three cutting intervals - 4, 8 and 12 weeks, on Desmodium intortum and found that plant numbers increased linearly with increasing cutting height from 7.2 - 9.5 plants per m^2 ($r = +0.992^{**}$). Although plant numbers were similar at each cutting interval, plants were very much smaller in the 4 week treatments than in both the 8 week and 12 week treatments. The reduction in Desmodium intortum with decreasing cutting height differed from the results obtained with Siratro. Jones (1974b) found that the increase in Siratro density between 7.5 and 15.0 cm cutting was not significant. Siratro plant numbers increased linearly with increasing cutting interval from 7.0 plants per m^2 at 4 week interval to 16.3 plants per m^2 at 16 week interval.

The effect of defoliation on persistency is also determined by time of defoliation. At Khon Kaen, Thailand, a single cut applied late in the growing season caused 53% mortality of Stylosanthes humilis plants due to removal of the elevated growing point above cutting height. Mortality was less under frequent cutting which modified plant habit (Robertson et al, 1976). Similarly, in Australia, Fisher (1973) observed that Stylosanthes humilis withstood repeated cutting at 5 cm provided that it was started early in the growing season, but would die if it was cut at 5 cm once, late in the growing season.

2.6 Effects of defoliation on pasture quality

The value of a pasture depends on the quantity eaten and its ability to meet animal requirements for energy, protein, vitamins and minerals. Deficiencies of vitamins and minerals may often limit animal production from tropical pastures, but such deficiencies can be overcome by supplementary feeding or injection (Milford and Minson, 1966a). Thus the majority of studies on the value of tropical pastures have dealt chiefly with protein and energy levels.

The simplest measure of nutritive value of crude protein is its apparent digestibility. This is closely related to the crude protein percentage of the feed. The digestible crude protein (DCP) percentage can, therefore, be estimated from the crude protein content of the feed (Milford and Minson, 1965).

The most precise measure of the energy value of herbage is net energy since this is the quantity that the animal can use for maintenance or production (Minson, 1977). However, most energy values have been determined in digestion trials and the results expressed as digestibilities of the dry matter or organic matter because the techniques required to measure net energy are too sophisticated for rapid routine analysis.

Cutting managements to produce maximum dry matter yields are not often those most suited for animal production systems since the nutritive value of herbage in terms of digestible energy or protein content is inversely related to stage of growth and the length of the growing period (Williams, 1980). Whyte et al (1959) referred to the findings of Nordfeldt et al (1951) who showed that while the yield of dry matter of Napier grass (Pennisetum purpureum) was highest at the 14 week cutting interval and percent protein content at the 6 week interval, the yield of crude protein was highest at the 10 week interval. They suggested that total yield of crude protein was generally regarded as a more useful measure of pasture productivity than total yield of dry matter.

In grass/legume mixtures, the presence of legumes can increase dry matter digestibility and crude protein of the sward (Siewerdt and Holt, 1974). Increased cutting interval increased total dry matter yield but had no effect on percent dry matter digestibility (Siewerdt and Holt, 1974). Murphy et al (1977) found that yield of dry matter, yield of digestible dry matter and crude protein yield of several mixtures were increased as cutting interval increased from 3 week to 6 week intervals. The virtues of legumes in the mixtures are that as the pasture sward matures, legumes generally have higher dry matter digestibility than the associated grass (Playne and Haydock, 1972) due to their slower decline in dry matter digestibility (Reid et al, 1973). As in the case of dry matter digestibility, the protein content of the legume is usually higher than that of the associated grasses at similar ages or stages of growth and the grasses tend to decline more rapidly in protein content with increasing maturity (Milford and Haydock, 1965). Thus the presence of legumes in the swards can act as the supplement for the lower protein and digestibility of the grasses under the less frequent cutting.

One of the striking differences between tropical and temperate grasses is that dry matter digestibility of tropical grasses is that dry matter digestibility of tropical grasses is generally lower than that of temperate grasses (Minson and McLeod, 1970). Minson and McLeod (1970) found a high negative correlation (r = -0.76) between dry matter digestibility and temperature in both tropical and temperate grasses. They concluded that the difference in digestibility between tropical and temperate grasses was mainly due to the conditions under which each was normally grown, the former in warm to hot and the latter in cool temperatures.

Increasing temperature appears to have rather direct effects on the digestibility of temperate grasses through declining soluble carbohydrate levels. In the tropical grasses, temperature effects are indirect. Increasing temperature reduces dry matter digestibility of tropical grasses by means of increasing the rate of growth and hastening the progress towards maturity. Growing 13 tropical and 11 temperate grasses at day/night temperatures of 21/13, 27/19 and 32/24°C and each plant harvested at the same physiological growth stage, two days after the fifth leaf reached maximum length, Wilson and Ford (1973) found that most of the temperate grasses declined an average of five units in *in vitro* dry matter digestibility with increase in temperature from 21/13 to 32/24°C. This decline was associated with a fall in the percentage soluble carbohydrates. In contrast, temperature had little effect on dry matter digestibility of the tropical grasses. Tropical grasses, in general, accumulated less soluble carbohydrate than the temperate grasses under all temperature regimes. Digestibility of the temperate grasses was generally higher than that of the tropical grasses at 21/13°C, but there was little difference between the two groups at 32/24°C. However, when eight tropical grasses and twelve legumes, grown at temperatures of 32/24, 26/15 and 20/6°C, were harvested at the same age of regrowth (28 days), in contrast to the same physiological stage of development, 't Mannetje (1975) found that *in vitro* dry matter digestibility of the plants generally declined with increasing temperature. At lower temperatures, plants had a higher leaf percentage and higher nitrogen concentrations.

Cutting experiments have limited application to grazed pastures where animals graze selectively. Animals improve the quality of their diet by seeking species and plant parts of higher nutritive value. Stobbs (1975, cited by Whiteman, 1980) showed that when cattle intensively grazed a pasture, the uppermost leaves were selected first, followed by leaf bearing stem and finally, if forced to it, the almost leafless stem.

Humphreys (1978) has reported that in the tropics, it is quite common to have animals grazing on grass pastures whose average nitrogen content is 0.5%, but to find that animals are actually ingesting a diet of 1.3% nitrogen, by selectively eating the green tissues.

Chapter 3

Materials and Methods

3.1 Experimental site

The experiment was conducted from 17 November 1983 to 18 March 1984 in a glasshouse at the Plant Growth Unit, Massey University, Palmerston North, New Zealand. The swards were grown under 30/25^{o}C day/night temperature.

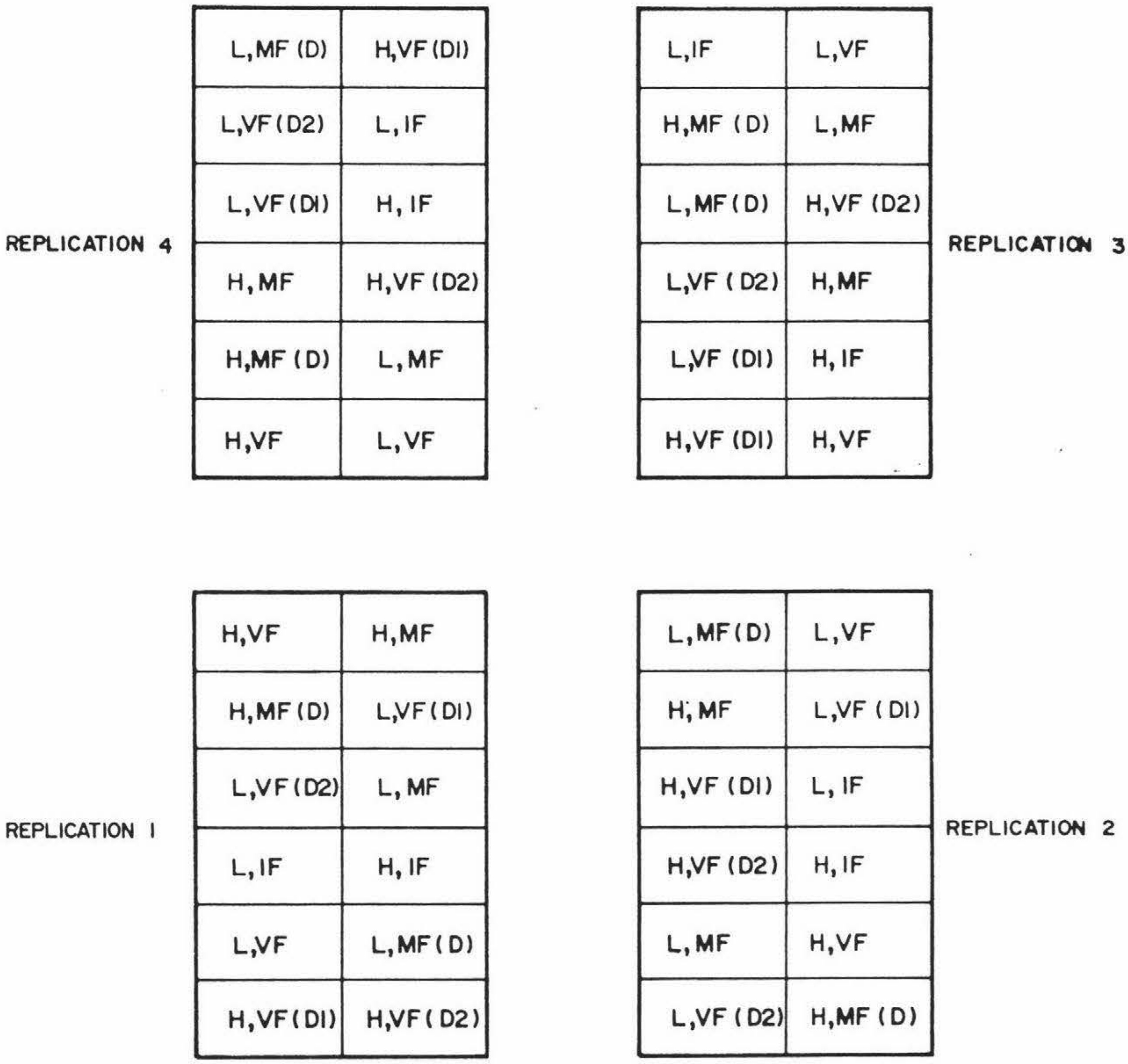
3.2 Treatments and designs

There were two intensities - the mixtures were mown to 7.5 cm and 15.0 cm heights above ground level - and three frequencies - the mixtures were mown every 2, 3, and 6 weeks. The six treatments were laid out in a completely randomized design with 4 block replicates. Twenty plots were added for destructive samples during the experiment (see Figure 1 and Plate 1).

3.3 Method

The Panicum maximum cv. Coloniao and Stylosanthes hamata cv. Verano were grown in 4 rectangular boxes. Each box, representing 1 replication, comprised 12 small plots. The size of each plot was 40 x 60 x 30 cm^3 (l x b x d).

Plants were grown in rows. The distance between rows and between plants within each row was 10 cm. The density of plants was 24 plants per plot (100 plants per m^2) with the ratio of 1:1 for grass and legume (see Figure 2 and Plate 2).



<u>FIGURE 1</u> EXPERIMENTAL LAYOUT:

H (HARD INTENSITY): PLOTS WERE MOWN TO A HEIGHT OF 7.5 CM ABOVE GROUND LEVEL

L (LAX INTENSITY): PLOTS WERE MOWN TO A HEIGHT OF 15.0 CM ABOVE GROUND LEVEL

VF (VERY FREQUENT DEFOLIATION): PLOTS WERE MOWN AT 2 WEEK INTERVALS

MF (MODERATELY FREQUENT DEFOLIATION): PLOTS WERE MOWN AT 3 WEEK INTERVALS

IF (INFREQUENT DEFOLIATION): PLOTS WERE MOWN AT 6 WEEK INTERVALS

D : DESTRUCTIVE SAMPLES AT 3 WEEK INTERVALS, FIRST HARVEST
D1: DESTRUCTIVE SAMPLES AT 2 WEEK INTERVALS, FIRST HARVEST
D2: DESTRUCTIVE SAMPLES AT 2 WEEK INTERVALS, SECOND HARVEST

Plate 1: Four rectangular boxes each containing twelve plots, as used for growing plants.

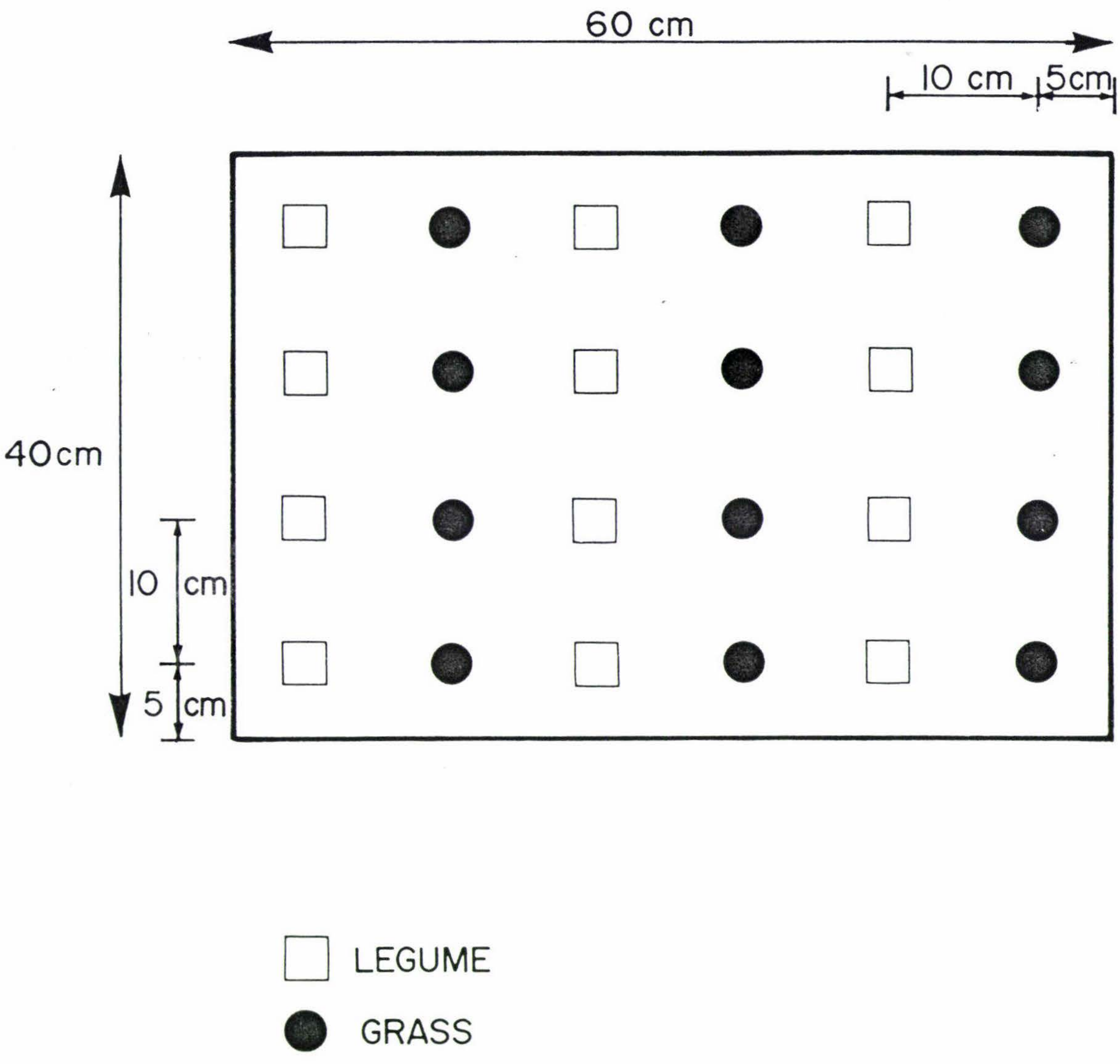


FIGURE 2 DIAGRAM SHOWING THE PLANTS GROWN IN EACH PLOT.

