EFFECTS OF PHOSPHORUS LEVEL AND SOIL TYPE ON THE GROWTH OF CARIBBEAN STYLO (*stylosanthes hamata* cv. Verano).

BY

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DECLARATION:

I hereby declare that this thesis has been written by me and that it is a record of my own research work. It has not been presented in any previous application for a higher degree. All quotations are indicated and all sources of information are specifically acknowledged by means of references.

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CERTIFICATION:

This thesis entitled 'Effects of phosphorus level and soil type on the growth of Caribbean stylo (Stylosanthes hamata cv. Verano) by MUSA Abubakar, meets the regulations governing the award of the degree of Master of Science of Ahmadu Bello University, Zaria, and is approved for its contribution to scientific knowledge and literary presentation.

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ABSTRACT;

A pot experiment was conducted in a glasshouse at Samaru between June and September, 1989 to investigate the effects of five phosphorus levels and three soil types collected from Samaru (Northern Guinea Savanna), Jos (Montane) and Sokoto (Sudan Savanna) on the growth of Caribbean stylo (Stylosanthes hamata cv. Verano).

Most of the plant morphological attributes, components of plant dry matter yield and plant nutrient composition and uptake were significantly affected by phosphorus. In soils collected from Samaru and Jos, phosphorus reduced days to 50% flowering and increased branch and nodule numbers while in the absence of added phosphorus Verano stylo planted into soils collected from Sokoto flowered earliest and produced the highest number of seeds and nodules. Phosphorus application increased dry matter yields of total plant and plant top. Yield of the root component was lowest and in fact declined further with phosphorus application. Phosphorus thus plays a greater role in increasing plant top dry matter yield.

The study suggested that soils collected from Jos suit seed production and would require up to 240 kg PpC/ha for this purpose while soils sampled from Samaru and Sokoto required 180 and 60 - 120 kg. P_2O_5/ha, respectively for forage production.

Nitrogen (N),phosphorus (P)$_t$potassium (K) and magnesium (Mg) concentrations peaked at 180 kg P_2O_5/ha, whereas uptake of these nutrients maximised between 120 and 180 kg P_2O_5/ha. The N, P, K, Ca and Mg concentrations obtained in this study were above the levels regarded as minimum needed for ruminant live weight maintenance- „ The need for field trials to support the findings in the present study was indicated.

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DEDICATION:

This work is dedicated to the greater challenges ahead of me and to those who sacrificed their lives and time in search of knowledge for the benefit of mankind.

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CHAPTER ONE:

1.0 INTRODUCTION:

The major limitation to ruminant livestock production in Nigeria is inadequate feed provision. From the point view of grassland vegetation, five broad ecological zones have been identified in the country. Located between the 6th and 7th parallels in the South is the Forest Zone with an annual rainfall of between 1800mm and 3000mm. At the other extreme is the Sahel zone which spreads from the north-east to the north-west and receives an erratic annual rainfall of 300 to 630mm. Between these two extremes, in a south to north direction, are the Derived, Southern Guinea, Northern Guinea and Sudan Savannas. Generally there is a bimodal rainy season in the South and only one short season in the North.

Although the Guinea Savanna has potential for profitable livestock production, this has not been realised because of the prevalence of tse-tse fly and the periodicity of forage supply. The bulk of the national herd is located in the Sudan where tse-tse infestation is minimal and the climate supports the growth of arable crops from which considerable crop residues are obtained. Here, as well as in the other sub-humid zones, the ruminants subsist largely on native pastures which provide enough herbage of reasonable quality only during the earlier part of the rainy season and limited quantity of fibrous herbage from the end of the rainy season onwards. Ways of achieving year-round good quality forage availability have been suggested but it is generally accepted that the best option is the use of improved pastures, particularly those based on high yielding tropical legumes (Thomas and Grof, 1986).

Trials at Shika in the Northern Guinea Savanna Zone (F.C. Agishi, Personal communications) have shown Caribbean stylo (Stylosanthes hamata cv. Verano) to be suitable for oversowing native pastures. This legume has been recommended for the establishment of fodder banks to supplement dry season grazing of unimproved grass pastures in sub-humid areas (Otsyina et al, 1987). It is superior in forage performance to the already well known Townsville stylo (Stylosanthes humilis) and well accepted by livestock. S. hamata forms compatible companions in mixtures with grasses and produces excellent yields of easily harvested and established seed.

However, there is a dearth of information in Nigeria on the responses to soil nutrients of tropical pasture legumes in general and S. hamata in particular. Phosphorus deficiency is widely acclaimed as characterising many tropical soils and it is unlikely that the soils of the Nigerian Savanna can be an exception. Since S. hamata has potential as a legume for standing hay and constituent of improved sown and range pastures in these areas with five to eight months of dry season, it is deemed necessary to conduct preliminary investigations into its growth responses to different phosphorus levels, using soils from dissimilar ecological areas. It is envisaged that data obtained on root, shoot and seed yields, leafiness and herbage nutrient composition may assist in recommending appropriate phosphorus rates for different locations in the sub-humid environment.

CHAPTER TWO:

LITERATURE REVIEW:

2.1 Introduction:

Legumes are known to be rich in nitrogen and independent of a low soil nitrogen status. As such, they are regarded as specially useful and dependable sources of protein in animal nutrition. Agishi (1983) listed seven important contributions of pasture legumes. These include build up of soil nitrogen; restoration and maintenance of soil fertility; improvement of the feeding value of associated grasses; provision of high quality feed in the dry season; extension of the life and feeding value of mixed grass/legume pastures; control of soil erosion and usefulness as cover crops.

2.2 Pasture legumes in Nigeria:

Several pasture legumes including species of Siratro, Centro, Puero, the Desmodiums and Glycines have been tried in Nigeria but have not demonstrated as much potential for animal production as members of the genus Stylosanthes such as the perennial stylos (S. guianensis), Caribbean stylo (S. hamata cv. Verano), shrubby stylo (S. scabra) and the annual, Townsville stylo (S. humilis). The genus Stylosanthes can tolerate conditions of low soil pH. At low phosphorus levels, legumes of this genus produce outstanding yields, while most of the legumes in other genera perform poorly (Burt, 1977). Many Stylosanthes species tolerate and even thrive on soils containing little phosphorus (Robinson, 1976). These noteworthy qualities suggest that the genus has higher potential as a source of promising pasture legume than other genera of legumes

introduced into Nigeria.

2.3 Classification of the genus Stylosanthes:

Stylosanthes belongs to the order leguminosease and the family Papillionaceae which contains a large number of tropical legumes. It is a member of the tribe Hedysarea. Stylosanthes contains some of the most widely distributed tropical herbs or shrubs among which are valuable pasture legumes that are drought resistant and combine well with certain grasses (Whyte et al., 1953). The genus is divided into Stylosanthes and Styposanthes, based on morphological differences. Species of Styposanthes have one inner bracteole and a rudiment axis whilst species of Stylosanthes have one inner bracteole but no rudiment axis ('t Mannetje, 1977). The genus Stylosanthes contains about 25 species from which introductions have been made into different parts of the world (Bogdan, 1977).

Stylosanthes consists of some very important pasture legume species that have been widely tried and used in livestock feeding. These include:-

S. guianensis. This incorporates important cultivars such as Cook, Endeavour, Oxley and Schofield which are all highly productive perennials.

S. humilis. An annual self regenerating pasture legume comprising cultivars such as Gordon, Lawson and Paterson.

S. hamata cv. Verano which behaves either as annual, biennial or short-lived perennial depending on environmental conditions.

S. scabra. This is a perennial shrubby legume that tolerates variable ranges of climatic conditions. Cultivars include Fitzroy and Seca from which new lines have been derived.

2.4 Introduction of Stylosanthes into Nigeria:

Studies of Stylosanthes in Nigeria started in 1947 with the introduction from Australia of S. guianensis cv. Schofield (Nwosu, 1960). This perennial legume is adapted to a wide range of soils and climatic conditions in Nigeria and its cultivation enjoys considerable popularity. Nwosu (1960) reported that it performed well on deeply leached and erodable sandy soil as well as shallow limestone soils in the drier areas of Nigeria. Another species that atracted attention between the late 1960s and mid - 1970s is S. humilis, a self regenerating annual adapted to the sub-humid and dry areas of Australia where its introduction into the range has resulted in increased cattle liveweight gains (Anon, 1973). S. hamata is another species that has been reported to be more promising than S. humilis in terms of dry matter yield, seed yield and nutritive value in the Northern Guinea and drier areas of Nigeria.