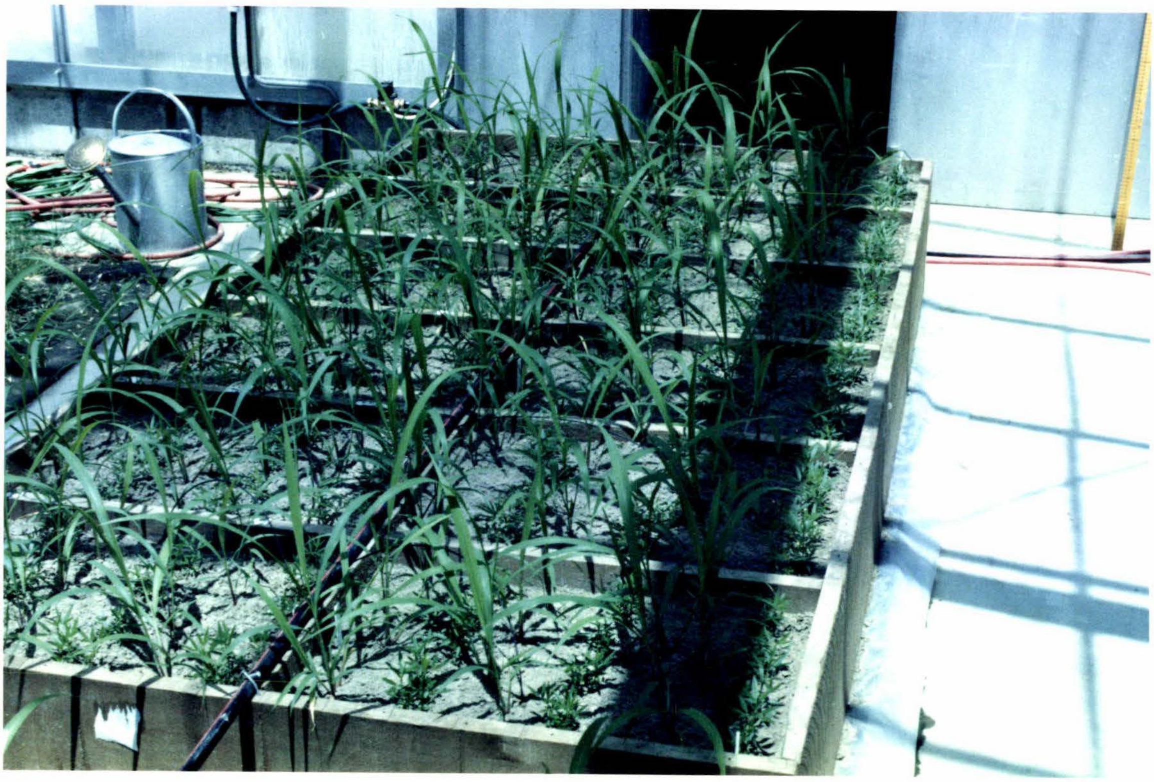


Plate 2: Experimental plants, six weeks after transplanting.

(1) Technique

To ensure good plant establishment, the grass and legume seeds were germinated in the incubator at 30°C and selected germinating seeds were transferred and grown in the plots. Two to four plants were grown in each position marked in the plots. A month after transplanting, they were thinned out so that only one plant was left in the position marked. This enabled plants in the boxes to be more uniform in size.

The defoliation treatment commenced on 1 February 1984, 2 months after transplanting. Every plot was cut to the height according to its treatment. The final harvest occurred on 18 March 1984. The 2 week interval treatments were cut three times, twice for the 3 week interval treatments, not including the first harvest on 1 February 1984.

(2) Potting medium

The mixtures were grown in Manawatu sandy silt soil.

(3) Fertilizer

1.7 gm KNO_3 and 7.2 gm 0-10-0-10 (N-P-K-S) per plot were mixed with the soil before planting. This was equivalent to 9.8 kg N, 30.0 kg P_2O_5, 32.9 kg K_2O and 30.0 kg S per ha. 0.26 gm/plot (5 kg N/ha) and 0.78 gm/plot (15 kg N/ha) of urea were applied to the mixture on 8 January 1984 and 3 February 1984 respectively.

(4) Inoculation

The legumes were well nodulated following spray of approximately 3-4 x 10^7 numbers of Rhizobium (obtained from fresh nodules of Verano stylo) per cm^3 on the soil in liquid culture form on 6 December 1983 at a rate of approximately 2 litres per box.

(5) Water

A trickle irrigation system was used to water the plots. Soil moisture was maintained at field capacity so that water was non-limiting.

(6) Weed

Weeds were eliminated by hand throughout the experiment.

3.4 Measurement

(1) Total dry matter yield

The first harvest was made on 1 February 1984, two months after transplanting. The successive harvests were taken as follows:

- on 16 February and 3 March 1984 for the very frequent defoliation treatment.
- on 25 February 1984 for the moderately frequent defoliation treatment.
- and on 18 March 1984 (final harvest) for all treatments.

At each harvest, total dry matter yield was measured above the cutting height according to the treatments imposed, except for the final harvest which was measured at ground level. It should be noted that dry matter yield of the first harvest was included in calculating cumulative yield.

Samples of each harvest were weighted after being dried in ventilated ovens at 80°C for 48 hours.

(2) Botanical composition

Grass and legume yields at each harvest were determined. Samples were also taken from grass and legume to measure yield of grass leaf, grass non-leaf (grass sheath and stem), grass dead material, legume leaf and legume non-leaf (petiole, stem and flower).

(3) Tiller characteristics

At final harvest, a count of the number of grass tillers was made from the destructive samples. A tiller was counted if it had already rooted. Tillers were divided into 4 groups according to their extended height; 0-20 cm, 20-40 cm, 40-60 cm and more than 60 cm. The number, dry weight, leaf dry weight, leaf area and leaf number per tiller in each group were measured.

(4) Branch characteristics

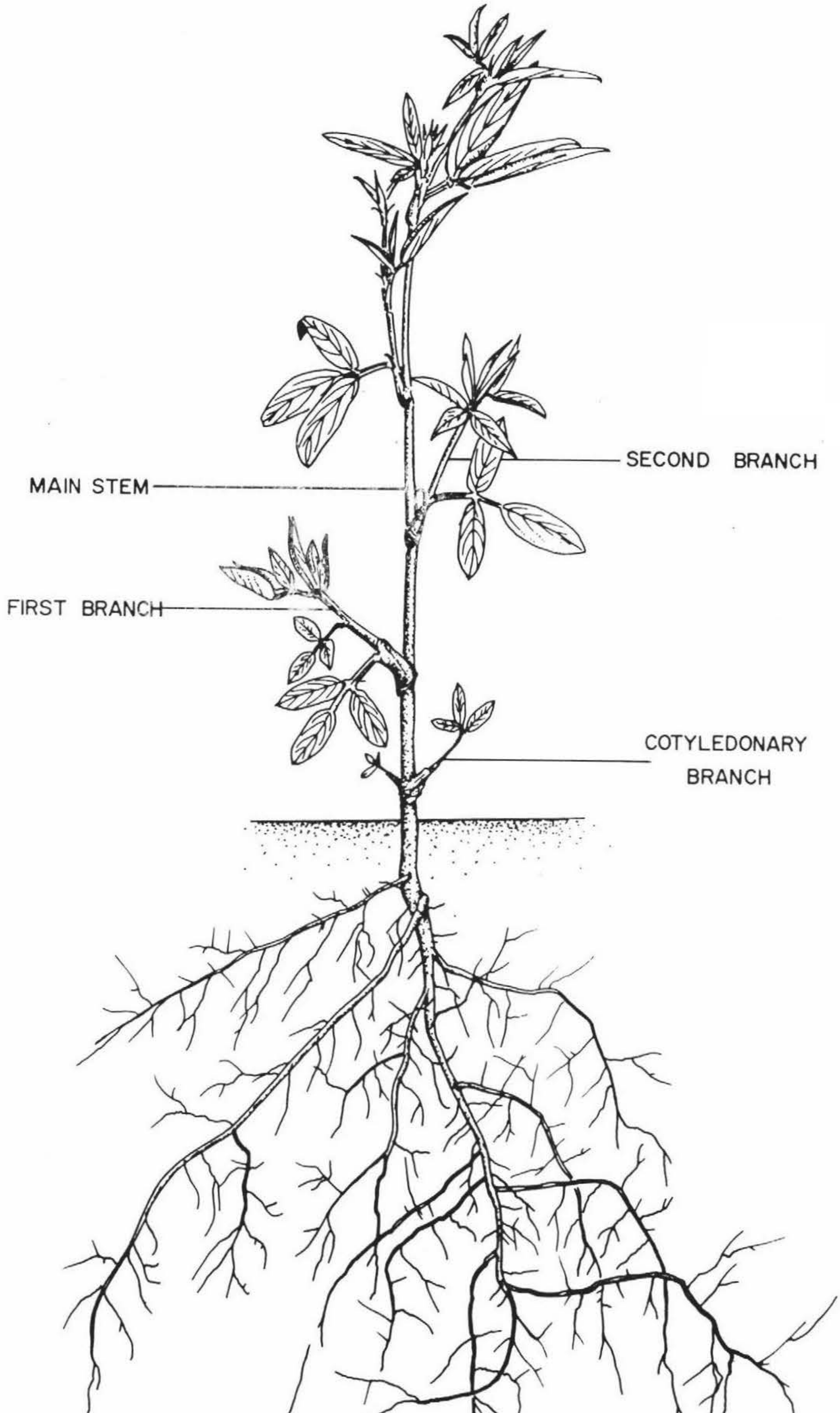
A count of the number of legume branches was made at each harvest from the destructive samples. The plants were divided into three parts (see Figure 3) - main stem, first branch and second branch. The number of branches in each part was recorded. The dry weight, number of leaves, leaf dry weight and leaf area of each part were also determined.

(5) Nitrogen analysis

Percent nitrogen was measured by the Kjeldahl technique as follows:

(a) Grass and legume components in total cumulative yield.
(b) Leaf and non-leaf of legume at the final harvest.
(c) Leaf, non-leaf and dead material of grass at the final harvest.

FIGURE 3 DIAGRAM DEMONSTRATING THE VERANO STYLO PLANT DIVIDED INTO THREE PARTS; MAIN STEM, FIRST BRANCH, SECOND BRANCH



3.5 Statistical analysis

Data were analysed using ANOVA in Genstat. Treatments were arranged in a factorial randomized complete block design.

Frequency and intensity treatment "main effect" are discussed where no interaction is present. Where an interaction is present between these two factors, the nature of the interaction is determined.

Significant and non-significant effects refer to the 5% level. The symbols used in this thesis are ns = not significant ($p > 0.05$); * = significant ($p \leqslant 0.05$); ** = significant ($p \leqslant 0.01$). Values with different letters are significant at the 5% level of probability.

Chapter 4

Results

4.1 Total yield

4.1.1 Total cumulative yield

4.1.1.1 Total cumulative dry matter yield

Total dry matter yield was higher under lax (L) than under hard (H) intensity of defoliation. At very frequent defoliation (VF), total dry matter yield was lowest while it was highest under moderate frequency of defoliation (MF) although the difference between infrequent (IF) and moderately frequent (MF) defoliation failed to reach 5% level of significance (Table 1).

Table 1 Effects of defoliation intensity and frequency on total cumulative dry matter yield (gm / plot).

Frequency		VF	MF	IF	Mean
Intensity	H	71.7	91.3	88.5	83.8
	L	79.7	98.6	92.8	90.4
Mean		75.7	94.9	90.6	

	$LSD_{.05}$	$LSD_{.01}$
Intensity	4.33	5.98
Frequency	5.31	7.34
Intensity x frequency	ns	

CV (%) = 5.7

4.1.1.2 Total cumulative crude protein yield

Total crude protein yield was higher at lax than at hard intensity and decreased with infrequent defoliation. However, the increase under lax cutting was only significant under very frequent and moderately frequent defoliation, but not under infrequent defoliation (Table 2).

Table 2 Effects of defoliation intensity and frequency on total cumulative crude protein yield (gm / plot).

Frequency		VF	MF	IF	Mean
Intensity	H	5.69	6.22	4.87	5.59
	L	7.15	7.11	5.02	6.43
Mean		6.42	6.66	4.95	

	$LSD_{.05}$	$LSD_{.01}$
Intensity	0.339	0.482
Frequency	0.415	0.591
Intensity x frequency	0.587	-

CV (%) = 5.4

4.1.1.3 Grass : legume ratio

Grass : legume ratio of total cumulative yield was not significantly affected by defoliation intensity or defoliation frequency (Table 3).

Table 3 Effects of defoliation intensity and frequency on grass : legume ratio of total cumulative yield.

Frequency		VF	MF	IF	Mean
Intensity	H	7.30	9.63	10.16	9.03
	L	7.73	8.41	8.32	8.15
Mean		7.51	9.02	9.24	

	$LSD_{.05}$
Intensity	ns
Frequency	ns
Intensity x frequency	ns

CV (%) = 20.6

4.1.2 Final harvest

4.1.2.1 Total dry matter yield

Total dry matter yield was significantly higher under lax than under hard intensity of defoliation and increased with decreasing defoliation frequency (Table 4).

Table 4 Effects of defoliation intensity and frequency on total dry matter yield at the final harvest (gm/plot).

Frequency	VF	MF	IF	Mean
Intensity H	27.32	35.25	59.57	40.71
L	41.03	52.53	73.26	55.60
Mean	34.17	43.89	66.41	

	$LSD_{.05}$	$LSD_{.01}$
Intensity	1.854	2.564
Frequency	2.273	3.142
Intensity x frequency	ns	

CV (%) = 4.4

4.1.2.2 Total crude protein yield

At the final harvest, total crude protein yield was higher at lax than at hard intensity and increased with decreasing defoliation frequency (Table 5).

Table 5 Effects of defoliation intensity and frequency on total crude protein yield at the final harvest (gm / plot).

Frequency		VF	MF	IF	Mean
Intensity	H	1.58	1.91	2.78	2.09
	L	2.10	2.42	3.17	2.56
Mean		1.84	2.17	2.98	

	$LSD_{.05}$	$LSD_{.01}$
Intensity	0.13	0.18
Frequency	0.16	0.23
Intensity x frequency	ns	

CV (%) = 6.6

4.1.2.3 Grass : legume ratio

At the final harvest, defoliation intensity had no effect on grass : legume ratio, but there was a significant increase in the porportion of grass as the defoliation frequency decreased (Table 6).

Table 6 Effects of defoliation intensity and frequency on grass : legume ratio at the final harvest.

Frequency		VF	MF	IF	Mean
Intensity	H	3.28	5.01	8.30	5.53
	L	3.96	4.70	6.47	5.05
Mean		3.62	4.86	7.38	

	$LSD_{.05}$	$LSD_{.01}$
Intensity	ns	
Frequency	1.25	1.73
Intensity x frequency	ns	

CV (%) = 22.2

4.2 Legume component

4.2.1 Cumulative yield

4.2.1.1. Cumulative dry matter yield and percent composition

Cumulative dry matter yield of legume was higher under lax than under hard intensity, but was not affected by defoliation frequency (Table 7).

Defoliation intensity and frequency had no effect on percent legume content of total cumulative dry matter yield (Table 7).

4.2.1.2 Cumulative dry matter yield of leaf and non-leaf

Cumulative yields of leaf were not affected by defoliation intensity, but those of non-leaf were higher under lax than under hard intensity. Cumulative yields of both components were not affected by defoliation frequency (Table 7).

Table 7 Effects of defoliation intensity and frequency on cumulative dry matter yield of legume, legume leaf, legume non-leaf and percent legume content.

	H	L		VF	MF	IF		CV(%)
Cumulative legume yield (gm/plot)	8.70	10.2	*	9.20	9.80	9.30	ns	15.9
Cumulative leaf yield (gm/plot)	4.80	5.10	ns	5.00	5.30	4.50	ns	14.8
Cumulative non-leaf yield (gm/plot)	3.90	5.10	**	4.20	4.60	4.80	ns	18.1
Percent legume content	10.6	11.4	ns	12.2	10.4	10.3	ns	19.2

4.2.1.3 Cumulative crude protein yield and percent crude protein content

Cumulative crude protein yield of legume was higher with less intense defoliation, but was not affected by defoliation frequency (Table 8).

Defoliation intensity had no effect on percent crude protein content of legume, but was reduced when defoliated at IF or MF (Table 8).

Table 8 Effects of defoliation intensity and frequency on cumulative crude protein yield of legume and percent crude protein content.