In the Guinea Savanna zone of Nigeria, establishment methods and management techniques of stylo/grass mixtures (Haggar and Agishi, 1969) have been studied. Also attention has been focussed on seed production of stylos in the Northern Guinea savanna (Agishi and Asare, 1980).

2.5 Morphological description of the genus Stylosanthes:

The general growth habit varies from stiffly erect to prostrate or near-creeping while such characters as hairiness and degree of leafiness are highly variable. The successful introduction of the plant into diverse environments can be attributed to this

inherent morphological and associated physiological variability. The degree of variation is perhaps all the more remarkable in that most introductions were initially made with small quantities of seed, very often from Australia or via an adjascent territory. Most countries have developed "strains' by selecting from their original population, and the general experience is that strains produced locally or population that have emerged from local selection pressure, invariably prove superior to those introduced from an outside source, particularly one having a markedly different environment (Naveh and Anderson, 1967).

Allowing for this diversity in morphology, a typical single plant has a radial growth form with prostrate, thin and pliable branches that spread out from the deep rooted central axis. From the branches shorter and leafier growth develops, the shoots being held vertically to a height up to 1 m above ground. With age and increasing weight however, this growth collapses on itself and a mat of tangled, lignified stems is formed on the ground, from which new erect stems may arise. The stems do not usually root at the nodes although this has been reported (Whyte et al., 1953; Gilchrist, 1967) and the mass of growth spreading from a central axis for up to 5 m can be rolled up like a carpet (Vivian, 1959). Although not typically scandent, some plants can if given support climb to a considerable height above ground. The stems bear trifoliate hirsute mucronate leaves, which are more crowded on the short-noded erect shoots than on horizontal branches, thus giving the plant a superficial resemblance to lucerne. The flower heads arise towards the ends of the erect shoots and tend to be held clear of the main mass of growth.

The root system is vigorous, spreading and penetrating deeply into the soil (Vivian, 1959; Lawton, 1965).

Morphological description of some Stylosanthes species:

2.5.1 S. Capitata

S. capitata is botanically described by Mohlembrock (1957) as an erect stemmed and decumbent branched plant with short white hairs and some scattered bristles. Leaflets are oblong and densely villous on both surfaces. Spikes are thick and many-flowered. It produces two types of fertile seeds:- the upper one long and glabrous while the lower is shorter and glabrous or sparsely pubescent.

2.5.2 S. guianensis

Cv. Cook. This is an erect to semi-erect plant. The stems are more pubescent than cv. Schofield and the leaves are more lanceolate than elliptical. The leaves are dark green to blue and are densely pubescent on both surfaces (Skerman, 1977). The plant is mid-season flowering with seeds either yellow-green or olive green. It flowers earlier than Schofield.

Cv. Endeavour.

It is an erect and densely branched with light-green pubescent stems. The leaflets are light-green, narrow and lanceolate. Flowers have a yellow standard with purple streak and yellow wings.. It is intermediate in flowering between Cook and Schofield (Skerman, 1977).

Cv. Oxley. Semi-erect and fine stemmed, the cultivar has fewer branches and flowers which mature late. Most of the perennating buds are found beneath the soil surface which thus makes it intrinsically resistant to fire and frost (Barnard, 1972).

Cv. Schofield. The plant is erect, coarse branched with hairy stems (McIlroy, 1962). The leaves are deep green, pointed and pubescent on the lower surface. It is late flowering, with yellow flowers and yellow-brown seeds.

2.5.3 S. hamata

Edye et al. (1974) described S. hamata as a very variable species with non-viscid stems and inflorescences. The plant is semi-erect or prostrate, non determinate with hairs (usually straight) concentrated down one side of the stem. The trifoliate leaves are glabrous. Inflorescence is elongate and loosely formed, usually occurring as single units in the leaf axils. Flowers are yellow and the spike produces two type of seeds. The upper seed has coiled beak about half the pod length while the lower seed is hookless. Seeds are usually square shaped and small (< 2mm long), with pale to medium brown colour.

2.5.4 S. humilis

Plants are generally robust with large leaflets and high seed yields. Some plants are generally vigorous, while others are less vigorous and may be variably densely branched (Edye, Burt, Nicholson, Williams and Williams, 1974). The three well known cultivars are:-

Cv. Gordon. It is late maturing and adapted to areas with over 1130mm annual rainfall.

Cv. Lawson. This cultivar is intermediate in maturity and adapted to areas with 890 - 1130mm annual rainfall.

Cv. Paterson. An early maturing annual, this is suitable for the 620 - 890mm annual rainfall zone with a characteristic long dry season.

2.5.5. S. macrocephala.

S. macrocephala, a fine - stemmed, many branched, prostrate to semi - erect plant with pubescent lanceolate leaflets, is a native of central and eastern Brazil. The inflorescences are dense and ovoid while the seeds are small, smooth and yellow (Schultze-Kraft, Costa and Flores, 1984).

2.5.6. S. scabra.

Humphreys (1980) described this plant as a woody and erect shrub growing up to 2 m high when conditions are favourable and especially when not grazed. Young stems are red while the trifoliate leaves are small and bluish green, slightly sticky with short hairs. Flowers are pale yellow and borne on short spikes. It produces a mixture of short coiled upper seeds about 1.5 mm long and lower hookless seeds. The tap root system is deep. Known cultivars include:-

Cv. Fitzroy. This is more bushy than cv. Seca and has paler green narrow leaves and stems. It also tolerates more cold and flowers earlier than Seca but is more susceptible to anthracnose disease. It is recommended for drier zones where annual rainfall is less than 1,000mm (Humphreys, 1980).

Cv. Seca. Deep tap - rooted and hardy plant that retain green foliage long into the dry season. It is therefore very suitable for tropical climates with pronounced wet and dry seasons. Seca may be recommended for areas receiving 600 - 1800mm annual rainfall (Humphreys, 1980).

2.6 Physiology of the genus Stylosanthes:

2.6.1 Adaptation.

Stylosanthes species flourish under an annual rainfall of over 2,500mm but will also survive in areas with a mean annual rainfall of only 650mm and 7 - 8 month dry season (Blair Rains, 1963; Mosnier, 1963; Habas, 1965). Anon (1973) considered S. hamata suitable for areas receiving an annual rainfall between 500 and 1,270mm. Stylosanthes species continue to make good growth at the end of the wet season and during at least the first part of the dry season. This uniform pattern of annual growth cycle contrasts with the typical fluctuating growth pattern of most tropical forages (Vivian, 1959; Allen, 1961; Blair Rains 1963; Cadot, 1965). In a well established stand of perennials, harvesting can proceed from 6 months into the 3rd and 4th year, but there is a general decline thereafter and six years is considered the maximum period of economic production (Vivian, 1959). Allen (1961) and Cadot (1965) reported that in common with other tropical legumes Stylosanthes have the ability to accumulate nutrients, especially phosphorus and calcium in their tissues even when these nutrients occur only in minute concentrations in the soil.

2.6.2 Responses to defoliation.

The mature plants of S. guianensis, S. scabra and their cultivars are extremely hardy and vigorous but the development of the young seedling is slow and sensitive to defoliation and damage in the first 3 or 4 months after sowing (Blouard and Thuriaux, 1962). Foster (1961) and Lawton (1965) reported that S. guianensis is highly susceptible to damage by fire. Groft and Harding (1968) showed that intensive harvesting every 18 weeks caused lower stem woodiness and almost loss of stand in S. guianensis. However, cutting at 8-week intervals at Sigatoka, Fiji, gave good persistence (Payne, Laing, Miles and Mason, 1955). Generally, cutting lower than 20cm is detrimental to survival (Vivian, 1959).

S. humilis has been reported to withstand heavy grazing and as the plant is being grazed, new axillary buds develop but this has an adverse effect on seed production especially close to the end of the growing season (Skerman, 1977).