	H	L		VF	MF	IF		CV(%)
Cumulative crude protein yield (gm / plot)	1.26	1.54	**	1.41a	1.48a	1.32a	ns	12.8
Percent crude protein content	15.4	15.1	ns	16.7a	14.8b	14.3b	**	5.3

4.2.2 Final harvest

4.2.2.1 Dry matter yield of legume and percent composition

At the final harvest, dry matter yield of legume was higher under lax than under hard intensity of defoliation, but was not affected by defoliation frequency (Table 9).

Defoliation intensity had no effect on percent legume content, but it was increased with increasing defoliation frequency (Table 9).

4.2.2.2 Legume leaf and legume non-leaf yield

Dry matter yield of legume leaf and legume non-leaf was higher with less intense defoliation, but was not affected by defoliation frequency (Table 9).

Table 9 Effects of defoliation intensity and frequency on dry matter yield of legume, legume leaf, legume non-leaf and percent legume content at the final harvest.

	H	L		VF	MF	IF		CV(%)
Legume dry matter yield (gm/plot)	6.45	9.32	**	7.53	7.72	8.40	ns	16.2
Legume leaf yield (gm/plot)	3.19	4.44	**	3.80	3.71	3.94	ns	14.8
Legume non-leaf yield (gm/plot)	3.26	4.88	**	3.73	4.02	4.46	ns	19.0
Percent legume content	17.6	17.5	ns	22.5a	17.6b	12.6c	**	19.5

4.2.2.3 <u>Crude protein yield and percent crude protein content of legume</u>

At the final harvest, crude protein yield of legume was higher at lax than at hard intensity, but defoliation frequency had no effect on crude protein yield of legume (Table 10).

Percent crude protein content of legume was higher under hard than under lax intensity of defoliation, but was not influenced by defoliation frequency. The results also indicated that the hard intensity of defoliation caused a significant increase in the percent crude protein content of the legume but only the moderate frequency of cutting. Infrequent defoliation tended to follow this trend, but very frequent defoliation showed little difference between hard or lax cutting (Table 11).

4.2.2.4 <u>Crude protein yield and percent crude protein content of legume leaf and legume non-leaf</u>

Crude protein yield of both legume leaf and legume non-leaf was higher with lax intensity but was not affected by defoliation frequency (Table 10).

Table 10 Effects of defoliation intensity and frequency on crude protein yield of legume, legume leaf and legume non-leaf at the final harvest (gm / plot).

	H	L		VF	MF	IF		CV(%)
Crude protein yield of legume	0.787	0.996	**	0.890	0.847	0.938	ns	18.1
Crude protein yield of legume leaf	0.350	0.414	*	0.376	0.365	0.406	ns	16.8
Crude protein yield of legume non-leaf	0.176	0.216	**	0.180	0.196	0.212	ns	18.4

Table 11 Effects of defoliation intensity and frequency on percent crude protein content of legume at the final harvest.

Frequency		VF	MF	IF	Mean
Intensity	H	11.89	12.64	12.05	12.19
	L	11.70	9.82	10.73	10.75
Mean		11.80	11.23	11.39	

	$LSD_{.05}$	$LSD_{.01}$
Intensity	0.70	0.96
Frequency	ns	
Intensity x frequency	1.67	

CV (%) = 7.0

The hard intensity of defoliation significantly increased the percent crude protein level of the legume leaf, but only under infrequent defoliation and moderate frequency of defoliation. Under very frequent defoliation, there was no difference between the hard or lax intensity of cutting (Table 12).

Table 12 Effects of defoliation intensity and frequency on percent crude protein content of legume leaf at the final harvest.

Frequency		VF	MF	IF	Mean
Intensity	H	15.4	17.1	16.5	16.3
	L	15.8	14.1	15.0	15.0
Mean		15.6	15.6	15.7	

	$LSD_{.05}$	$LSD_{.01}$
Intensity	0.85	
Frequency	ns	
Intensity x frequency	1.47	

CV (%) = 6.2

In terms of the non-leaf component, the same trend in the percent crude protein response to defoliation intensity and frequency was again evident, although the differences did not reach statistical significance. Only the main effect of defoliation intensity showed a significant increase under hard cutting (Table 13).

Table 13 Effects of defoliation intensity and frequency on percent crude protein content of legume non-leaf at the final harvest.

Frequency		VF	MF	IF	Mean
Intensity	H	8.07	8.35	8.00	8.14
	L	7.68	6.69	7.01	7.13
Mean		7.87	7.52	7.50	

	$LSD_{.05}$	$LSD_{.01}$
Intensity	0.67	0.93
Frequency	ns	
Intensity x frequency	ns	

CV (%) = 10.1

4.2.2.5 Leaf (L) : non-leaf (NL) ratio

At the final harvest, L : NL ratio of the legume was higher under hard intensity of defoliation and increased under very frequent defoliation (Table 14).

Table 14 Effects of defoliation intensity and frequency on N : NL ratio of the legume component at the final harvest.

Frequency		VF	MF	IF	Mean
Intensity	H	1.077	0.982	0.922	0.994
	L	0.995	0.907	0.892	0.932
Mean		1.036	0.945	0.907	

	$LSD_{.05}$	$LSD_{.01}$
Intensity	0.057	-
Frequency	0.070	0.096
Intensity x frequency	ns	

CV (%) = 6.8

4.3 Grass component

4.3.1 Cumulative yield

4.3.1.1 Cumulative dry matter yield and percent composition

The cumulative dry matter yield of grass was higher in the lax than in the hard cutting treatments. Very frequent defoliation also significantly depressed yield compared with moderate and infrequent defoliation, the two latter treatments showing no significant difference (Table 15).

Neither defoliation intensity nor defoliation frequency had any significant effect on percent grass content of the total yield (Table 15).

4.3.1.2 Cumulative dry matter yield of leaf, non-leaf and dead material

The cumulative dry matter yield of grass leaf was not affected by defoliation intensity but very frequent defoliation depressed grass leaf yield significantly (Table 15).

The cumulative dry matter of grass non-leaf was significantly reduced under both hard and very frequent defoliations (Table 15).

Defoliation intensity and frequency had no significant effect on the total dry matter yield of grass dead material (Table 15).

Table 15 Effects of defoliation intensity and frequency on cumulative dry matter yield of grass, grass leaf, grass non-leaf, dead material and percent grass content of total cumulative dry matter yield.

	H	L		VF	MF	IF		CV(%)
Cumulative grass yield (gm/plot)	75.1	80.2	*	66.5a	85.1b	81.3b	**	7.3
Cumulative leaf yield (gm/plot)	42.5	44.2	ns	38.6a	48.2c	43.2b	**	7.9
Cumulative non-leaf yield (gm/plot)	25.2	28.4	**	20.1a	29.1b	31.2b	**	7.8
Cumulative yield of dead material (gm/plot)	7.43	7.63	ns	7.77	7.83	7.00	ns	14.4
Percent grass content	89.4	88.7	ns	87.8	89.6	89.7	ns	2.40

4.3.1.3 Cumulative crude protein yield and percent crude protein content of grass

The cumulative crude protein yield of grass was higher under lax than under hard cutting and decreased significantly under infrequent defoliation. The difference in the cumulative crude protein yield of grass between VF and MF was not significant (Table 16).

Percent crude protein content of grass was not influenced significantly by defoliation intensity. However, it was significantly depressed under infrequent cutting, but there was no difference between moderate and very frequent cutting in this respect (Table 16).

Table 16 Effects of defoliation intensity and frequency on cumulative crude protein yield and percent crude protein content of grass.

	H	L		VF	MF	IF		CV(%)
Crude protein yield (gm/plot)	4.33	4.88	*	5.01a	5.18a	3.63b	**	10.4
Percent crude protein content	5.82	6.14	ns	7.41a	6.03a	4.41b	**	5.6

4.3.2 Final harvest

4.3.2.1 Dry matter yield of grass and percent composition

At the final harvest, grass dry matter yield was higher with lax intensity and was increased with decreasing defoliation frequency (Table 17).

The percentage grass content at final harvest was not affected by defoliation intensity, but was increased with decreasing defoliation frequency (Table 17).

4.3.2.2 Grass leaf, non-leaf and dead material

At the final harvest, grass leaf yield was increased with less intense defoliation and was increased with decreasing defoliation frequency (Table 17).

Grass non-leaf yield was higher at lax intensity and was increased with decreasing defoliation frequency. However, it was evident that the increase due to the lax defoliation intensity was considerably greater under very frequent than under infrequent defoliation (Table 18).

Defoliation intensity and frequency had no effect on grass dead material at the final harvest (Table 17).

Table 17 Effects of defoliation intensity and frequency on grass dry matter yield, grass leaf yield, grass dead material and percent grass content at the final harvest.

	H	L		VF	MF	IF		CV(%)
Grass dry matter yield (gm/plot)	34.3	46.3	**	26.6a	36.2b	58.0c	**	6.8
Grass leaf yield (gm/plot)	11.3	13.6	*	4.9a	8.0b	24.4c	**	8.7
Grass dead material (gm/plot)	7.43	7.63	ns	7.77	7.83	7.00	ns	14.4
Percent grass content	82.4	82.5	ns	77.5a	82.4b	87.5c	**	4.1

Table 18 Effects of defoliation intensity and frequency on grass non-leaf yield at the final harvest (gm / plot)

Frequency		VF	MF	IF	Mean
Intensity	H	9.20	14.1	23.3	15.5
	L	18.7	26.5	30.0	25.1
Mean		13.9	20.3	26.6	

	$LSD_{.05}$	$LSD_{.01}$
Intensity	1.27	1.76
Frequency	1.56	2.15
Intensity x frequency	2.20	3.04

CV (%) = 7.2

4.3.2.3 Crude protein yield and percent crude protein content of grass

At the final harvest, crude protein yield of grass was higher under lax intensity of defoliation and increased with decreasing defoliation frequency (Table 19).

Percent crude protein content of grass at the final harvest was not affected by defoliation frequency but was reduced with less intense defoliation (Table 19).

4.3.2.4 Crude protein yield and percent crude protein content of grass leaf, grass non-leaf and dead material

Crude protein yield of grass leaf was not sensitive to defoliation intensity, but it was increased with decreasing defoliation frequency (Table 19).

Crude protein yield of grass non-leaf was sensitive to defoliation intensity and frequency. It was significantly reduced with more intense defoliation but not under infrequent defoliation (Table 20).

Table 19 also shows that defoliation intensity and frequency had no effect on crude protein yield of grass dead material.

At the final harvest, percent crude protein content of grass leaf and grass non-leaf was higher at hard than at lax intensity, but that of dead material was not affected. At IF, percent crude protein content of grass leaf was reduced, but the difference in crude protein content between MF and VF was not significant. Percent crude protein content of grass non-leaf and dead material was not affected by defoliation frequency (Table 19).

Table 19 Effects of defoliation intensity and frequency on crude protein yield of grass, grass leaf, dead material (gm/plot) and percent crude protein content of grass, grass leaf, grass non-leaf, dead material at the final harvest.

	H	L		VF	MF	IF		CV(%)
Crude protein yield of grass	1.31	1.57	**	0.95a	1.32b	2.04c	**	10.3
Crude protein yield of leaf	.695	.741	ns	.383a	.591b	1.18c	**	13.4
Crude protein yield of dead material	.128	.140	ns	.144	.136	.123	ns	15.1
Percent crude protein content of grass	3.81	3.14	*	3.59a	3.29a	3.54a	ns	18.5
Percent crude protein content of leaf	7.29	5.69	*	7.91a	6.69a	4.86b	**	21.3
Percent crude protein content of non-leaf	3.33	2.58	**	3.31	2.72	2.83	ns	18.5
Percent crude protein of dead material	1.72	1.71	ns	1.86	1.53	1.75	ns	22.3

Table 20 Effects of defoliation intensity and frequency on crude protein yield of grass non-leaf at the final harvest (gm/plot).

Frequency		VF	MF	IF	Mean
Intensity	H	0.340	0.470	0.697	0.502
	L	0.548	0.741	0.793	0.694
Mean		0.444	0.605	0.745	

	$LSD_{.05}$	$LSD_{.01}$
Intensity	0.055	0.076
Frequency	0.067	0.093
Intensity x frequency	0.095	-

CV (%) = 10.5

4.3.2.5 Leaf (L) : non-leaf (NL) ratio

At the final harvest, L : NL ratio of grass was higher at hard than at lax intensity and decreased with increasing defoliation frequency (Table 21).

Table 21 Effects of defoliation intensity and frequency on L : NL ratio of the grass component at the final harvest.

Frequency		VF	MF	IF	Mean
Intensity	H	0.405	0.510	0.995	0.637
	L	0.332	0.335	0.860	0.509
Mean		0.369	0.422	0.928	

	$LSD_{.05}$	$LSD_{.01}$
Intensity	0.051	0.071
Frequency	0.063	0.087
Intensity x frequency	ns	

CV (%) = 10.3

4.4 Branch characteristics

4.4.1 Branch number

Defoliation intensity and frequency had no effect on branch number per plot (Table 22).

4.4.2 Branch dry weight

Dry weight per branch was higher with less intense defoliation, but was not affected by defoliation frequency (Table 22).

4.4.3 Leaf dry weight per branch

Leaf dry weight per branch was increased with less intense defoliation, but was not affected by defoliation frequency (Table 22).

Table 22 Effects of defoliation intensity and frequency on branch number, dry weight per branch, leaf dry weight per branch and specific leaf area per branch.

	H	L		VF	MF	IF		CV(%)
Branch number per plot	185.4	206.3	ns	184.9	190.3	212.5	ns	23.0
Dry weight per branch (gm)	.0354	.0479	**	.0417	.0405	.0426	ns	21.5
Leaf dry weight per branch (gm)	.0176	.0231	**	.0211	.0196	.0203	ns	21.5
Specific leaf area	147.3	145.3	ns	143.6	138.6	156.6	ns	18.8

4.4.4 Leaf area per branch

Leaf area per branch was higher at lax than at hard intensity but was not affected by defoliation frequency. The significant interaction recorded suggests a decline in leaf area per branch as cutting frequency is decreased under hard intensity, but an increase as cutting frequency is decreased under lax intensity of defoliation (Table 23).

Table 23 Effects of defoliation intensity and frequency on leaf area per branch (cm^2).

Frequency		VF	MF	IF	Mean
Intensity	H	2.71	2.70	2.31	2.57
	L	3.34	2.68	3.79	3.27
Mean		3.02	2.69	3.05	

	$LSD_{.05}$	$LSD_{.01}$
Intensity	0.39	0.54
Frequency	-	
Intensity x frequency	0.68	

CV (%) = 15.4

4.4.5 Leaf number per branch

Again, the significant interaction is difficult to explain, but the data suggest that the decline in leaf number under infrequent cutting is only important under hard defoliation intensity (Table 24). The main effects of intensity and frequency of defoliation showed no significant difference.

Table 24 Effects of defoliation intensity and frequency on leaf number per branch.

Frequency		VF	MF	IF	Mean
Intensity	H	4.297	4.425	3.622	4.115
	L	4.335	3.808	4.340	4.161
Mean		4.316	4.116	3.981	

	$LSD_{.05}$	$LSD_{.01}$
Intensity	ns	
Frequency	ns	
Intensity x frequency	0.548	0.757
CV (%) = 8.8		

4.4.6 Specific leaf area

Defoliation intensity and frequency had no effect on specific leaf area of each branch (Table 22).

4.4.7 The contributiion of various branch categories

(1) The contribution to total branch number

The first branch contributed the most to total branch number at both intensities and in all frequencies of defoliation (Figure 4).

(2) The contribution to total branch dry weight

Under both lax and hard cutting, the main stem and the first branch were both major contributors to total branch dry weight. Of particular note was the increased importance of the first branch and even the second branch under hard, infrequent defoliation (Figure 5).

(3) The contribution to total leaf number

Under very frequent defoliation, the main stem tended to be the major contributor to total leaf number, whereas the first branch appeared to be the major contributor under moderately frequent and infrequent cutting. It was also noteworthy that the second branch appeared to contribute more to leaf number under hard cutting than under lax cutting (Figure 6).

(4) The contribution to total leaf dry weight

Under hard intensity, the first branch appeared to contribute the most to total leaf dry weight at all frequencies. However, under lax intensity, the main stem contributed a similar or greater leaf dry weight compared with the first branch. The contribution of the second branch, although still appreciable, was less than the main stem and the first branch and relatively smaller in amount across all treatments (Figure 7).

(5) The contribution to total leaf area

The branch contribution to total leaf area was very similar to that of total leaf dry weight, as explained above (Figure 8).

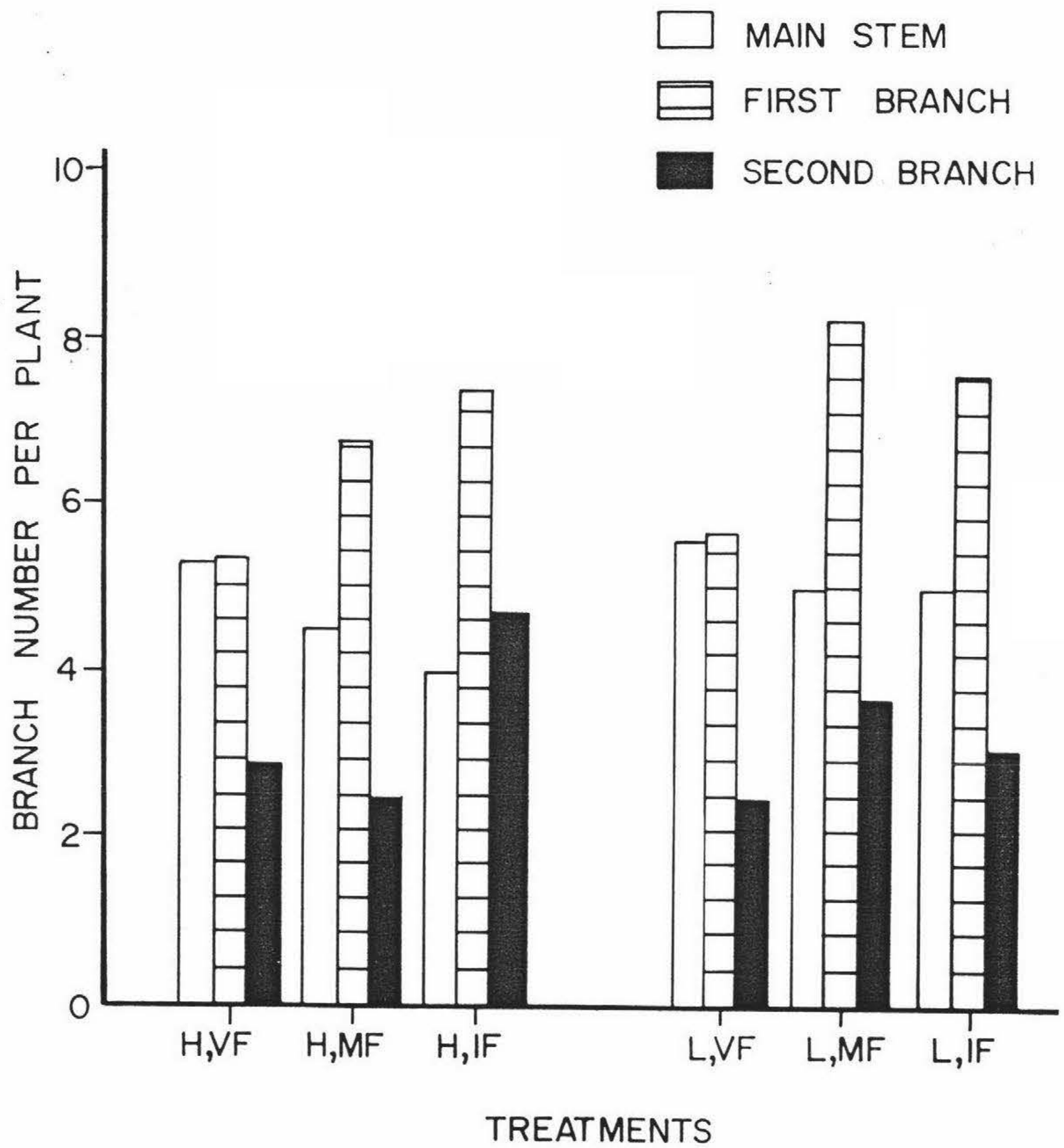


FIGURE 4 EFFECTS OF DEFOLIATION INTENSITY AND FREQUENCY ON THE CONTRIBUTION OF THE MAIN STEM, THE FIRST BRANCH AND THE SECOND BRANCH TO TOTAL BRANCH NUMBER (H = HARD INTENSITY, L = LAX INTENSITY, VF = VERY FREQUENT DEFOLIATION, MF = MODERATELY FREQUENT DEFOLIATION, IF = INFREQUENT DEFOLIATION).

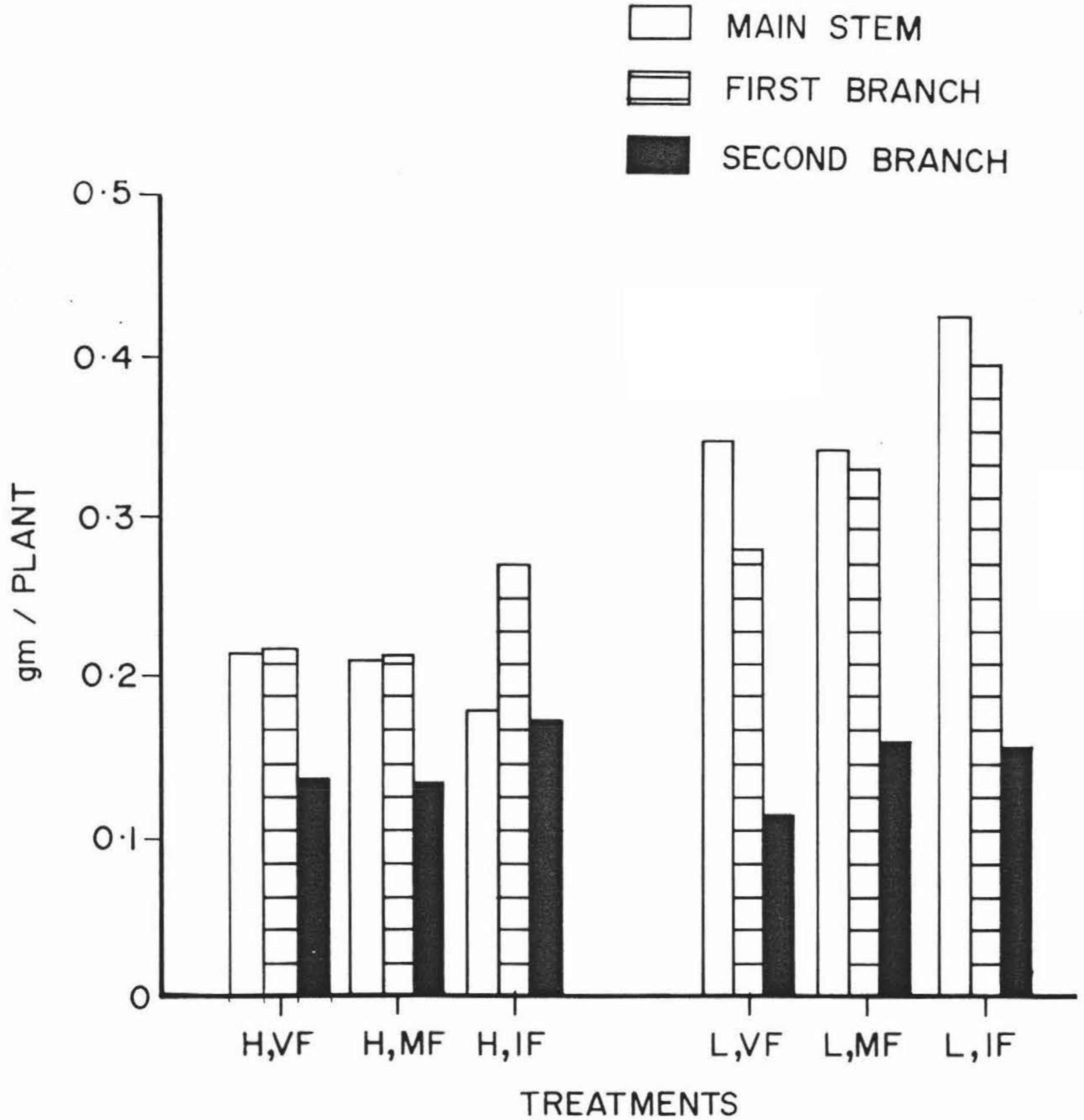


FIGURE 5 EFFECTS OF DEFOLIATION INTENSITY AND FREQUENCY ON THE CONTRIBUTION OF THE MAIN STEM, THE FIRST BRANCH AND THE SECOND BRANCH TO TOTAL BRANCH DRY WEIGHT. ABBREVIATIONS AS FOR FIGURE 4

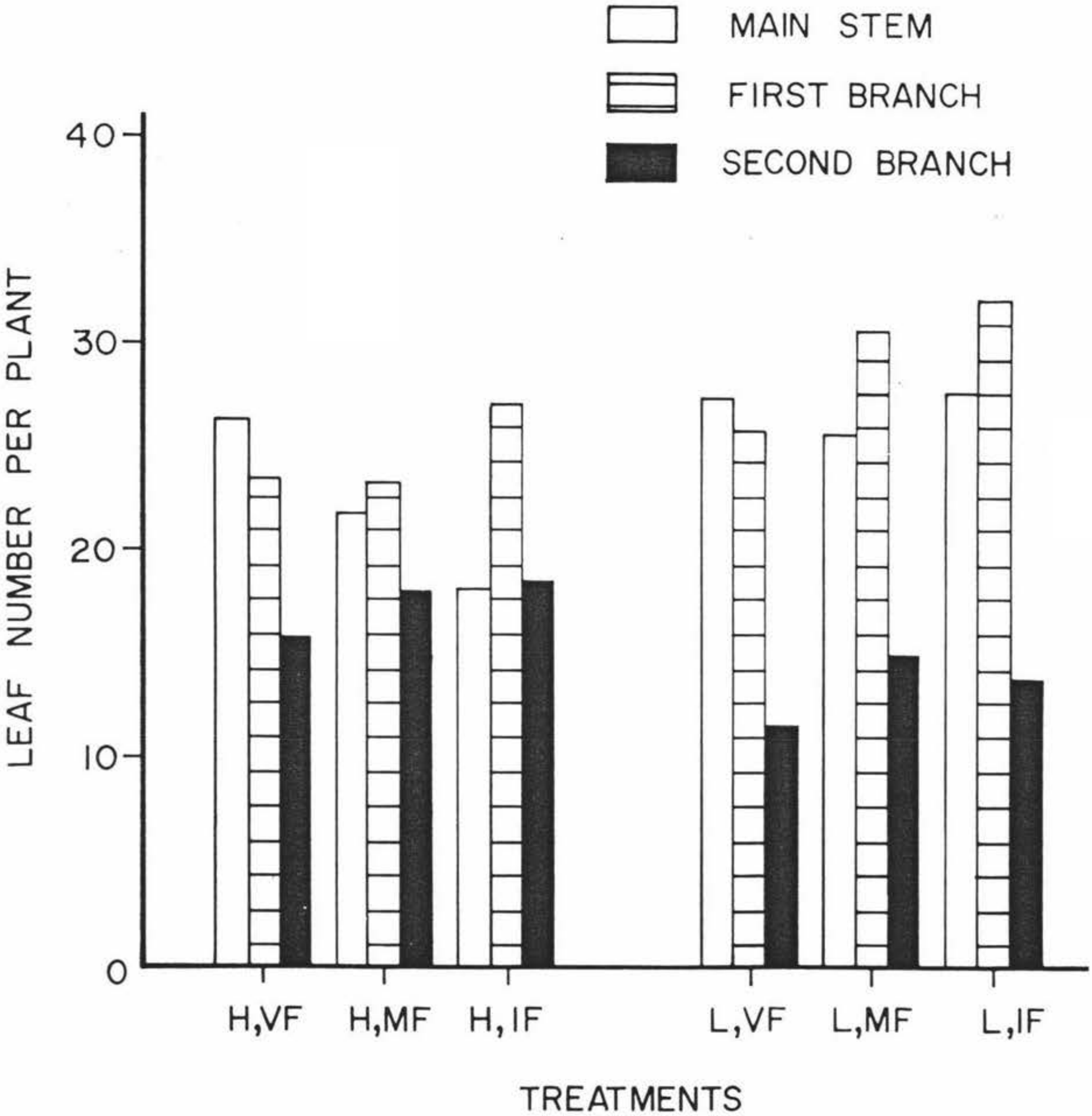


FIGURE 6 EFFECTS OF DEFOLIATION INTENSITY AND FREQUENCY ON THE CONTRIBUTION OF THE MAIN STEM, THE FIRST BRANCH AND THE SECOND BRANCH TO TOTAL LEAF NUMBER. ABBREVIATIONS AS FOR FIGURE 4

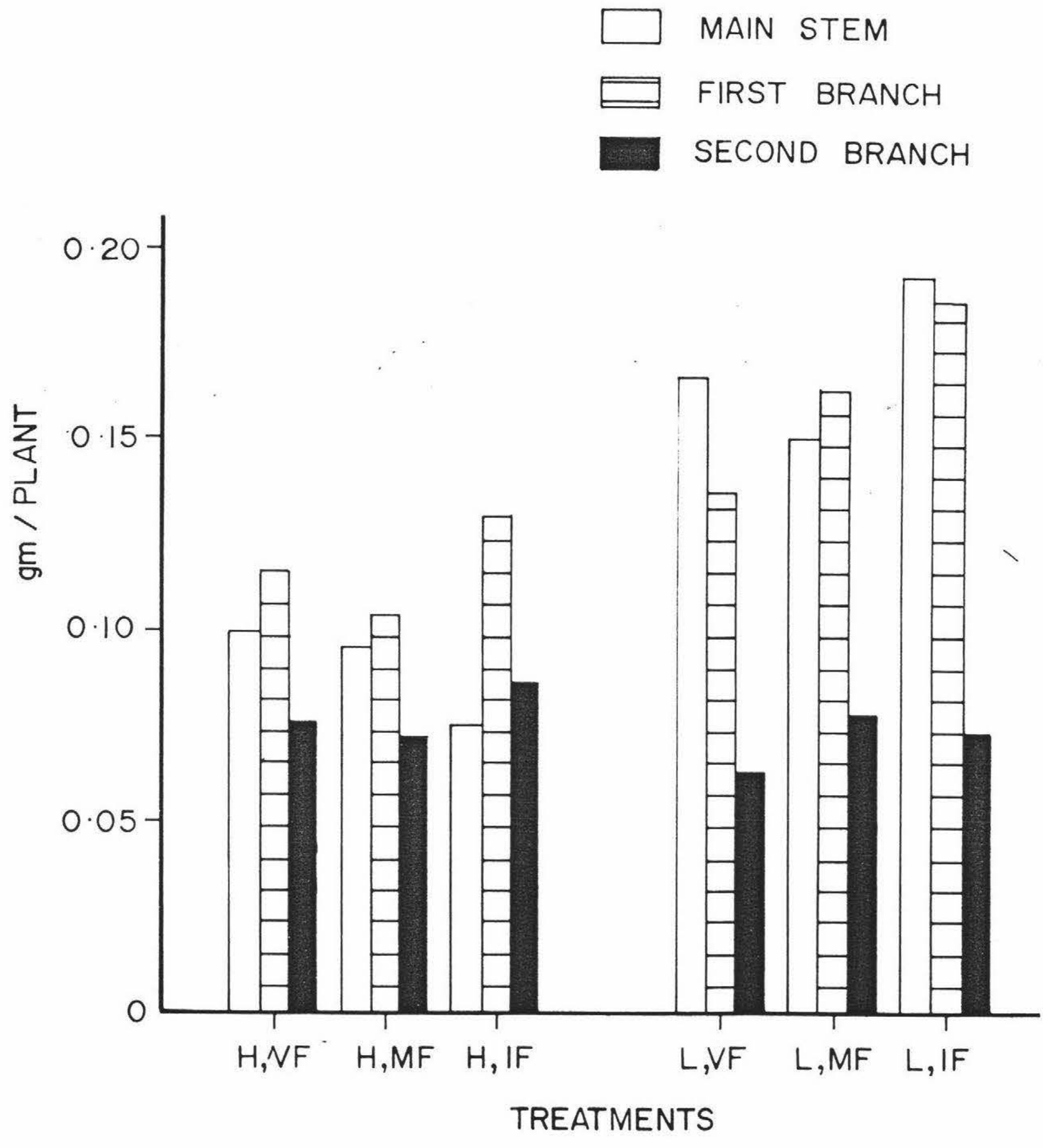


FIGURE 7 EFFECTS OF DEFOLIATION INTENSITY AND FREQUENCY ON THE CONTRIBUTION OF THE MAIN STEM, THE FIRST BRANCH AND THE SECOND BRANCH TO TOTAL LEAF DRY WEIGHT. ABBREVIATIONS AS FOR FIGURE 4