2.6.3 Responses to photoperiod:

Responses to light is very crucial in most flowering plants especially in relation to seed production. Garner and Allard (1920) studied and divided plants into three groups. Those that flower very rapidly in day - length of 12hrs or less (short-day) others that flower readily in day-lengths of 12hrs or more (long-day) and those that flower irrespective of day-length (day-neutral). 't Mannetje (1965) and Okigbo (1972) classified S. guianensis as a short-day plant. Similarly S. humilis is a short day plant (Skerman, 1977) while S. erecta and S. fruticosa

were classified as day-length neutral plants because they flowered at both short and long day lengths (Okigbo, 1972). S. montevidensis was classified as long-day plant ('t Mannetje, 1965). Dry matter and seed yields of S. guianensis were reduced by more than 75% when grown under closely planted oil palm (Anon, 1965) while in S. humilis reduction of 71% daylight reduced yields by 47% (Sillar, 1967). This clearly shows that the most important Stylosanthes pasture species are not shade tolerant and are short-day in responses.

2.6.4 Tolerance to drought.

S. guianensis is reasonably drought tolerant due to the deep tap-root system even in areas subject to frost (Skerman, 1977). S. humilis have been noted as surviving drought because of its annual habit and heavy seeding capacity (Skerman, 1977) and coping with intermittent flooding (Kretschmer, 1968).

2.6.5 Responses to temperature.

Stylosanthes species are essentially warm tropical climate plants that make their best growth under high temperature conditions (Humphreys, 1980). The plants are also adapted to wide variations in temperature. S. guianensis for example, continued active growth up to 15°C (Allen and Cowdry, 1961) and defoliated at 0°C (Loelcke, 1964). Skerman (1977) cited adaptation to temperature ranges of 27 - 43 °C for S. guianensis and 15 - 22 °C for S. humilis.

2.6.6 Hardseededness.

The seeds of most pasture legumes are known to be associated with hard testa which resists water imbibition, causing a delay

in or prevention of consequent swelling, germination and emergence of the new seedling. Most Stylosanthes seeds have high percentages of hardseededness. Risopoulos (1966) reported 30 - 75% hardseededness in S. guianensis while Cameron (1965) recorded 74 - 99% hardseededness in S. humilis. Fresh seed germination in S. humilis ranged from 2 - 35% (Graham, 1963).

Hardseededness can be removed by mechanical scarification, using abrasives or treatment with hot water, dry heats or concentrated sulphuric acid. When seeds of S. guianensis are mechanically harvested, no treatment or scarification may be required (Rijkebusch, 1967; Gilchrist, 1967). Effective treatment can however be achieved by soaking seeds in water at 55 °C for 25 minutes (Risopoulus, 1966) or at 85 °C for two minutes (Gilchrist, 1967). Alternatively seed treatment can be either by using a mechanical scarifier (Blouard and Thuriaux, 1962) or treating with conc. sulphuric acid for 10 minutes (Gilchrist, 1967). Treated seeds generally give higher percentage germination thus, expectation of good plant establishment using lower seed rates is higher and more economical.

2.7 Origin, morphology and agronomy of S. hamata cv. Verano.

2.7.1 Origin.

S. hamata is a native of the islands of West Indies and the coastal region of the U.S.A., Colombia, Venezuela and Honduras that border the Caribbean Sea. Verano stylo was first introduced into Australia in 1965. Early trials at the Lansdown field station of CSIRO (Commonwealth Scientific and Industrial Research Organisation) near Townsville in 1967 with

single spaced plants, indicated that Verano stylo would outyield the best Townsville stylo cultivars (Anon, 1973). Since that time it has undergone widespread testing in the northern parts of Australia. It was released in July, 1973 by the Queensland Herbage Plant Liaison Committee to seedsmen as S. hamata cv. Verano.

Agishi (Personal Communications) indicated that Verano stylo was first introduced into Nigeria in 1974 by the Pasture Unit of the Federal Livestock Department. Since 1976, intensive studies have been carried out on Verano stylo at the National Animal Production Research Institute (NAPRI), Shika, in the Northern Guinea Savanna Zone of Nigeria.

2.7.2 Morphology.

Verano stylo is a deep tap-rooted herbaceous, non-determinate plant with a semi-erect growth habit and an often dichotomous branching pattern. The plant can grow up to 1 m high; the stems have short white hairs down one side while the other side is smooth. Leaves are trifoliate and the leaflets are lanceolate with acute, glabrous 4 - 6 paired veins and a lenth : breadth ratio of 4.5 - 5.3. Rachis is 4 - 6mm long and the bidentate stipules are adnate to the base of the petiole with hairs on the teeth and sheath. The inflorescence is an oblong spike ($\angle$ 20mm) with 8 - 14 flowers on a long stem. Outer bracts have hairs on the edges and there is an outer bracteole, two inner bracteoles with rudimentary axis subtending each flower (Skerman, 1977). The flowering spike produces double seeds; the upper having a reduced coiled hook about 3 - 5mm long, while the lower seed which

develops later is hookless (Humphreys, 1980). Seeds are usually square - shaped, small ($\angle$ 2mm long) and are pale to medium brown in colour (Edye et al; 1974).

2.7.3 Agronomy.

Establishment.

Verano can be established with or without land preparation. Methods employed in uncultivated land include seed broadcasting into (a) natural grassland, usually after partial defoliation by burning, cutting or use of herbicide (b) fallow land or unprepared seedbed. Pastures established using these techniques are often subjected to severe competition from existing vegetation resulting in slow growth and poor vigour. However, Verano stylo establishes well when sown into burnt ground followed by superphosphate application at the rate of 100 kg/ha since this ensures that competition for soil nutrients, water and light is minimal. It also establishes easily when broadcast or sown at about 1cm depth, but seedling emergence may not occur in sowings deeper than 4cm (Agishi, 1978a). Reeleveld and de Leeuw (1978) recorded 59% germination of Verano stylo when adequate rains were available compared with 32% when rainfall was erratic.

Verano stylo exhibits a high degree of hardseededness which results in establishment failures. Hard seed content, which usually exceed 90% (Mott and Mckeon, 1982) can be reduced by hot water treatment. McIvor and Gardner (1987) applied boiling water to Verano stylo seed (55% hard) for one minute and obtained over 60% germination. Indications from a number of

studies were that early and uniform germination occurred, following Verano seed treatment with hot water at 80 °C for 5 to 10 minutes. Argel (1979) associated the hardseededness in Verano stylo with temperature during seed formation and also indicated that dormancy was more strongly developed in the hooked upper articulation of the seeds.

Responses to defoliation.

The persistence of Verano stylo is probably on account of its ability to produce a lot of seed for early regeneration where it grows as an annual and its survival during long droughts when annuals would have been dry and stemmy (Anon, 1973).

Verano stylo tolerates heavy grazing (Anon, 1973; Humphreys, 1980; Alacantra and Paulino, 1984) and produces a lot of seeds on branches close to the ground in such a situation. Continuous grazing is considered quite suitable for its management. In a grazing trial at Shika, Agishi (1978b) stocked a Verano stylo/buffel grass pasture at 1.1, 1.67 and 3.33 heifers/ha and reported increases in proportion of Verano stylo with increasing grazing pressure from 10.20, 16.50 and 18.80% in the low, medium and high stocking rates respectively in the establishment year. In the fourth year this proportion increased to corresponding values of 28.30, 44.70 and 60.50%.

Animal responses to Verano stylo:

Controlled grazing studies on pure Verano stylo based pastures have not been carried out in Nigeria. It has however been observed that cattle always frequented Verano stylo seed crops at Shika. Sheep and goats prefer chopped Verano hay and it

is relished by most ruminant animals once they get used to it. Anon (1973) reported on grazing trials at Wrotham Park, Australia, in which 18-month old steers gained 150 kg/head on Verano stylo stocked at 1.3/ha compared with 130 kg/head on Townsville stylo cv. Lawson similarly stocked. Also steers in the Verano stylo paddock gained weight for a month longer, at the end of the first wet season and started gaining a month earlier at the beginning of the second, giving a total of two extra months' growth.

The fore-going review suggests that limited research has been carried out in Nigeria on P requirements for growth, herbage yield and seed production of Verano stylo. The Northern Guinea and the Sudan Savannas are environments with P deficiency but where Verano stylo has great potential. It is therefore necessary to examine representative soils for their physical and chemical characteristics and evaluate the growth responses of Verano stylo to different rates of P added to the soils.

Diseases of Verano stylo.

Verano stylo has been described as being moderate in field resistance to the anthracnose disease Colletotrichum gloeosporioides (Humphreys, 1980). Most Townsville stylo lines are susceptible to the disease, which reduces growth and seed production. The disease is more prevalent in areas with high rainfall and relative humidity and explains why Verano stylo has a wider climatic adaptation than Townsville stylo. The incidence of anthracnose has so far not been reported in Nigeria although it may assume importance when Verano stylo is grown on a large scale.

2.8 Climatic adaptation

2.8.1 Responses to photoperiod.

Verano stylo has been classified as a short-day plant because it flowers in photoperiods of 10 - 11½ hours, with greater flowering occurring under 10 hours (Cameron and 't Mannetje, 1977). At Shika the plants flowered three to four months after sowing in June but from the second year onwards, flowering of regrowths occurred throughout the year as long as soil moisture was non-limiting.

2.8.2 Responses to temperature.

Humphreys (1980) described Verano stylo as a heat - loving plant which does not do well in the sub-tropics where its growth is less vigorous and seed formation is impaired because of cool nights. Verano stylo has been reported to be clearly well adapted to the hotter districts of northern Australia and the hottest part of north-east Thailand (Anon, 1973; Humphreys, 1980).

2.8.3 Responses to rainfall.

Verano stylo is well grown in climates with a pronounced wet season followed by a dry season, but by virtue of its being a short - lived perennial with rapid seed production, it can be grown in environments with erratic patterns of seasonal rainfall distribution (Humphreys, 1980). It has been considered (Anon, 1973) suitable for tropical areas with a short and variable growing season having an annual rainfall between 500 - 1270mm. It is therefore more versatile than Townsville stylo which requires from 650mm annual rainfall upwards. This special characteristics of Verano stylo would even take it into tropical areas with lower and less reliable rainfall than that suited to Townsville stylo

(Humphreys, 1980). Verano stylo, being more versatile than Townsville stylo and adaptable to tropical dry areas with even less than 500 mm, annual rainfall (Anon, 1973). It may as well fit into both the Sudan and Sahel Savanna Zones of Nigeria with mean annual rainfall of 500mm or less.

2.9 Edaphic adaptation:

Verano stylo is adapted to well-drained sandy soils of low fertility status. It tolerates highly acid conditions and nitrogen fixation is less impaired by high exchangeable aluminium than it is in almost all other cultivated legumes (Humphreys, 1980). At Shika, it performs satisfactorily on gravelly, stony, rocky, fine sandy, sandy loam and clay loam soils (Agishi, Personal Communications).

2.9.1 Rhizobium inoculation:

Verano stylo is non-specific in its Rhizobium needs as it readily nodulates freely and fixes nitrogen with native "Cowpea type" Rhizobium (Anon, 1973; Humphreys, 1980). Plants of Verano stylo, S. humilis and S. scabra were grown in nutrient solution following inoculation with a suspension of "Cowpea type" Rhizobium CB 756 and 21 days after, aluminium concentrations of 0, 25, or 100 µm were applied and the plants allowed to grow further for 10 or 20 days (Carvalho, Andrews, Edwards and Asher, 1980). Measurement of nitrogen fixation based on total nitrogen contents and acetylene reduction demonstrated that aluminium within the range used had no detrimental effect on any species.

In pot trials Pahwa and Patil (1983) inoculated Centro, Townsville stylo, Lablab (Lablab purpureus), Siratro and Verano stylo with "Cowpea type" Rhizobium and reported significant

increase in plant height, nodulation, fresh and dry weights of all species. Similar results were obtained by Kale and Konde (1985) when Stylo (S. guianensis), S. viscosa, S. scabra, Verano stylo and Siratro were inoculated with 1 - 5 Rhizobium strains isolated from each of these species. Also an S - 1 strain isolated from Verano stylo gave the most effective nodulation when compared with the others and uninoculated seeds.

2.9.2 Nutrient requirements:

Although research has shown that phosphorus is the major requirement for adequate legume performance, other macronutrients like potassium (K), sulphur (S), magnesium (Mg) and micronutrients such as cobolt (Co) and molybdenum (Mo) (for nodulation) are also required for optimum performance of the legume plant.

2.9.3 Responses to phosphorus:

Importance of phosphorus - Phosphorus (P) has been reported to affect nodulation and symbiotic nitrogen fixation as well as plant growth (Horrel and Court, 1965; Skerman, 1977). Arnon (1953) pointed out that P was needed in photosynthesis as well as carbon reduction, as a constituent of cell nucleus, in cell division, development of meristems, nodulation, blossom and seed formation. Andrew and Robins (1969) showed that addition of P to soils where legumes grow increased nitrogen percentage in their tops beyond maximum increase in dry matter production and this was attributed to promotion of better root development, nodulation and improved metabolism by the added P. Similarly in another experiment they reported Townsville stylo as having potential for absorbing greater quantities of P from soils with low available P.

P. deficiency in Nigerian soils - P is probably the major limiting factor in pasture legume production from tropical soils which are generally low in available P (Skerman, 1977). Enwezor and Moore (1965) reported the average total P content of Nigerian soils as low, ranging from 80 - 150 ppm in the Savanna to 126 - 403 ppm in the Forest Zone. These generally low levels of P in the Savanna and its tendency to react with soil components to form relatively insoluble compounds that are therefore unavailable to plants results in further widespread P deficiency. Savanna soils with less than 220 - 390 ppm total P have been reported to respond to P application (Bouyer, 1958; Berger, 1964).

P. toxicity - Despite the very important roles played by P in nodulation and plant growth activities, excess amounts cause plant toxicity. Fletcher and Kurtz (1964) showed that P toxicity led to the reduction in the number of nodules produced by legumes. Jones (1974) indicated that P applications higher than 100 kg/ha decreased dry matter yield in some Stylosanthes species. However, in Nigeria no known P toxicity has so far been reported for Verano stylo, presumably low rates of P have been applied.

2.9.3.1 Effect of phosphorus on dry matter yield of Stylosanthes species:

Various experiments involving the application of different rates of P have shown reasonable Stylosanthes dry matter yield responses. In a field trial at Shika, Abdullahi (1981) reported increases in dry matter yield with increasing P rates from 0 - 59.24 kg/ha applied to each of the Cook, Endeavour and Schofield S. guianensis cultivars. The corresponding dry matter yields varied from 1.9 to 6.9 t/ha for Cook, 1.8 to 4.7 t/ha for

Endeavour and 1.8 to 3.3 t/ha for Schofield. Similarly Gilbert and Shaw (1980) applied various rates of P from 0 to 45 kg/ha to S. humilis cv. Paterson, Verano stylo and S. scabra cv. Fitzroy and recorded dry matter yields that ranged from 2,707 kg/ha without P. to 4,528 kg/ha with 45 kg P/ha. As little as 7.4 kg P/ha in the form of molybdenised superphosphate considerably increased dry matter yield in Townsville stylo (Shaw, Gate and Wilson, 1966). At Shika where Haggar (1971) applied 0 to 43.6 kg P/ha to swards of a mixture of Rhodes grass cv. Callide and Schofield stylo, increase in dry matter yield occurred but was more clearly demonstrated in the legume component. Similarly in Queensland, Bruce (1972) reported that the dry matter yield of a Stylo/grass mixture increased as the rate of P rose from 0 to 59 kg/ha.

2.9.3.2 Effect of phosphorus on dry matter yield of Verano stylo:

Verano stylo has been reported to produce higher dry matter yields than Townsville stylo (Anon, 1973). Shehu (1981) obtained mean dry matter yields from sowings made in cleared and cultivated rangeland of 4.05 and 2.66 t/ha for the first and second year crops respectively which received only 100 kg/ha single superphosphate at sowing.

2.9.3.3 Effect of phosphorus on seed yield:

Verano stylo responds well to superphosphate, producing high seed yields at high levels of application. At Shika a second year crop of Verano stylo received 0, 30, 60, 90 and 120 kg P_2O_5/ha (as single superphosphate) and produced 480.6, 552.8, 961.3, 1266.0 and 1280.5 kg seed/ha, respectively. This emphasizes

the important role phosphorus can play in Verano stylo seed production. Rai and Patil (1987) studied the effect of pelleting the seeds of Verano stylo, S. guianensis, S. scabra, S. viscosa and S. humilis with clay soil, clay soil + farm yard manure (FYM), clay soil + FYM + single superphosphate (SSP). Irrespective of species and type of pelleting, P increased seed yields and Verano stylo gave the highest of 369.7 kg/ha.