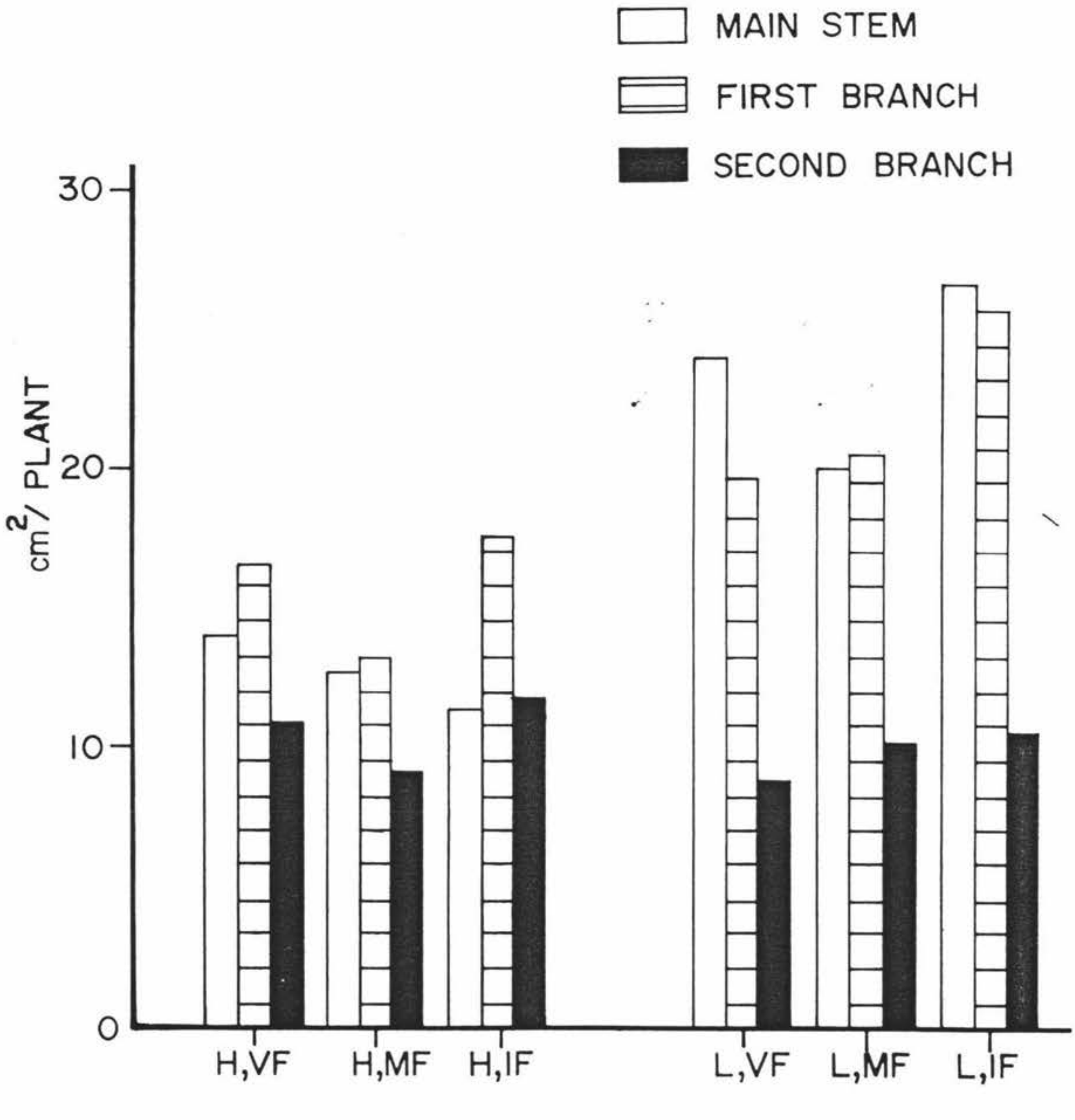


FIGURE 8 EFFECTS OF DEFOLIATION INTENSITY AND FREQUENCY ON THE CONTRIBUTION OF THE MAIN STEM, THE FIRST BRANCH AND THE SECOND BRANCH TO TOTAL LEAF AREA. ABBREVIATIONS AS FOR FIGURE 4

4.5 Tiller characteristics

4.5.1 Tiller number

Tiller number per plot was significantly higher under hard than under lax intensity of cutting. Defoliation at MF resulted in the highest tiller number per plot whereas VF and IF treatments gave no significant difference in tiller number per plot (Table 25).

Table 25 also shows that the number of dead tillers per plot was not affected by defoliation intensity, but was significantly reduced under infrequent and moderately frequent cutting compared with very frequent cutting.

4.5.2 Tiller dry weight

Dry weight per tiller was higher in the lax than in the hard cutting treatment and increased with decreasing defoliation frequency (Table 25).

4.5.3 Leaf area per tiller

Leaf area per tiller was significantly higher under lax than under hard defoliation and increased with decreasing defoliation frequency (Table 25).

4.5.4 Leaf dry weight per tiller

Leaf dry weight per tiller was reduced with more intense defoliation and was decreased with increasing defoliation frequency (Table 25).

4.5.5 Leaf number per tiller

The number of leaves per tiller was higher at lax than at hard intensity. This superiority in leaf number per tiller under lax cutting was apparent under very frequent and moderately frequent defoliation, but not under infrequent cutting (Table 26).

4.5.6 Specific leaf area per tiller

Specific leaf area per tiller was reduced with lax cutting and showed a significant reduction under infrequent cutting compared with moderately frequent and very frequent defoliation. Moderate and very frequent cutting showed no significant difference in specific leaf area per tiller (Table 25).

<u>Table 25</u> Effects of defoliation intensity and frequency on tiller number per plot, dry weight per tiller, leaf dry weight per tiller, leaf area per tiller and specific leaf area per tiller.

	H	L		VF	MF	IF		CV(%)
Tiller number per plot	49.7	42.0	**	43.8a	49.5b	44.3a	*	9.0
Dead tiller per plot	3.00	4.67	ns	7.25a	2.75b	1.50b	**	75.0
Dry weight per tiller (gm)	.569	.958	**	.443a	.651b	1.20c	**	10.8
Leaf dry weight per tiller (gm)	.239	.342	**	.117a	.180b	.576c	**	15.0
Leaf area per tiller (cm^2)	48.0	56.5	**	24.9a	38.3b	93.5c	**	13.5
Specific leaf area (cm^2/gm)	221.4	181.3	**	220.9a	217.7a	165.5b	**	7.9

Table 26 Effects of defoliation intensity and frequency on leaf number per tiller.

Frequency		VF	MF	IF	Mean
Intensity	H	2.75	2.50	3.66	2.97
	L	4.08	3.85	3.85	3.93
Mean		3.42	3.18	3.76	

	$LSD_{.05}$	$LSD_{.01}$
Frequency	0.297	0.410
Intensity	0.363	-
Intensity x frequency	0.514	0.711

CV (%) = 9.9

4.5.7 The contribution of various tiller categories

Tillers of 0 - 20 cm extended length only made a worthwhile contribution to total tiller numbers under hard and very frequent defoliation and only minor or nil contribution in all other treatments.

Tillers of 20 - 40 cm extended length were major contributors to total tiller numbers under hard cutting when very frequently and moderately frequently defoliated; also under lax cutting when defoliated very frequently.

Tillers of 40 - 60 cm extended length were major contributors to total tiller numbers only under hard and infrequent cutting and under lax and moderately frequent defoliation.

Tillers of > 60 cm extended length were major contributors to total tiller numbers only in the lax and infrequent cut treatment (Figure 9).

A very similar treatment response was also recorded for total tiller dry weight, total leaf dry weight, total tiller leaf number and total tiller leaf area (Figures 10, 11, 12 and 13).

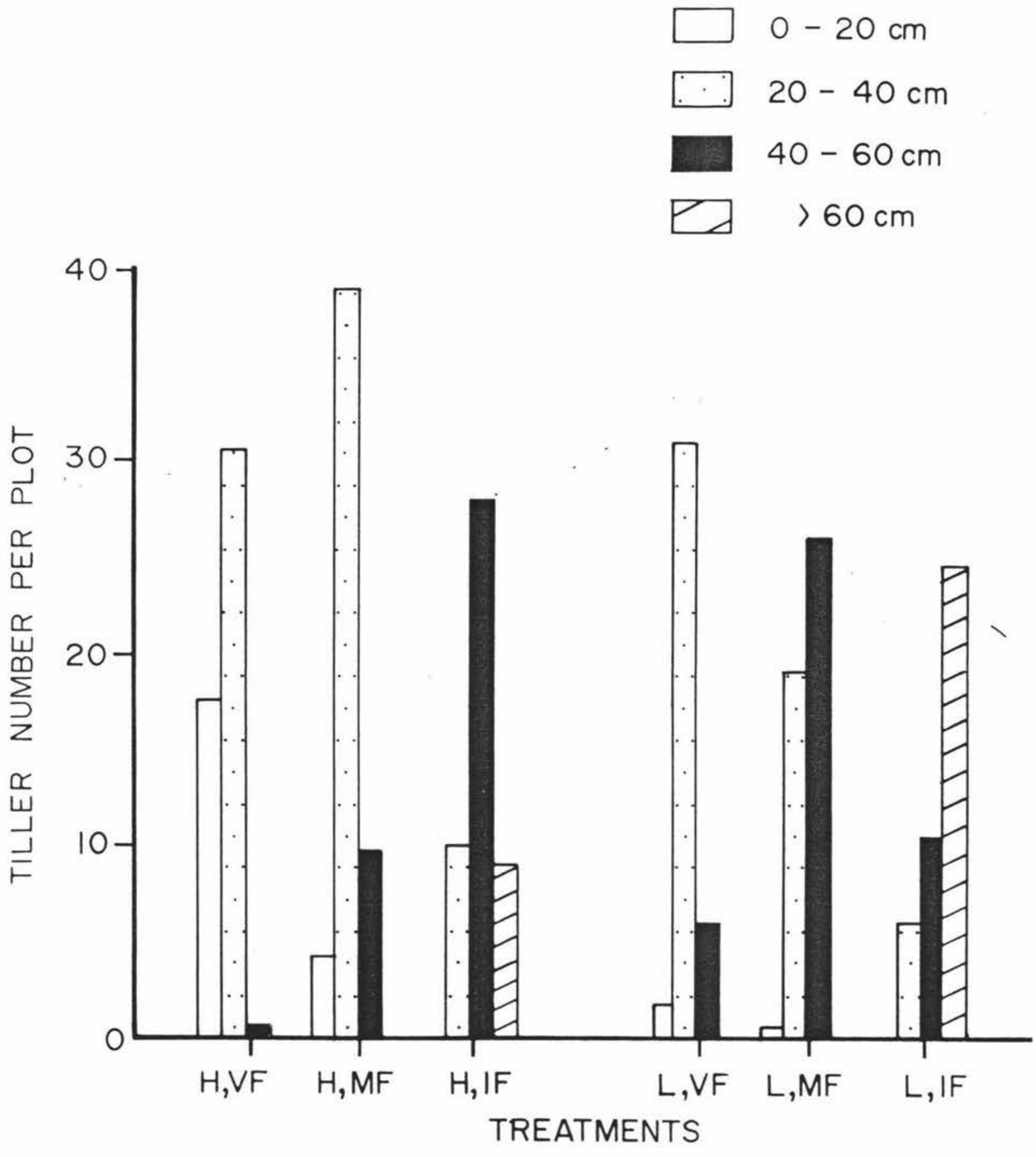


FIGURE 9 EFFECTS OF DEFOLIATION INTENSITY AND FREQUENCY ON THE CONTRIBUTION OF TILLERS HAVING THE EXTENDED LENGTH OF 0-20 CM, 20-40 CM, 40-60 CM AND >60 CM TO TOTAL TILLER NUMBER. (H = HARD INTENSITY, L = LAX INTENSITY, VF = VERY FREQUENT DEFOLIATION, MF = MODERATELY FREQUENT DEFOLIATION, IF = INFREQUENT DEFOLIATION)

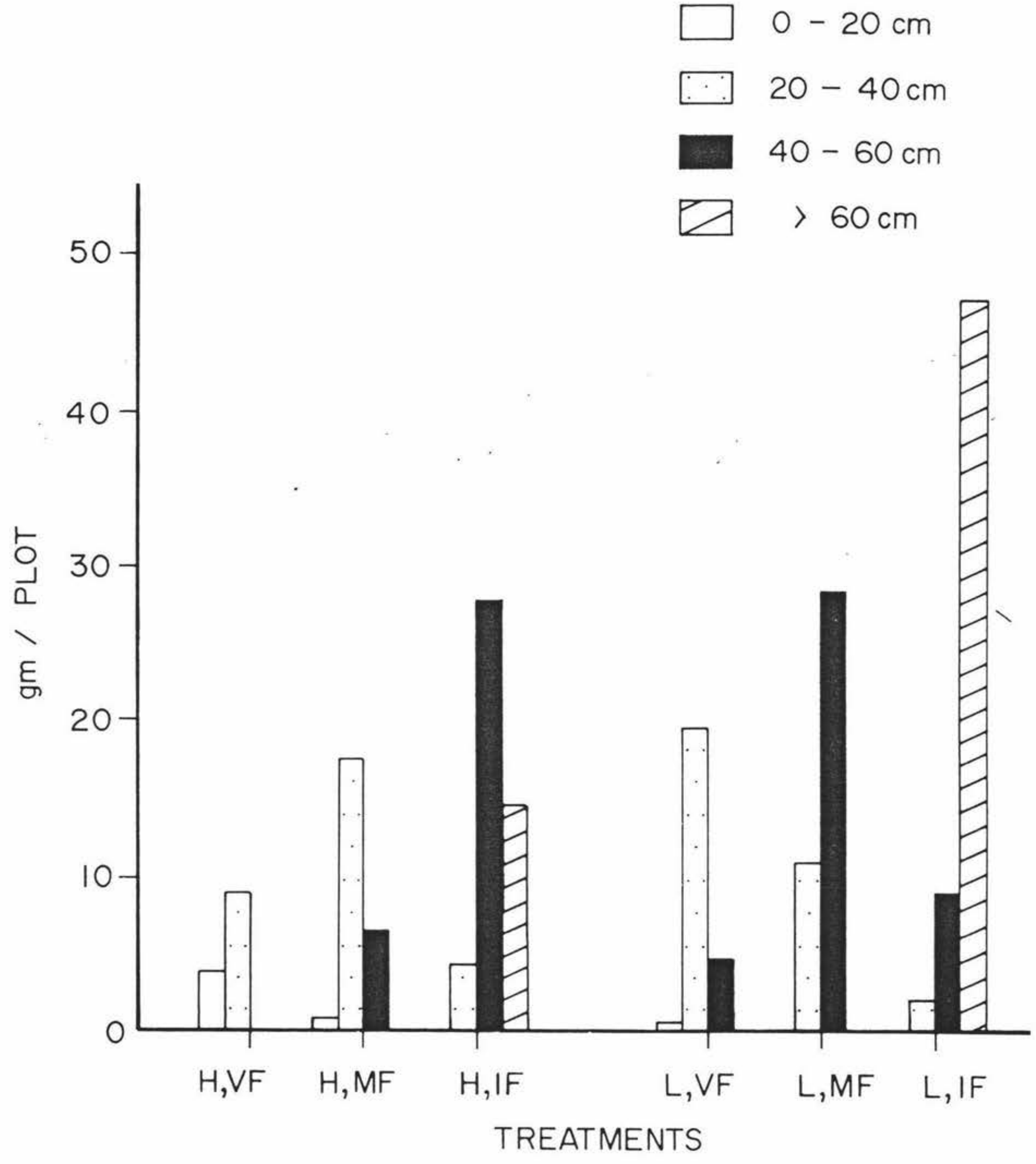


FIGURE 10 EFFECTS OF DEFOLIATION INTENSITY AND FREQUENCY ON THE CONTRIBUTION OF TILLERS HAVING THE EXTENDED LENGTH OF 0-20 CM, 20-40 CM, 40-60 CM AND >60 CM TO TOTAL TILLER DRY WEIGHT.
ABBREVIATIONS AS FOR FIGURE 9