2.9.3.4 Effect of phosphorus on mixed Verano stylo/grass swards:

In a mixture of grass and Verano stylo, application of phosphorus has been shown to increase the sward dry matter yield more than the pure grass or Verano stylo sward alone. Following application of 18 kg P/ha, Shehu (1981) observed that Verano stylo/green panic (Panicum maximum var. Trichoglume) and Verano stylo/buffel grass (Cenchrus ciliaris) swards produced the greatest dry matter yields of 3.83 and 3.30 t/ha in the first year and 4.97 and 4.88 t/ha in the second year. The corresponding values for mixtures of these grasses with Townsville stylo were lower being 2.76 and 2.47 t/ha in the first year and 3.80 and 4.12 t/ha in the second year. In the northern territory of Australia, Verano stylo has been shown to contribute 50 - 60% of the total dry matter yield of the mixture with Sabi grass (Urochloa mosambicensis) (Anon, 1973). At Shika, Shehu et al. (1978) found the dry matter yield of Verano stylo/buffel and Verano stylo/green panic mixtures to be higher than those of the pure legume or grass alone when 100 kg/ha superphosphate was applied only in the year of establishment.

2.9.3.5 Effect of phosphorus on herbage chemical composition (N and P):

Although the nutritive value of pastures depends on many factors among which are soil nutrient status, stage of growth and type of pasture plants, legumes generally have higher nutritive values than grasses. The nutritive value of Stylosanthes species is known to increase with P application.

Abdullahi (1981) at Shika showed that N and P contents of three S. guianensis cultivars at the pre-flowering, flowering and post-flowering growth stages increased with increase in the level of applied phosphorus. Also in this environment, the crude protein content of Verano stylo which received 30 - 120 kg P_2O_5/ha in the form of single superphosphate in the establishment year varied from 13.6 to 18.9% during the early flowering stage and 6.5 to 9.0% at maturity (Agishi, Personal Communications).

2.9.3.6 Effect of phosphorus in the presence of potassium on Verano stylo:

Mohammed Saleem and Otsyina (1987) studied the effect of different phosphorus and "Kanwa" (Local potassium containing 4.7% K) levels for Verano stylo production in the Sub-Humid Zone of Nigeria. Without the application of P and Kanwa, the authors recorded 2.94 t dry matter yield/ha, 2.27% N and 417 kg crude protein yield/ha but with the application of 36 kg P/ha and 100 kg Kanwa/ha, the values increased to 6.48 t dry matter yield/ha, 2.81% N and 1151 kg crude protein yield/ha. On the other hand, Rai and Patil (1985) reported that Verano stylo showed no significant response to the application of 30 to 120 kg P_2O_5/ha and 30 kg K_2O in terms of fresh fodder, dry matter and crude protein yield.

2.9.3.7 Effect of phosphorus in the presence of potassium and sulphur on Verano stylo:

On a semi arid red sandy clay loam soil, Singh (1984) applied 0 to 264 kg P, 0 to 44.8 kg K and 0 to 20 kg S/ha to a mixed Verano stylo/green panic sward and found that the highest dry matter and crude protein yields resulted from the highest rates of application of each nutrient. The yield of Verano stylo was not affected by S alone, but was increased significantly by its addition to P and K.

2.9.3.8 Responses to calcium:

Limited information is available on the yield response of Verano stylo to calcium presumably because, like most other tropical legumes that are associated with "Cowpea type" Rhizobium, it does not usually require liming. Reports from Sao Paulo, Brazil showed that potted S. guianensis cvs. Cook, Endeavour and Schofield; Townsville stylo and Verano stylo fertilized at 1.2 or 2.9 t calcium (Ca/ha) 30 days before sowing produced higher yields with increase in the level of Ca in all but Townsville stylo and Verano stylo (Savastano, Mattos and Monteiro, 1982).

CHAPTER THREE:

MATERIALS AND METHODS:

3.1 Location:

The experiment was conducted in a glasshouse located at the Institute for Agricultural Research (IAR) / Faculty of Agriculture, Ahmadu Bello University, Samaru, Zaria.

3.2 Soil sampling and analysis:

Top - soil (0 - 15cm) samples were collected from fallow fields at three locations:- Samaru, 686 m above sea level (formed on drift material (loess) overlying crystalline basement complex (Klinkenberg and Higgins, 1968) in the Northern Guinea Savanna zone; Ta - Hoss (Jos), 1430 m above sea level, (developed from basaltic deposit) a hilly area in the Jos Plateau; and Rawiyya (Sokoto) 304 m above sea level (formed from aeolian drift overlying crystalline basement complex) in the Sudan Savanna zone, during May/June 1989. 12 cores were composited to form each sample. Each soil sample was air-dried, sieved through a 2 mm screen and mixed thoroughly before analysis. Sub-samples of these soils were subjected to routine analysis for the purpose of their characterisation.

Exchangeable cations were extracted with 1 N neutral ammonium acetate and determined with an atomic absorption spectrophotometer and flame photometer while cation exchange capacity (CEC) was estimated by summation. Total nitrogen was analysed by the Macrokjeldahl procedure of Bremner (1965). Available phosphorus was extracted with Bray No. 1 solution (0.03 N NH_4F + 0.025N HCl) and phosphorus in the extract obtained using the Molybdate Blue colour method as modified by

Murphy and Riley (1962). Particle size distribution was estimated by the hydrometer method while pH was determined in both 1:1 (soil : water) and 1:2 (soil : 0.01 M $CaCl_2$) solution ratios with glass electrode pH meter. Organic carbon was determined by the dichromate wet combustion procedure of Walkley - Black as described by Allison (1965). The results of these are shown in Table 1.

3.3 Treatments and experimental design:

All possible combinations of five phosphorus levels:- 0, 60, 120, 180 and 240 kg P_2O_5/ha (denoted by P_0, P_1, P_2, P_3 and P_4 respectively) and three soil types - Samaru (S_1), Ta-Hoss (Jos, S_2) and Rawiyya (Sokoto, S_3) - were allocated to pots in a randomized complete block design with four replicates. Phosphorus was given as single superphosphate.

Four kg of each soil was carefully mixed with each level of single superphosphate and put in a 14 cm diameter plastic pot in which the holes had been blocked with polythene sheet to prevent soil loss during watering. In all, there were 60 pots. Blanket applications of the following amounts of reagent grade nutrients were supplied in solution along with the superphosphate to each pot - 10 ppm N as Urea (80.85 mg); 100 ppm K as KCl (762.72 mg); 30 ppm Mg as MgO (198.90 mg); 0.05 ppm Mo as ammonium molybdate (0.37 mg) and 10 ppm Zn as Zinc sulphate (175.92 mg).

3.4 Sowing:

All pots were moistened with de-ionised water to field capacity and allowed to equilibrate before seeds were sown. Hot water treated (80°C for 15 minutes) Caribbean stylo (Stylosanthes hamata cv. Verano) seed pods were sown in pots at the rate of 5 kg/ha on 19 June, 1989. The seedlings were thinned to four plants per pot

28 days later. De-ionised water was used in wetting the soil throughout the 12-week (19 June to 10 September, 1989) experimental period.

3.5 Harvesting:

All plants were harvested on pot basis on 10 September, 1989 by cutting at the cotyledonary node using a pair of secateurs. Plant tops were separated into leaf, stem and seed components, weighed fresh, oven dried at 80°C for 48 hours and counted before oven drying and weighing.

3.6 Observations and measurements:

The parameters observed and measured during the experimental period and/or at harvest included: days to 50% flowering; number of inflorescences; number of seeds per pot; number of branches per pot; number of leaves per pot; plant height (cm); number of nodules per pot and fresh and dry weights (g) of seeds, leaves, stems, roots and nodules.

Plant top and root samples were oven dried at 80°C for 48 hours, ground with a wiley mill and analysed for nutrient uptake using procedures described by Chapman and Pratt (1962) for nitrogen and phosphorus. Cations in the digest were determined by atomic absorption spectrophotometry and flame photometry.

Table 1: Physical and chemical properties of top-soil (0-15cm) representatives taken from the three experimental locations.

Properties	Location Samaru	Ta-Hoss(Jos)	Rawiyya(Sokoto)
Particle size analysis(%)			
Sand	56.0	36.0	68.0
Silt	40.6	27.6	19.6
Clay	3.4	36.4	12.4
Textural class	Sandy loam	Clayey loam	Sandy loam
Exchangeable bases (meq/100g)			
Ca	0.873	3.244	2.807
Mg	0.514	2.143	0.954
K	0.102	0.205	0.199
Na	0.087	0.189	0.218
Cation exchange capcity (meq/100g)	4.8	14.3	8.1
pH (H_2O)	5.1	4.9	5.2
pH ($CaCl_2$)	4.6	4.7	4.7
Organic carbon(%)	0.84	1.06	0.86
Total N (%)	0.058	0.130	0.053
C/N	14.48	8.15	16.23
Available P (ppm) Bray 1	11.33	12.48	14.04

3.7 Statistical analysis:

The data were subjected to the standard analysis of variance to test for significant effects of the treatments, using "F" test as described by Snedecor and Cochran (1967). Treatment means were compared, following Duncan's new multiple range test procedure as outlined by Steele and Torrie (1980).

CHAPTER FOUR:

RESULTS:

4.1 Experimental Soils:

The physical and chemical properties of soil samples from the three experimental locations are presented in Table 1. The data showed the Samaru and Rawiyya (Sokoto) soils to be sandy loam and the slightly more acidic Ta - Hoss (Jos) soil, a clayey loam. The organic carbon and total nitrogen (N) contents of the Jos soil were higher than those of either Samaru or Sokoto. Jos soil was intermediate in available phosphorus and exchangeable sodium and highest in exchangeable calcium and magnesium. Exchangeable potassium in Jos and Sokoto soils doubled that in Samaru soil.

4.2 Effects of phosphorus level and soil type on plant growth attributes:

Data on number of days to 50% flowering and on plant growth attributes at maturity such as height, number of branches, number of inflorescences, number of seeds and number of nodules are presented in Table 2.

4.2.1 Number of days to 50% flowering:

Days to 50% flowering decreased significantly ($P \leq 0.05$) with increasing phosphorus level. Although there was no significant main soil effect, on the average, S_2 (Jos) and S_3 (Sokoto) plants tended to have flowered earlier than S_1 (Samaru) plants. The interaction between phosphorus and soil type was significant. Whereas S_1 and S_2 plants appeared to have flowered progressively earlier with increasing phosphorus level, response by S_3 plants was not clearcut.

4.2.2 Plant height (cm):

Plant height increased with phosphorus application only up to 60 kg P_2O_5/ha (S_1 and S_3) or 120 kg P_2O_5/ha (S_2). S_2 plants were significantly ($P<0.01$) taller than S_1 plants, which were in turn taller than S_3 plants. For the S_1 and S_3 plants, heights maximised at P_1 but for the S_2 plants height was greatest with either 120 kg P_2O_5/ha (P_2) or 240 kg P_2O_5/ha (P_4).

4.2.3 Number of branches:

Although the number of branches rose as phosphorus level increased, response was highest up to 60 kg P_2O_5/ha (P_1) which did not differ significantly from response to higher phosphorus levels. S_3 plants were significantly ($P<0.05$) more branched than S_1 or S_2 plants which themselves produced equal number of branches. Without phosphorus S_1 and S_2 plants developed rather few branches whereas branch numbers in S_3 tended not to have been significantly ($P<0.05$) affected by phosphorus level.

4.2.4 Number of inflorescences:

Both phosphorus and soil type exerted significant ($P<0.01$) effects on the number of inflorescences produced. Without phosphorus, S_1 plants had the lowest and S_3 plants the highest number of inflorescences. The addition of P_1 caused 103, 86 and 3 per cent increases in the number of inflorescences produced by S_1, S_2 and S_3 plants respectively. The responses to higher phosphorus levels were variable. In S_2 and S_3 plants, inflorescence numbers maximised at P_2 and then declined. The highest number of inflorescences borne by S_1 plants were recorded at 18 kg P_2O_5/ha (P_3).

Table 2: Effects of phosphorus level and soil type on days to 50% flowering and plant characteristics at harvest:

Treatment	Days to 50% flowering	Plant height (cm)	Number of branches/pot	Number of inflorescences/ pot	Number of seeds/pot	Number of nodules/pot
P_0S_1	53.75a	35.19cde	22.25b	43.50h	90.25g	522ef
P_0S_2	51.50a	36.69bc	24.50b	53.60g	110.50fg	630ef
P_0S_3	46.75b	34.00de	34.00a	62.75f	200.00de	734de
P_1S_1	45.75b	38.38ab	31.50a	85.50cd	280.25bc	730de
P_1S_2	44.25b	36.13cd	31.75a	99.25b	280.00bc	727de
P_1S_3	46.25b	36.38bc	30.50a	64.75f	225.50cde	749de
P_2S_1	44.75b	36.26bcd	31.25a	89.00cd	254.75bcd	893cd
P_2S_2	44.67b	38.38ab	32.33a	111.33a	313.67b	910cd
P_2S_3	46.00b	36.06bcd	33.25a	85.50de	257.75bcd	819d
P_3S_1	44.75b	36.94abc	34.25a	99.00b	260.00bcd	1011bc
P_3S_2	43.75b	34.94de	30.25a	96.75bc	274.25bcd	904cd
P_3S_3	44.75b	33.31e	34.00a	79.75e	165.75ef	729de
P_4S_1	43.75b	36.13bcd	33.75a	98.50b	219.50cde	1142ab
P_4S_2	43.25b	39.25a	32.50a	99.25b	386.00a	1205a
P_4S_3	45.50b	34.56cde	35.75a	79.75e	206.50cde	751de
SE ± for phosphorus P	0.61**	0.48*	1.00**	1.75**	13.84**	32.31**
SE ± for soil S	0.47NS	0.37**	0.77*	1.36**	10.72**	25.03**
SE ± for P x S	1.05*	0.83*	1.72*	3.04*	23.96**	55.96**

*, **, NS = Significant at P/0.05, P/0.01 and Not significant at P/0.05, respectively.

Means followed by the same letter(s) do not differ significantly at (P/0.05) according to Duncan's New Multiple Range Test.

4.2.5 Number of seeds:

The pooled data suggested that the addition of phosphorus significantly ($P \leq 0.01$) increased the number of seeds produced. However, P_2 plants produced numerically but not significantly more seeds than P_1 or P_4 plants. The number of seeds produced by unfertilized S_3 plants significantly ($P \leq 0.01$) exceeded that by S_1 or S_2 plants but with phosphorus application, S_2 plants recorded by far the greatest number of seeds. S_1, S_3 and S_2 appeared to require up to 60, 120 and 240 kg P_2O_5/ha to produce their respective highest number of seeds.

4.2.6 Number of nodules per pot:

The Number of nodules increased significantly ($P \leq 0.01$) with added phosphorus. Although this increase continued upt to the highest level applied, the differences in nodule numbers between the P_2 and P_3 plants was only marginal. Irrespective of phosphorus level, S_1 and S_2 were equally effective and superior to S_3 in supporting nodule formation. The significant ($P \leq 0.01$) P x S interaction could be explained in terms of the rise in nodule numbers with increasing phosphorus in S_1 and S_2 plants while nodule numbers tended to have attained a peak at P_2 in respect of S_3.

4.3 Effects of phosphorus level and soil type on plant component dry matter yield:

Data on components of the above and below ground plant dry matter yields are presented in Table 3.

4.3.1 Leaf yield:

Generally, phosphorus application significantly ($P \leq 0.01$) increased leaf yield. However, P_2 and P_3 leaf yields were similar.

The effect of soil type was significant ($P<0.01$). S_1 and S_3 leaf yields ranked equal and were greater than those of S_2 plants. The interaction between P and S was significant ($P<0.05$). S_1 and S_3 leaf yields increased with additional phosphorus up to P_2 while S_2 leaf yield increased negligibly up to P_4.

4.3.2 Main stem yield:

Main stem dry matter yield without phosphorus was significantly ($P<0.01$) lower than that when phosphorus was applied. The response within the range P_1 to P_4 was however not significant ($P<0.05$). Stem yield was higher in S_2 than S_1 or S_3 plants regardless of phosphorus level. While stem yield of S_1 plants increased unnoticeably from P_1 to P_4, it rose up to the P_2 level regarding S_2 and S_3 plants before declining, even if only slightly.