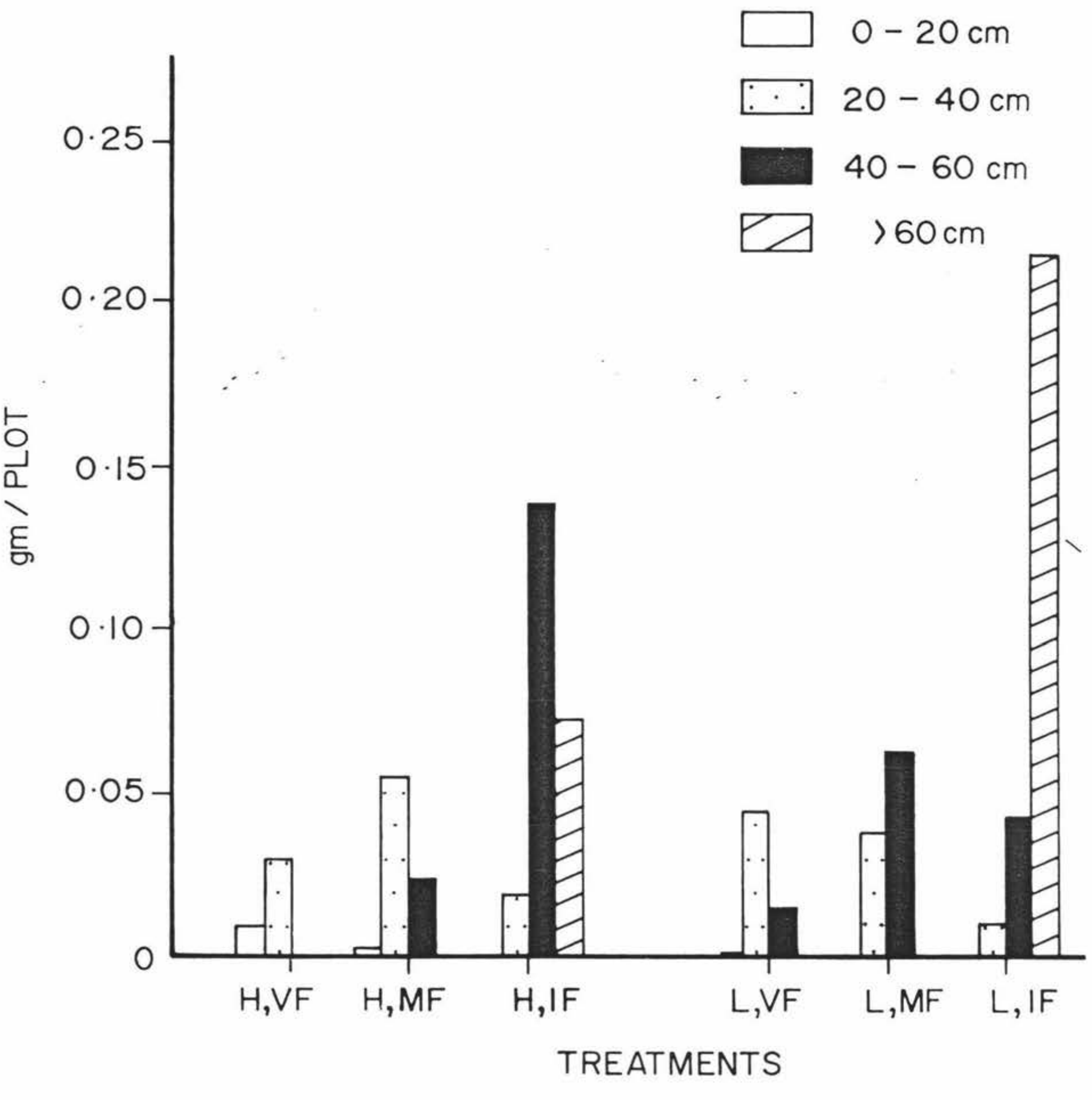


FIGURE 11 EFFECTS OF DEFOLIATION INTENSITY AND FREQUENCY ON THE CONTRIBUTION OF TILLERS HAVING THE EXTENDED LENGTH OF 0-20 CM, 20-40 CM, 40-60 CM AND >60 CM TO TOTAL LEAF DRY WEIGHT.
ABBREVIATIONS AS FOR FIGURE 9

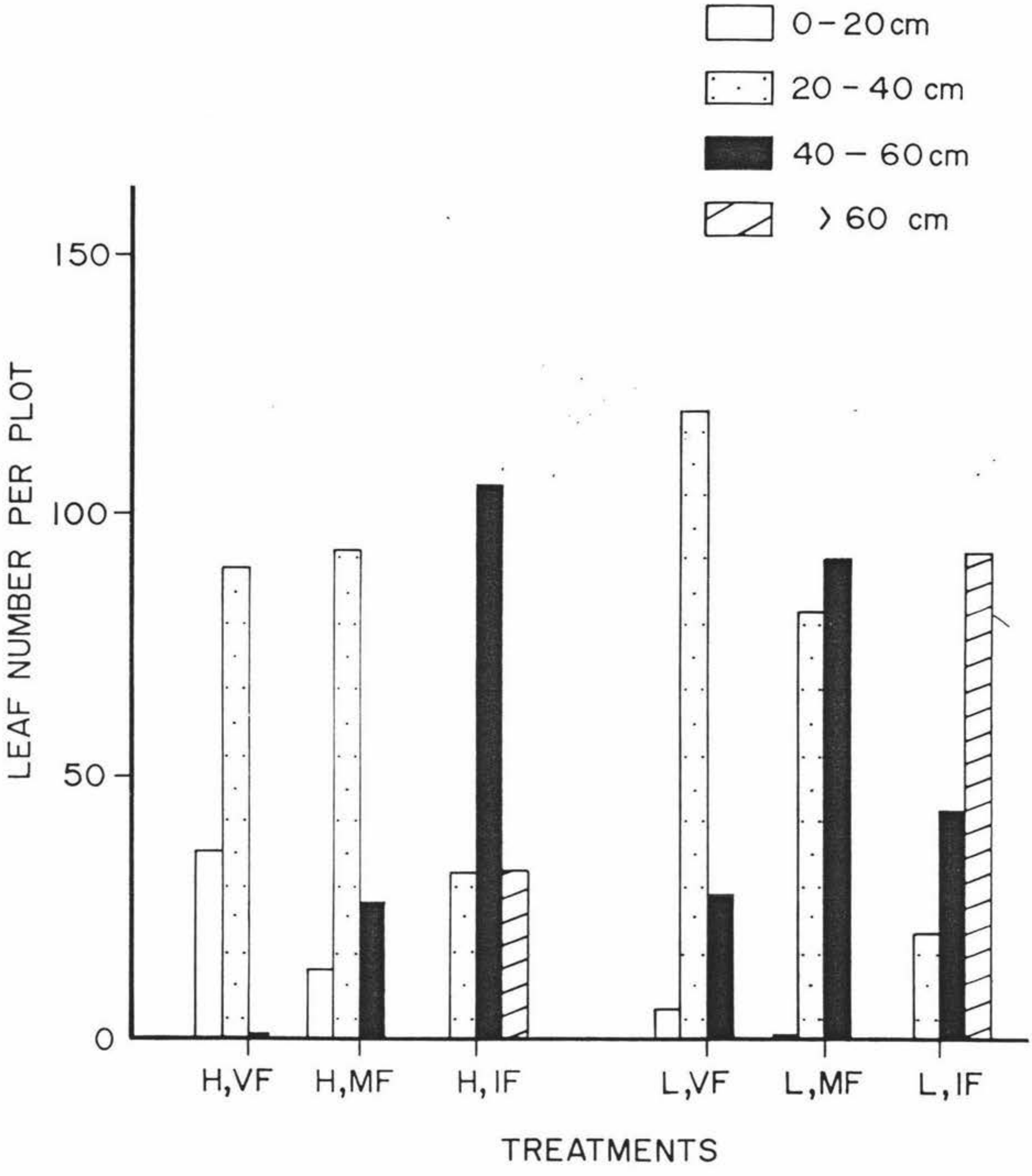


FIGURE 12 EFFECTS OF DEFOLIATION INTENSITY AND FREQUENCY ON THE CONTRIBUTION OF TILLERS HAVING THE EXTENDED LENGTH OF 0-20 CM, 20-40 CM, 40-60 CM AND >60 CM TO TOTAL LEAF NUMBER.
ABBREVIATIONS AS FOR FIGURE 9

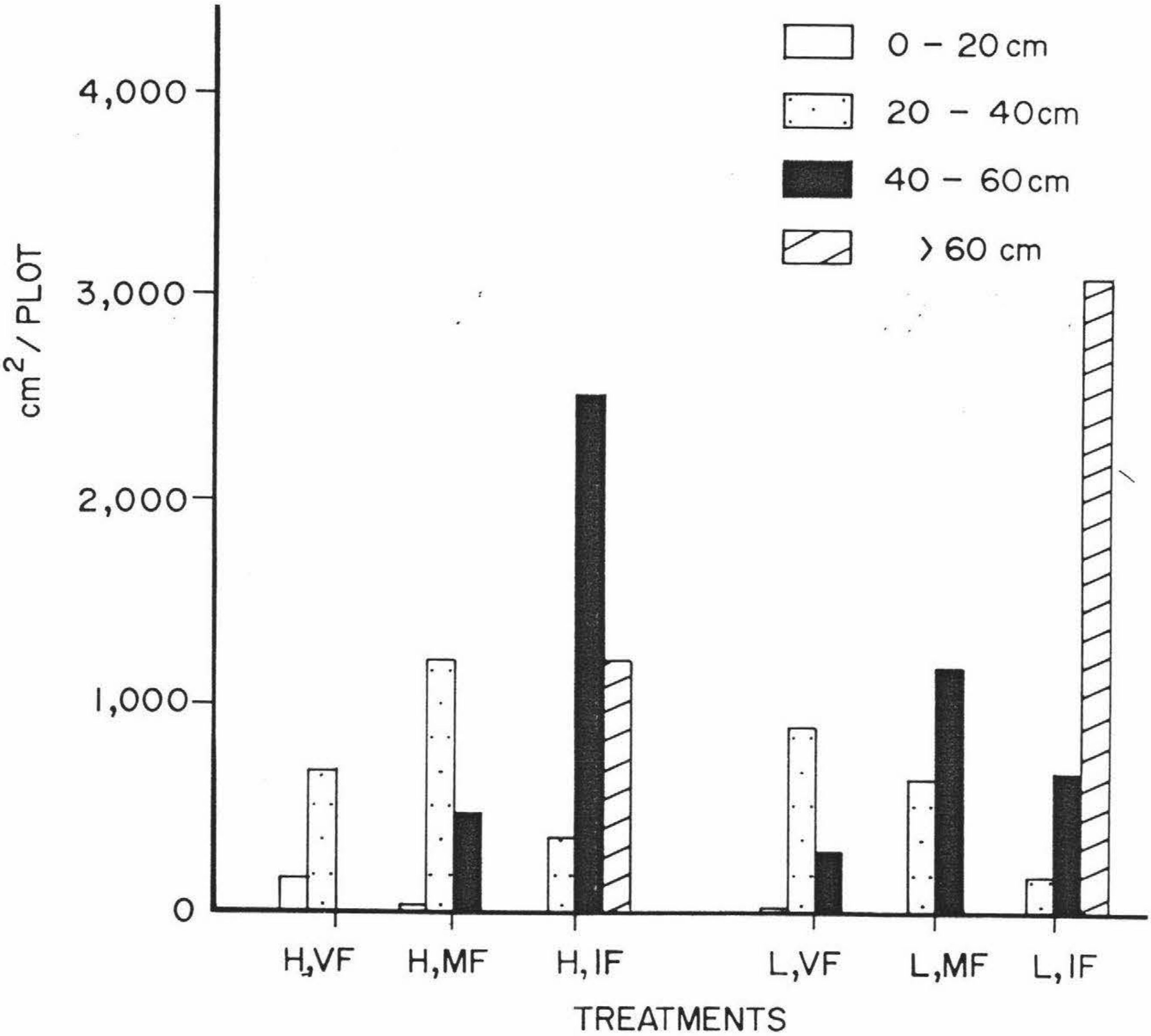


FIGURE 13 EFFECTS OF DEFOLIATION INTENSITY AND FREQUENCY ON THE CONTRIBUTION OF TILLERS HAVING THE EXTENDED LENGTH OF 0-20 CM, 20-40 CM, 40-60 CM AND >60 CM TO TOTAL LEAF AREA.
ABBREVIATIONS AS FOR FIGURE 9

Chapter 5

Discussion

5.1 Effects of defoliation on total dry matter yield

Defoliation frequency had more influence on total cumulative dry matter yield than defoliation intensity. This is in agreement with Dradu and Nabusiu-Napulu (1977) who found that total dry matter yield of the *Panicum maximum*/*Stylosanthes guianensis* cv Schofield mixture was less affected by defoliation intensity than by defoliation frequency. In this study, total cumulative dry matter yield defoliated very frequently (VF) was 20% lower than that defoliated at moderate frequency (MF), but intense defoliation only reduced total cumulative dry matter yield by 7% compared with lax defoliation (Table 1). The response to different defoliation frequency was not linear since total cumulative dry matter yield was not significantly different between the moderately frequent (MF) and infrequent (IF) treatments. A similar result was reported in the *Panicum maximum* /*Stylosanthes guianensis* mixture. Total dry matter yield was not significantly different between the sward cut every 3 weeks and every 6 weeks, but it was linearly increased when the interval of cutting varied from 6 to 12 to 24 weeks (Dradu and Nabusiu-Napulu, 1977). The reduced total cumulative dry matter yield with more intense defoliation in this study was due to the reduction in both grass (6%) and legume (15%) yields (Tables 7, 15), but the reduced total cumulative dry matter yield at VF was due to a 22% reduction in grass yield only (Table 15) since legume yield was not affected by defoliation frequency (Table 7).

Although total cumulative dry matter yield defoliated at MF and IF was not different, it appears that the MF treatment gave 12% higher leaf yield than did the IF treatment (Table 15) while legume leaf yield was not affected by defoliation frequency (Table 7). This suggests that both high total cumulative dry matter yield and high leaf yield can be obtained by defoliating the sward at MF.

However, it is important to note that by the final harvest total herbage growth had become highly sensitive to defoliation intensity and frequency. It was reduced with more intense defoliation and was decreased with increasing defoliation frequency. More intense defoliation reduced total herbage growth by 27% and it was 22% and 49% lower when cut at VF that at MF and IF respectively (Table 4). This arose from a depression of both the grass and legume components e.g. the grass and the legume were reduced by 26% and 31% respectively (Tables 9, 17). In contrast, defoliation frequency had no effect on legume growth (Table 9), but grass growth was increased with decreasing defoliation frequency (Table 17). Thus the reduction in total herbage growth at VF was due to grass only. The results suggest that further close and frequent defoliation will cause severe reductions in grass yield and persistency and hence lead to a reduction in the total dry matter yield of the sward. To obtain high dry matter yield, defoliation should be lax and less frequent. However, the need for feed presentation to the animals also requires herbage of higher quality. Although high herbage growth can be obtained with IF, the quality of herbage is low. This will be discussed later.

5.2 Effects of defoliation on botanical composition

Cumulative yield of both grass and legume were sensitive to defoliation intensity and frequency. However, the response to the defoliation treatments imposed was markedly different. Defoliation intensity had a dominant effect on cumulative yield of legume. It was reduced by 17% with more intense defoliation, but was not significantly affected by defoliation frequency (Table 7). In contrast, cumulative yield of grass was more influenced by defoliation frequency being reduced by 22% at VF compared with only 6% reduction with more intense defoliation (Table 15).