4.3.3 Branch yield:

Across soil types, branch yield was significantly ($P<0.01$) lowest without phosphorus and highest at P_4. It is not immediately clear why the yield dropped at P_3. S_2 plants had the highest and S_3 plants the lowest, branch yield. Branch dry matter production peaked at P_3, P_4 and P_2 in S_1, S_2 and S_3 plants, respectively.

4.3.4 Total stem yield:

Phosphorus increased total stem yield significantly ($P<0.01$), with the value maximising at P_4. Total stem yield response to soil type was as recorded for branch yield (above). S_1 plants produced their highest stem yield at P_3 compared with P_4 and P_1 or P_2 for S_2 and S_3 plants, respectively.

4.3.5 1,000 - seed weight:

The effects of phosphorus and soil type were significant ($P \leq 0.01$ and $P \leq 0.05$, respectively). In all the soil types, 1,000 - seed weight was highest without phosphorus. S_1 and S_3 plants gave higher weights than S_2. The P x S interaction was not significant and the weight trend inconsistent.

4.3.6 Seed yield:

The effect of phosphorus application and soil type on seed yield were significant $P \leq 0.01$ and $P \leq 0.05$ respectively. Seed yield increased 69, 78, 62 and 71% with application of 60, 120, 180 and 240 kg P_2O_5/ha respectively, regardless of soil type. Seed yield responded to S_2 than it did to the other soil types. The P x S interaction was significant ($P \leq 0.01$). The trend of seed yield response to rising phosphorus level was inconsistent among plants grown on the different soil types. While for S_2 plants it tended to increase as phosphorus level was increased, for S_1 and S_3 plants, it reached maximum levels at P_3 and P_2 respectively and decreased thereafter.

4.3.7 Plant top yield:

Plant top dry matter yield was significantly influenced by phosphorus in the range 60 to 240 kg P_2O_5/ha, but soil type had no markedly different effect. Without phosphorus, S_3 plants produced the highest yield but with phosphorus they gave the lowest, at comparable application levels. Plant top yields attained maximum values in the different soil types at varying phosphorus rates. No reason could be advanced for the sudden yield jump observed for S_2 plants at P_4.

Table 3: Effects of phosphorus level and soil type on dry matter partition among plant components

Treatment	Leaf yield (g/pot)	Main stem yield (g/pot	Branch yield (g/pot)	Total stem yield (g/pot)	1000-seed weight(g)	Seed yield (g/pot)	Plant top yield (g/pot)	Leaf %	Root yield (g/pot)	1000-nodule weight (g)	Nodule yield (g/pot)	Total plant yield (g/pot)	Plant top: root ratio
P_0 S_1	3.75g	1.96d	6.74f	8.70e	5.36a	0.45e	12.90e	29.18ab	1.87d	0.21c	0.11e	14.87h	6.74bc
P_0 S_2	3.52g	2.48c	7.72def	10.20de	4.99ab	0.51e	14.23e	25.09cd	2.35bcd	0.28bc	0.17de	16.75gh	5.76c
P_0 S_3	4.98def	2.67bc	7.19ef	9.86de	4.14bcd	0.77d	15.61d	31.90a	1.95d	0.41ab	0.30bc	17.87fg	7.07abc
P_1 S_1	5.46bcd	2.80bc	9.59c	12.39bc	3.83cd	1.04bc	18.89bc	28.95ab	2.09cd	0.40ab	0.29bc	21.26bcd	8.07abc
P_1 S_2	4.24fg	2.91ab	10.06bc	12.97b	3.63cd	1.00bc	18.21bc	23.26d	3.05ab	0.35bc	0.26cd	21.52bcd	5.53c
P_1 S_3	5.14cde	2.64bc	9.05cd	11.69bcd	4.05bcd	0.90bcd	17.72bcd	29.28ab	1.82d	0.40ab	0.30bc	19.84cdef	8.89ab
P_2 S_1	6.39a	2.83abc	9.58c	12.41bc	4.20bcd	1.04bc	19.84b	32.21a	1.86d	0.37b	0.31bc	22.18bc	9.68a
P_2 S_2	4.18fg	3.21a	11.35b	13.49b	3.56cd	1.11b	19.93b	20.91e	3.20a	0.33bc	0.30bc	23.41ab	5.87c
P_2 S_3	5.53bc	2.83abc	8.89cd	11.72bcd	3.72cd	0.95bcd	18.20bc	30.41a	2.03d	0.55a	0.45a	20.69bcde	7.51abc
P_3 S_1	5.83ab	2.85ab	10.19bc	13.94b	4.28bcd	1.10b	19.96b	29.34ab	2.15cd	0.35bc	0.35abc	22.46b	8.52ab
P_3 S_2	4.61ef	3.05ab	8.60cde	11.65bcd	3.60cd	0.98bcd	17.23cd	26.66bc	2.91abc	0.30bc	0.27cd	20.41cde	5.65c
P_3 S_3	4.86def	2.75bc	7.65def	10.39de	4.53bc	0.74d	15.99d	30.52a	1.73d	0.41ab	0.34bc	18.38efg	7.94abc
P_4 S_1	6.21ab	2.85ab	9.55c	12.41b	3.92cd	0.86cd	19.47b	31.79a	2.16cd	0.36b	0.40ab	22.03bc	8.03abc
P_4 S_2	5.06cde	3.01ab	12.89a	15.90a	3.45d	1.33a	22.29a	22.79de	2.96ab	0.20c	0.24cd	25.49a	7.14abc
P_4 S_3	5.17cd	2.67bc	8.05def	10.72cd	4.22bcd	0.85cd	16.75cd	30.87a	2.29bcd	0.43ab	0.32bc	19.36def	6.49bc
SE ± for P	0.15**	0.07**	0.29**	0.35**	0.17**	0.04**	0.42**	NS	NS	0.029*	0.02**	0.49**	NS
SE ± for S	0.15**	0.06**	0.23**	0.27**	0.13*	0.03*	0.33**	0.48**	0.12**	0.023**	0.02**	0.38**	0.74**
SE ± for PxS	0.26*	0.13*	0.51**	0.61*	NS	0.07**	0.73**	1.07*	NS	NS	0.03*	0.85*	NS

*, **, NS = Significant at P/0.05, P/0.01 and not significant at P/0.05 respectively.
Means followed by the same letter(s) do not differ significantly at P/0.05, according to Duncan's New Multiple Range Test.

4.3.8 Leaf percentage:

Leafiness or leaf percentage, was not significantly affected by phosphorus application while the effect of soil type was significant ($P<0.01$). S_1 and S_3 plants had obviously higher leaf percentages than S_2 plants. While the S_1 plants tended to be leafier, the S_2 and S_3 plants appeared to retain less leaf, as phosphorus level was increased.

4.3.9 Root yield:

Root yield was not significantly affected by phosphorus. However, there was a marginal increase in response up to the P_2 level. S_2 plants had a greater root development than S_1 and S_3 plants.

4.3.10 1,000 - nodule weight:

Phosphorus application significantly ($P<0.05$) increased 1,000 - nodule weight and peaked at P_2, followed by a decline at higher phosphorus levels. The effect of soil type was significant ($P<0.01$) while that of the P x S interaction was not. S_3 nodules were the heaviest. Weight per nodule increased up to 60 kg P_2O_5/ha for S_1 and S_2 and 120 kg P_2O_5/ha for S_3.

4.3.11 Nodule yield:

Phosphorus and soil type significantly ($P<0.01$) affected nodule yield. In the main, nodule yield followed the order $S_3 > S_1 > S_2$. Whereas S_1 nodule yield apparently rose with additional phosphorus, S_2 and S_3 declined after maximising at P_2. The data indicated that phosphorus was more required by S_1 plants for nodule development.

4.3.12 Total plant yield:

The effects of phosphorus and soil type on total plant (above + below ground) dry matter yield were largely similar to those on plant top yield (See 4.3.7 above). Unfertilized S_3 plants produced higher yields, while the fertilized ones gave lower yields than S_2 and S_3 plants at comparable phosphorus treatment levels.

4.3.13 Plant top : root ratio:

Although the main effect of phosphorus was non-significant ($P/0.05$), plant top : root ratio increased up to P_2 and then declined. At similar phosphorus levels (except P_4) S_2 plants had the lowest ratios, and S_1 plants the highest. Plant top : root ratio was greatest with S_3 and smallest with S_2 without phosphorus.