Cumulative leaf dry matter yield of legume was insensitive to both defoliation intensity and defoliation frequency (Table 7), but that of grass was more influenced by defoliation frequency than by defoliation intensity. The MF treatment gave 25% and 12% higher cumulative grass leaf yield than did the VF and IF treatments respectively (Table 15). The lax intensity (L) treatment gave higher cumulative leaf yield of grass and legume than the hard intensity (H) treatment, although the difference was not significant (Tables 7, 15). Thus it is suggested that the highest leaf yield of the mixture can be obtained when the sward is cut laxly at moderate frequency.

At the final harvest, it appears that the growth of legume, legume leaf and legume non-leaf components were sensitive to defoliation intensity. With more intense defoliation, legume growth, leaf growth and non-leaf growth were reduced by 31%, 28% and 33% respectively (Table 9). The higher non-leaf growth when defoliated at lax intensity resulted in lower leaf : non-leaf ratio with less intense defoliation (Table 14). Legume growth was higher with less intense defoliation because more growing points were retained on stubble (Appendix 2). Infrequent defoliation gave no advantage in legume growth due to strong competition from grass. It should be noted that root growth was not affected by defoliation intensity (Appendix 1). This is contrary to the result obtained in Stylosanthes guianensis cv Oxley fine-stem, by Mufandaedza (1976). When plants of the cultivar Oxley fine-stem were cut at 2-, 4- or 8-week intervals, to heights of 4 cm, 10 cm or to a height progressively increasing from 4 - 10 cm, the mass of stubble and of roots were decreased with decreasing height of cutting. In this study, the non sensitivity of root growth to intensity of defoliation may have been attributed to the root measurement technique employed. The relatively crude method of lifting the tap rooted legume from the soil is not satisfactory due to the difficulty of extracting the entire root system. This is also reflected in the very high coefficients of variation recorded (Appendix 1).

In contrast to legume, the growth of grass, grass leaf and grass non-leaf components were sensitive to both intensity and frequency of defoliation. They were reduced with more intense defoliation and were decreased with increasing defoliation frequency (Tables 17, 18). An interaction effect on legume non-leaf indicated that the adverse effect of more intense defoliation on the growth of non-leaf could be reduced by decreasing defoliation frequency. As reported in the literature, close and frequent defoliation can cause a reduction in grass growth by reducing leaf area (Humphreys and Robinson, 1966), the level of carbohydrate reserves (Weinmann, 1948) and root growth (Troughton, 1957; Appendix 1). Since the grass was still in the vegetative stage, the increased growth with increasing defoliation was mainly due to increased leaf growth. This resulted in the higher leaf : non-leaf ratio under the longer interval of cutting (Table 21).

Although defoliation intensity and frequency influenced grass and legume yield, grass : legume ratio, percent grass and legume content were not affected (Tables 3, 7, 15). The non-sensitivity of the percent legume content to defoliation intensity was perhaps due to the treatments selected being too similar to each other since Dradu and Nabusiu-Napulu (1977) found that the percentage of Stylosanthes guianensis content grown with Panicum maximum cut at 7.5 cm and 15.0 cm height was not very different, but was reduced when cut either at 3.8 cm or at 30 cm cutting height.

The similar proportion of legume in the mixture under different frequencies was contrary to the results obtained for twining legumes. Jones (1974b) found a linear increase in the percentage of Siratro (Macroptilium atropurpureum) with an increase in cutting interval. These differences were linked to the different growth habits of the species concerned. Unlike the semi-erect type of Verano stylo in this study, the twining legume can grow up through the sward to overtop and shade associated grass when the defoliation interval is extended (Jones, 1974b).

It is important to develop a so-called balance of grass and legume in the sward. Norman and Stewart (1964) recorded increasing live weight gains of beef cattle with an increasing percentage of Townsville stylo (Stylosanthes humilis) from 23 - 63% in the mixture. Bryan and Evans (1968) showed that at least 30% of legumes should be maintained in a pasture for high animal production. Thus the approximately 10 - 12% legume content in this study is rather low. The dominant effect of defoliation frequency on grass : legume, percent grass and percent legume content at the final harvest (Tables 6, 9, 17) suggested that the percentage legume content could be increased by increasing defoliation frequency.

From the current results, it appeared the desirable improvement in legume content can be achieved under a moderate frequency of defoliation. Although VF can quickly increase the percent legume content, the increase can suppress grass growth rather than favouring legume growth. This results in lower total dry matter yield of the mixture. Moreover, under field conditions, the pasture will be invaded by weeds when cut very frequently (Humphreys, 1981).

5.3 Effects of defoliation on branch characteristics

Branch number was insensitive to defoliation intensity and defoliation frequency (Table 22). The non-sensitivity of branch number to intensity of defoliation was similar to the result obtained in Lucerne (Medicago sativa) (Ridgman, 1960). However, the response to different defoliation frequencies is contrary to the result of Gutteridge and Whiteman (1975) who found that shoot number in four accessions of Psoralea eriantha was markedly reduced with more frequent defoliation. Plant structural differences may well account for the differences in response. Erect species have poor basal branching and a deficiency of basal buds, while Verano stylo, a semi-erect type, is observed to respond to severe defoliation by more basal branching. From information on average branch size, it appears that lax intensity produced a higher average branch dry weight (Table 22) with higher leaf dry weight and leaf area per branch (Tables 22, 23) than lax cutting, but not in the number of leaves per branch (Table 24). The higher branch size under lax intensity was attributed to the higher number of shoots remaining immediately after cutting (Appendix 2). Leach (1969) found that shoot size depended mainly on the length of its growing period. Therefore, more shoots under lax intensity can grow larger because they have more time whereas under hard intensity, most of the shoots are newly emerged. Where branch number is unaltered by hard or lax intensity, production advantages are expected to result from differences in average branch size.

It should be noted that defoliation frequency had a dominant effect on the contribution to total branch number and total leaf number (Figures 4, 6). The contribution of the first branch to total branch number and total leaf number was reduced in the VF treatment while that of the main stem was increased. It was also observed that more intense and frequent defoliation stimulated branching of the cotyledonary node. Since the number and position of growing points are quite important in determining regrowth, as mentioned in Section 2.2.2.1, the sward which is allowed to grow unchecked for a long period and then suddenly defoliated, or defoliation of the sward under a system using lax and long intervals in order to obtain high total dry matter yield and then defoliated at hard intensity, will reduce regrowth potential of legumes because few basal buds are then left to initiate regrowth after defoliation. Thus, for long term productivity, defoliation practices should also aim to produce more branches at the base of the legume plant to prevent any damage caused by sudden hard defoliation which may occur under field conditions.

In this study, regrowth arose mostly from the main stem and the first branch (Figures 5, 7, 8). Lax intensity resulted in higher dry weight with higher leaf dry weight, leaf area and leaf number of the main stem (Appendices 4, 5, 6, 7). It also resulted in higher dry weight with higher leaf dry weight and leaf area of the first branch (Appendices 4, 5, 6). Where branch number of the main stem and the first branch was not altered by hard and lax intensity, the production advantage resulted from the size of the main stem and the first branch. The size of the main stem and the first branch can be influenced both as a direct result of herbage removal with its influence on subsequent regrowth and also by changed plant form in response to continued defoliation.

5.4 Effects of defoliation on tiller characteristics

The tiller is considered to be the primary growth unit of a grassland community (Laude, 1972; Langer, 1977). Yield of the grass component of a pasture can be expressed as the product of the density of these tillers and their average size (Nelson and Zarrough, 1981). This experiment showed that defoliation intensity and frequency influenced tiller number and the size of each tiller. More intense defoliation increased tiller number by 18% (Table 25). This was attributed to the higher tiller appearance rate. The number of dead tillers was not significantly different between hard and lax intensity (Table 25). This effect was also observed in a tetraploid hybrid ryegrass sward (Korte et al, 1982). Rate of tillering may have been restricted under lax intensity by greater base shading (Davies, 1977) and apical dominance (Laidlaw and Berrie, 1974). Moderately frequent defoliation produced 13% and 12% more tillers than defoliation at very frequent and infrequent intervals (Table 25). Low tiller number under very frequent defoliation was attributed to a higher number of dead tillers (Table 25) caused by an energy shortage (Troughton, 1957), but low tiller numbers under infrequent defoliation were mainly due to low tiller appearance rate since the differences in number of dead tillers between moderate and infrequent defoliation were not significant (Table 25). The size of each tiller was reduced with more intense defoliation and was linearly decreased with increasing defoliation frequency. This was due to lower average dry weight, leaf area and leaf dry weight (Table 25) but not the result of leaf number per tiller (Table 26).

Grass yield differences were not due to a difference in tiller number, but were the result of differences in average tiller size. This finding is in agreement with Korte (1981). The compensatory effect between tiller size and tiller number which often affects the importance attached to tillering has been shown under field conditions. In a study with green panic (Panicum maximum var. Trichoglume) and buffel grass (Cenchrus ciliaris), the differences in shoot growth were often due to variation in shoot size rather than shoot number (Humphreys and Robinson, 1966).

In this study, it appears that regrowth arose from the base of the plants since stem apices still remained short at the time of defoliation (Appendix 9). Thus the interpretation of this experiment into management practices must be made with caution. However, aerial tillers may occur with further defoliation, and the number of tillers with elevated growing points which are prone to defoliation are more influenced by defoliation intensity than by defoliation frequency (Appendix 9).

In order to investigate the nature of defoliation advantages, tillers having the extended length of 0 - 20 cm, 20 - 40 cm, 40 - 60 cm, and > 60 cm were measured. It appears that under lax and infrequent defoliation, tillers having the extended length of > 60 cm contributed the most to total tiller number (Figure 9), total tiller dry weight (Figure 10), total leaf area (Figure 13), total leaf dry weight (Figure 11) and total leaf number (Figure 12). This indicates that if dry matter yield is the prime objective, management should aim to produce tillers having the extended length of > 60 cm because they will lead to higher average dry weight, leaf area and leaf dry weight than other types of tillers (Appendices 11, 12, 13, 14). However, percent crude protein content of tiller is also dependent on dry weight (% CPC = 3.93 - 0.684 log DW) (Appendix 10). Management which produces a majority of tillers having the extended length of 40 - 60 cm is therefore recommended since this can produce the desirable compromise between dry matter yield and percent crude protein content. This can be best achieved by defoliating the sward laxly and at moderate frequency (i.e. L, MF).

5.5 Effects of defoliation on crude protein

The percent crude protein content of the legume in this experiment was more than double that of grass. This indicates that Verano stylo has important implications in the development and management of legume-based tropical pastures. The dominant effect of defoliation frequency on percent crude protein content of both grass and legume was in agreement with the results as reported by Middleton (1982), Olson (1973), and Whitney (1970). It was reduced with less frequent defoliation (Tables 8, 16). However, the response to defoliation frequency was different between grass and legume. In grass, it was the infrequent treatment that reduced percent crude protein content, but the reduction in that of legume commenced with moderately frequent treatment and then decreased slightly but not significantly as the cutting frequency decreased from MF to IF. The decrease in crude protein was presumably associated with an increase in crude fibre (Burton et al, 1963; Guessous, 1981).

At the final harvest, defoliation intensity had a dominant effect on percent crude protein content of both grass and legume (Tables 11, 19) with hard cutting resulting in higher percent crude protein content than lax cutting. However, in the legume, an interaction effect indicated that defoliation frequency was important in modifying the effect of defoliation intensity. The adverse effect of lax intensity could in fact be reduced by increasing defoliation frequency. The higher percent crude protein content of grass and legume under hard cutting was due to higher percent crude protein content of both leaf and non-leaf (Tables 12, 13, 19).

Defoliation intensity had a more dominant effect on percent crude protein content of legume leaf. With less intense defoliation, percent crude protein content of leaf was reduced by 8% but was not affected by defoliation frequency. However, defoliation frequency was important in modifying the effect of defoliation intensity, with a moderate frequency of defoliation achieving an improved crude protein level (Table 12). In contrast, percent crude protein content of grass leaf was sensitive to both defoliation intensity and frequency. It was reduced by 22% with less intense defoliation and reduced by 39% when defoliated at IF (Table 19).

Percent crude protein content of non-leaf of both grass and legume was more influenced by defoliation intensity than by defoliation frequency. Percent crude protein content of grass non-leaf and legume non-leaf was reduced by 23% and 12% respectively with less intense defoliation (Tables 13, 19).

Total cumulative crude protein yield was more influenced by defoliation frequency than by defoliation intensity. It was reduced by 26% in the frequent, but only by 13% in the H treatment (Table 2). However, defoliation intensity is still important in modifying the effects of defoliation frequency. With VF, total cumulative crude protein yield was much higher when cut at lax than at hard intensity of defoliation as shown in Table 2.

The reduced total crude protein yield in the IF treatment was due to the relatively poor quality of the grass component, but that recorded in the H treatment was due to both grass and legume. Cumulative crude protein yield of grass and legume was 11% and 18% lower when cut at hard than at lax intensity (Tables 8, 16). The lower cumulative crude protein yield of grass in the IF treatment was due to the rapid decline in percent crude protein content of the grass component (Table 16).

At the final harvest, total crude protein yield was sensitive to both defoliation intensity and frequency. It was reduced with more intense defoliation and decreased with increasing defoliation frequency (Table 5). The reduction with more intense defoliation was due to both grass and legume, but the reduction with more frequent defoliation was due to grass only (Tables 10, 19). With more intense defoliation, crude protein yield of grass and legume was reduced by 17% and 21% respectively. Whereas defoliation frequency had no effect on the crude protein yield of legume, that of grass was generally decreased with increasing defoliation frequency.

Leaf crude protein yield of legume was influenced more by defoliation intensity, but that of grass was influenced more by defoliation frequency. More intense defoliation reduced leaf crude protein yield of legume by 15%, while that of grass was increased with decreasing defoliation frequency (Tables 10, 19).

Similar to leaf crude protein yield of legume, non-leaf crude protein yield of the legume was influenced more by defoliation intensity. It was reduced by 19% with more intense defoliation (Table 10). In contrast, non-leaf crude protein yield of grass was sensitive to both defoliation intensity and frequency. It was reduced by 28% with more intense defoliation and was increased with decreasing defoliation frequency. However, the adverse effect of more intense defoliation could be reduced by decreasing the defoliation frequency (Table 20).

In this study, all mixtures under the different defoliation regimes provided adequate crude protein since Milford and Minson (1966b) consider that crude protein content does not limit animal intake until it falls below 7%. The results indicated that defoliating such a Panicum maximum/Verano stylo sward laxly and at moderate frequency will lead to relatively high yields of dry matter of good quality (viz. adequate crude protein).

Conclusions

1. Intense and frequent defoliation reduced total dry matter yield of the Panicum maximum/Verano stylo sward. The reduction in total dry matter yield with more intense defoliation was due to both grass and legume, but that occurring under very frequent defoliation was due to a reduction in the grass component only.

2. Lax defoliation of the grass/legume mixture at moderate frequency (L, MF) resulted in relatively high yields of total dry matter and leaf and of high quality (i.e. high total crude protein yield).

3. Short term differences in grass yield were due to differences in tiller size rather than to differences in tiller number.

4. Similarly, differences in legume yield were due to differences in branch size rather than differences in branch number.

5. Percent legume content in the sward was increased by increasing the defoliation frequency. The increase in percent legume content was due more to depressed grass growth rather than a promotion of legume growth.

6. Percent crude protein content in the legume (15%) was more than double that in the grass (6%) and decreased with decreasing defoliation frequency in both the grass and legume components.

7. Results indicated that management should aim to produce tillers with an extended length of 40 - 60 cm as tillers within this range provide a more desirable compromise between yield and crude protein content.

8. Grass regrowth came from the base of the plants since the growing points remained close to ground level. The height of the growing points increase with less intense defoliation and when the plants were allowed to grow unchecked.

9. Legume regrowth arose mainly from the main stem and the first branch. Hard defoliation of the plants at frequent intervals stimulated the growth from the cotyledonary buds and appeared to encourage a more prostrate growth habit.

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Appendix 1

Effects of defoliation intensity and frequency on root dry weight and top : root ratio of grass and legume at the final harvest.

	H	L		VF	MF	IF		CV(%)
Legume								
Root dry weight (gm / plant)	.178	.135	ns	.225	.125	.119	ns	109.4
Top:root ratio	5.04	5.77	**	5.32ab	5.10a	5.8b	*	9.0
Grass								
Root dry weight (gm / plant)	.273	.262	ns	.229a	.261b	.313c	*	17.9
Top:root ratio	10.3	14.5	**	9.8a	11.8b	15.9c	**	14.4

Appendix 2

Effects of defoliation intensity on number of shoots remaining on the stubble of legume after harvest (number / plot).

	H	L		CV(%)
Precut	21.8	33.3	*	16.5
2 week interval, first cut	85.0	86.0	ns	24.0
2 week interval, second cut	117.5	140.5	*	0.80
3 week interval, first cut	75.0	103.0	*	11.3

Appendix 3

Effects of defoliation intensity and frequency on branch number on the main stem, the first branch and the second branch (number per plant).

	H	L		VF	MF	IF		CV(%)
Main stem	4.56	5.15	ns	5.40	4.71	4.46	ns	29.5
First branch	6.46	7.11	ns	5.48a	7.44b	7.44b	*	22.7
Second branch	3.32	3.04	ns	2.63	3.06	3.85	ns	60.6

Appendix 4

Effects of defoliation intensity and frequency on dry weight of the main stem (gm / plant).

Frequency		VF	MF	IF	Mean
Intensity	H	0.214	0.210	0.179	0.201
	L	0.347	0.341	0.424	0.371
Mean		0.281	0.275	0.301	

	$LSD_{.05}$	$LSD_{.01}$
Intensity	0.039	0.055
Frequency	ns	
Intensity x frequency	0.068	-

CV (%) = 15.9

Effects of defoliation intensity and frequency on dry weight of the first and second branch (gm / plant).

	H	L		VF	MF	IF		CV(%)
First branch	0.232	0.335	**	0.248a	0.271ab	0.332b	*	20.7
Second branch	0.147	0.142	ns	0.124a	0.146a	0.164a	ns	48.1

Appendix 5

Effects of defoliation intensity and frequency on leaf dry weight of the main stem (gm / plant).

Frequency	VF	MF	IF	Mean
Intensity H	0.100	0.096	0.075	0.091
L	0.166	0.150	0.193	0.170
Mean	0.133	0.123	0.134	

	LSD.05	LSD.01
Intensity	0.019	0.033
Frequency	ns	
Intensity x Frequency	0.026	-

CV (%) = 16.8

Effects of defoliation intensity and frequency on leaf dry weight of the first and second branch (gm / plot).

	H	L		VF	MF	IF		CV(%)
First branch	0.117	0.161	**	0.126	0.133	0.158	ns	19.1
Second branch	0.078	0.071	ns	0.069	0.075	0.080	ns	40.9

Appendix 6

Effects of defoliation intensity and frequency on leaf area of the main stem, the first branch and the second branch (cm^2/plant).

	H	L		VF	MF	IF		CV(%)
Main stem	12.8	23.5	**	19.0	16.4	19.0	ns	27.7
First branch	15.8	22.0	**	18.1	17.0	21.7	ns	19.8
Second branch	10.7	10.0	ns	9.9	9.8	11.2	ns	46.7

Appendix 7

Effects of defoliation intensity and frequency on leaf number of the main stem, the first branch and the second branch (number/plant).

	H	L		VF	MF	IF		CV(%)
Main stem	22.1	26.8	*	26.8	23.8	22.9	ns	16.1
First branch	24.6	29.4	ns	24.6	26.9	29.5	ns	22.2
Second branch	17.3	13.4	ns	13.7	16.4	16.1	ns	41.6

Appendix 8

Effects of defoliation intensity and frequency on specific leaf area of the main stem, the first branch and the second branch (cm^2/gm).

	H	I		VF	MF	IF		CV(%)
Main stem	139.0	137.3	ns	142.0	132.8	139.7	ns	14.2
First branch	136.7	139.5	ns	146.0	129.3	139.1	ns	12.8
Second branch	139.0	133.4	ns	142.6	127.2	138.8	ns	15.4

Appendix 9

Effects of defoliation intensity and frequency on number of tillers having the height of growing point within the range 0-1.9 cm, 2-3.9 cm, 4-5.9 cm, 6-7.9cm and >8.0 cm at the final harvest (A) and other harvests (B).

(A)

	VF		MF		IF	
	H	L	H	L	H	L
0 - 1.9 cm	38.5 ±9.71	24.0 ±7.12	32.0 ±4.90	27.0 ±6.83	33.0 ±5.29	24.5 ±5.97
2 - 3.9 cm	8.00 ±4.62	7.50 ±2.52	12.5 ±4.43	8.00 ±4.32	10.0 ±2.83	7.50 ±3.00
4 - 5.9 cm	3.33 ±2.31	6.00 ±2.83**	4.50 ±3.79	4.00 ±1.63	4.67 ±3.06***	6.00 ±3.65
6 - 7.9 cm	-	4.00 ±2.83**	4.00 ±0.0 **	4.50 ±2.52	2.00 ±0.0 **	4.00 ±2.00***
> 8.0 cm	-	2.67 ±1.15***	-	3.33 ±1.15***	-	2.00 0.0 ***

* n = 1

** n = 2

*** n = 3

(B)

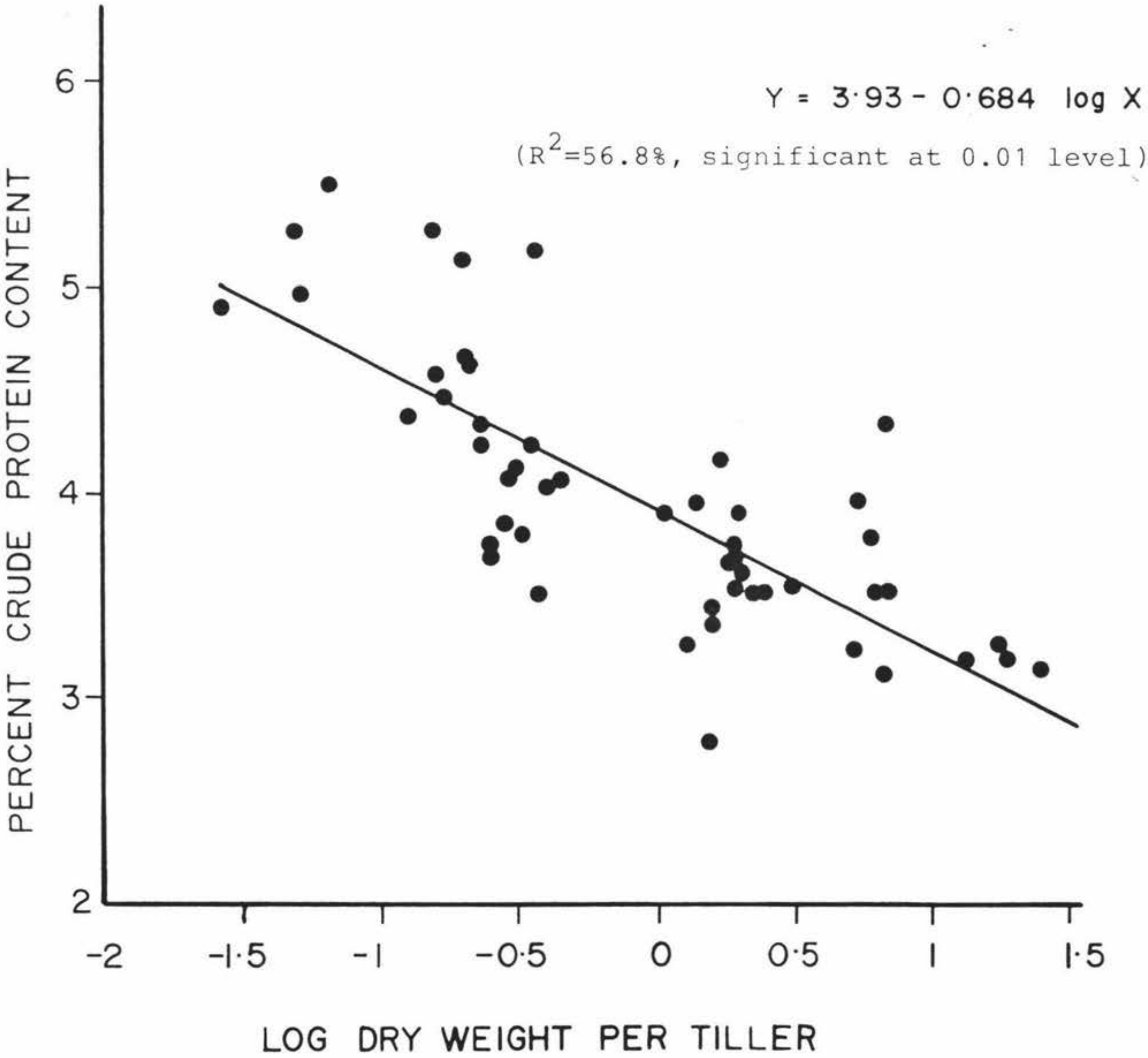
	VF				MF	
	First cut[1]		Second cut		First cut[2]	
	H	L	H	L	H	L
0 - 1.9 cm	31.0 ±2.65	25.7 ±7.64	39.5 ±6.40	29.5 ±8.39	35.0 ±10.39	27.0 ±8.19
2 - 3.9 cm	9.00 ±1.00	6.70 ±4.16	6.50 ±3.42	5.00 ±2.50	12.3 ±4.73	6.67 ±2.08
4 - 5.9 cm	2.00 ±1.73	4.33 ±1.53	4.00 ±4.00	7.00 ±3.46	3.33 ±0.58	4.33 ±3.21
6 - 7.9 cm	1.00*	1.33 ±0.58	- -	3.33 ±1.15***	-	3.33 ±1.53
> 8.0 cm	-	1.00*	-	4.00 ±2.83**	-	2.00*

1,2 = data observed from 3 replications

* n = 1
** n = 2
*** n = 3

Appendix 10

The relationship between percent crude protein content per tiller and dry weight per tiller.



Appendix 11

Effects of defoliation intensity and frequency on tillers having the extended length of 0 - 20 cm.

Number per plot

Frequency	VF	MF	Mean
Intensity H	17.50	4.25	10.88
L	1.50	0.50	1.00
Mean	9.50	2.38	

	$LSD_{.05}$	$LSD_{.01}$
Intensity	3.95	5.67
Frequency	3.95	5.67
Intensity x Frequency	5.58	8.02

CV(%) = 58.8

	H	L		VF	MF		CV(%)
Average dry weight (gm/tiller)	0.195	0.135	ns	0.201	0.130	ns	81.3
Leaf number per tiller (gm)	2.50	2.38	ns	2.78	2.10	ns	72.2
Leaf area per tiller (cm^2)	7.9	10.0	ns	11.7	6.2	ns	79.1
Leaf dry weight per tiller (gm)	0.038	0.047	ns	0.051	0.033	ns	96.3
Specific leaf area	210.0	117.0	*	200.0	127.0	ns	50.0
L : NL ratio	0.242	0.534	ns	0.340	0.340	ns	75.3

Appendix 12

Effects of defoliation intensity and frequency on tillers having the extended length of 20 - 40 cm.

Number per plot

	VF	MF	IF	Mean
Intensity H	30.5	39.0	10.0	26.5
L	31.0	19.0	6.0	18.7
Mean	30.8	29.0	8.0	

	$LSD_{.05}$	$LSD_{.01}$
Intensity	6.18	-
Frequency	7.57	10.46
Intensity x Frequency	10.70	-

CV (%) = 31.5

Average dry weight (gm/tiller)

	VF	MF	IF	Mean
Intensity H	0.292	0.449	0.417	0.386
L	0.622	0.575	0.348	0.515
Mean	0.457	0.512	0.382	

	LSD.05	LSD.01
Intensity	0.062	0.086
Frequency	0.076	0.105
Intensity x Frequency	0.107	0.149

CV(%) = 15.8

Leaf number per tiller

		VF	MF	IF	Mean
Intensity	H	2.95	2.40	3.20	2.85
	L	3.88	4.28	3.35	3.83
Mean		3.41	3.34	3.28	

	$LSD_{.05}$	$LSD_{.01}$
Intensity	0.537	0.743
Frequency	ns	
Intensity x Frequency	0.929	-

CV (%) = 18.4

Leaf area per tiller (cm^2)

		VF	MF	IF	Mean
Intensity	H	22.4	31.1	35.9	29.8
	L	28.9	33.7	27.7	30.1
Mean		25.6	32.4	31.8	

	$LSD_{.05}$	$LSD_{.01}$
Intensity	ns	
Frequency	4.91	-
Intensity x Frequency	6.95	-

CV (%) = 15.4

Leaf dry weight per tiller (gm)

		VF	MF	IF	Mean
Intensity	H	0.094	0.139	0.186	0.139
	L	0.142	0.199	0.165	0.169
Mean		0.118	0.169	0.175	

	$LSD_{.05}$	$LSD_{.01}$
Intensity	0.020	0.028
Frequency	0.024	0.034
Intensity x Frequency	0.035	0.048

CV (%) = 14.9

	H	L		VF	MF	IF		CV(%)
Specific leaf area (cm^2/gm)	219.3	181.1	**	221.4a	198.8b	180.5c	**	7.8
L : NL ratio	0.576	0.589	ns	0.389a	0.503b	0.856c	**	16.3

Appendix 13

Effects of defoliation intensity and frequency on tillers having the extended length of 40 - 60 cm.

Number per plot

	VF	MF	IF	Mean
Intensity H	0.50	9.75	28.00	12.75
L	6.00	26.00	10.50	14.17
Mean	3.25	17.88	19.25	

	$LSD_{.05}$	$LSD_{.01}$
Intensity	ns	
Frequency	5.12	7.08
Intensity x Frequency	7.24	10.01

CV(%) = 35.7

Average dry weight (gm/tiller)

	VF	MF	IF	Mean
Intensity H	0.115	0.651	0.985	0.584
L	0.783	1.086	0.828	0.899
Mean	0.449	0.868	0.907	

	$LSD_{.05}$	$LSD_{.01}$
Intensity	0.119	0.164
Frequency	0.145	0.201
Intensity x Frequency	0.206	0.284

CV (%) = 18.4

Leaf number per tiller

	VF	MF	IF	Mean
Intensity H	1.00	2.67	3.78	2.48
L	4.57	3.52	4.17	4.09
Mean	2.79	3.10	3.97	

	$LSD_{.05}$	$LSD_{.01}$
Intensity	0.96	1.33
Frequency	ns	
Intensity x Frequency	1.67	-

CV (%) = 33.7

Leaf area per tiller (cm^2)

	VF	MF	IF	Mean
Intensity H	12.9	48.3	89.8	50.3
L	48.2	45.5	63.4	52.3
Mean	30.5	46.9	76.6	

	$LSD_{.05}$	$LSD_{.01}$
Intensity	ns	
Frequency	11.5	15.9
Intensity x Frequency	16.3	22.5

CV (%) = 21.0

Leaf dry weight per tiller (gm)

	VF	MF	IF	Mean
Intensity H	0.066	0.232	0.495	0.264
L	0.244	0.239	0.406	0.296
Mean	0.155	0.236	0.450	

	$LSD_{.05}$	$LSD_{.01}$
Intensity	ns	
Frequency	0.071	0.099
Intensity x Frequency	0.101	0.140

CV (%) = 23.9

Specific leaf area (cm^2/gm)

	VF	MF	IF	Mean
Intensity H	48.9	208.2	182.3	146.4
L	196.9	191.0	158.2	182.0
Mean	122.9	199.6	170.2	

	$LSD_{.05}$	$LSD_{.01}$
Intensity	34.2	-
Frequency	41.9	57.9
Intensity x Frequency	59.2	81.9

CV (%) = 23.9

	H	L		VF	MF	IF		CV(%)
L : NL ratio	0.641	0.566	ns	0.399a	0.426a	0.985b	**	47.3

Appendix 14

Effects of defoliation intensity and frequency on tillers having the extended length of > 60 cm.

	H	L		CV(%)
Number per plot	9.00	24.50	**	10.6
Average dry weight (gm)	1.60	1.92	*	6.7
Leaf number per tiller	3.60	3.78	ns	3.3
Leaf dry weight per tiller (gm)	0.80	0.88	ns	6.8
Leaf area per tiller (cm^2)	134.4	126.6	ns	4.7
Specific leaf area (cm^2/gm)	167.2	143.2	*	3.8
L : NL ratio	1.02	0.85	**	4.2