4.4 Effects of phosphorus level and soil type on nutrient concentration (% dry matter) in plant top:

Data on plant top nutrients such as nitrogen, phosphorus, potassium, calcium, magnesium and sodium are presented in Table 4.

4.4.1 Nitrogen:

Application of phosphorus significantly ($P/0.05$) increased N concentration in plant top. The increase was linear with increasing levels of phosphorus. The effect of soil type on N concentration was also significant ($P/0.01$). Plants grown on S_3 had the highest N concentration (3.24%). Although the P x S interaction was not significant, all soil types responded to phosphorus added and increased plant top N concentration with increasing phosphorus levels.

Table 4: Effects of phosphorus level and soil type on nutrient concentration (% dry matter) in plant top.

Treatment	N	P	K	Ca	Mg	Na
P_0 S_1	2.24o	0.08d	1.02fg	0.68	0.173d	0.006c
P_0 S_2	2.05c	0.15abc	1.04f	0.76	0.173d	0.006c
P_0 S_3	3.08a	0.17ab	1.28bcd	0.63	0.204a	0.007bc
P_1 S_1	3.03a	0.12bcd	1.15e	0.61	0.180cd	0.006c
P_1 S_2	2.21c	0.11cd	0.97gh	0.77	0.180cd	0.006c
P_1 S_3	3.20a	0.17ab	1.28bcd	0.68	0.190bc	0.008ab
P_2 S_1	3.01ab	0.16abc	1.22d	0.62	0.183bcd	0.007bc
P_2 S_2	2.38c	0.11cd	0.91h	0.80	0.184bcd	0.007bc
P_2 S_3	3.29a	0.17ab	1.33abc	0.66	0.188bcd	0.008ab
P_3 S_1	3.13a	0.17ab	1.24d	0.56	0.183bcd	0.006c
P_3 S_2	2.38c	0.13bcd	1.07f	0.66	0.195ab	0.007bc
P_3 S_3	3.40a	0.19a	1.34ab	0.71	0.182bcd	0.009a
P_4 S_1	3.34a	0.17ab	1.26cd	0.66	0.185bcd	0.006c
P_4 S_2	2.57bc	0.13bcd	1.00fgh	0.64	0.185bcd	0.007bc
P_4 S_3	3.26a	0.19a	1.36a	0.56	0.195ab	0.007bc
SE ± for P	0.09*	NS	0.01**	NS	NS	NS
SE ± for S	0.07**	0.01**	0.01**	NS	0.002**	0.0002**
SE ± for P x S	NS	0.02*	0.03**	NS	0.004*	NS

*, **, NS = Significant at P/0.05, P/0.01 and not significant at P/0.05.

Means followed by the same letter(s) do not differ significantly at P/0.05 according to Duncan's New Multiple Range Test.

4.4.2 Phosphorus:

The plant top phosphorus concentration was not significantly affected by the phosphorus levels applied, but there were slight increases with increasing phosphorus levels up to P_3. S_3 plants had significantly ($P<0.01$) higher phosphorus concentration than S_1 and S_2 at all levels of applied phosphorus. Interaction between P and S was however significant ($P<0.05$). In both S_1 and S_3, phosphorus concentration increased with increasing phosphorus level although the increase was not significant. In S_2 the trend was not consistent but the plants grown on the soil tended to have the least response to phosphorus application and the lowest phosphorus concentration.

4.4.3 Potassium:

The effects of both phosphorus application, soil type and their interaction were significant ($P<0.01$) on potassium concentration in plant top. Potassium concentration increased with increasing levels of phosphorus. The highest K concentration was found in S_3 (1.32%) plants, followed by S_1 (1.18%) and then S_2 (1.00%). At all levels of phosphorus, S_3 plants also had the highest K concentration.

4.4.4 Calcium, magnesium and sodium:

The effect of phosphorus on the concentration of calcium, magnesium and sodium was not significant. However, the concentrations of calcium and magnesium tended to increase with increasing levels of phosphorus. The effect of soil type, while not influencing calcium concentration, significantly influenced

those of magnesium and sodium. Plants grown on S_3 had higher concentrations of magnesium and sodium than those grown on S_1 and S_2. The interaction effect was significant only with magnesium. Magnesium concentration in plants grown on S_1 and S_2 increased as the levels of phosphorus increased while with S_3, values decreased with increasing levels of phosphorus.

4.5 Effects of phosphorus level and soil type on nutrient uptake by plant top (mg/pot):

Data on nitrogen, phosphorus, potassium, calcium, magnesium and sodium uptake by plant top are contained in Table 5.

4.5.1 Nitrogen:

Application of phosphorus significantly ($P<0.01$) affected nitrogen uptake by plant top. Nitrogen uptake increased with increasing phosphorus levels up to the maximum level applied. For example in S_1 the nitrogen uptake values were 290, 580, 600, 630 and 650 mg/pot for P_0, P_1, P_2, P_3 and P_4, respectively. Similarly, the effect of soil type was also significant ($P<0.01$). Mean values were 550, 440 and 550 mg/pot for S_1, S_2 and S_3, respectively. Interactive effect was significant ($P<0.05$). Without phosphorus application, nitrogen uptake was highest with S_3 and least with S_1 plants. The trend changed from P_1 to P_4 with S_1 plants having the highest nitrogen uptake.

4.5.2 Phosphorus:

Phosphorus uptake was significantly ($P<0.01$) increased with increasing phosphorus levels up to the maximum. Soil type

Table 5: Effects of phosphorus level and soil type on nutrient uptake by plant top (mg/pot).

Treatment	N	P	K	Ca	Mg	Na
P_0 S_1	290e	10c	130d	90c	20f	1.0
P_0 S_2	350de	20b	150d	110bc	25ef	1.0
P_0 S_3	480bc	30a	220b	100bc	30de	1.0
P_1 S_1	580ab	30a	220b	120abc	30cde	1.0
P_1 S_2	400cd	20b	180c	140ab	30de	1.0
P_1 S_3	570ab	30a	230ab	120abc	33cde	2.0
P_2 S_1	600a	33a	250a	120abc	38abc	2.0
P_2 S_2	470bc	20b	190c	160a	38bcd	1.0
P_2 S_3	600a	30a	240ab	120abc	35bcd	1.0
P_3 S_1	630a	40a	240ab	120abc	38abc	1.0
P_3 S_2	410cd	20b	190c	140ab	40ab	1.0
P_3 S_3	540ab	30a	220b	110bc	30de	2.0
P_4 S_1	650a	33a	250a	130abc	38abc	1.0
P_4 S_2	580ab	33a	230ab	140ab	42a	2.0
P_4 S_3	550ab	33a	230ab	90c	30de	1.0
SE ± for P	20.0**	2.0**	5.0**	10.0*	1.00**	NS
SE ± for S	20.0**	1.0**	3.0**	10.0*	NS	NS
SE ± for P x S	40.0*	3.0*	8.0**	NS	2.00*	NS

*, **, NS = Significant at P/0.05, P/0.01 and not significant at P/0.05, respectively.

Means followed by the same letter(s) do not differ significantly at P/0.05 according to Duncan's New Multiple Range Test.

also significantly affected phosphorus uptake. S_1 and S_3 plants had higher phosphorus uptake than S_2 plants. Interaction between P and S was significant only at 5% level.

4.5.3 Potassium:

Plant top uptake of potassium was significantly ($P \leq 0.01$) influenced by both phosphorus, soil type and their interaction. The uptake of potassium increased with increasing levels of phosphorus. S_1 and S_3 plants had higher potassium uptake than S_2 plants. Without phosphorus, S_3 plants had the highest potassium uptake but the trend from P_1 to P_4 in all soils was not consistent.

4.5.4 Calcium:

The effect of phosphorus and soil type on calcium uptake was significant only at 5% level. Values increased with increasing levels of phosphorus up to P_2 after which there was a drop. Calcium uptake was highest in S_2 plants followed by S_1 and then S_3. Interaction effects were not significant.

4.5.5 Magnesium and Sodium:

Magnesium uptake by plant top was significantly ($P \leq 0.01$) influenced by phosphorus addition. There was an increase in the uptake with increasing levels of phosphorus up to P_2 beyond which a decrease was observed. The effect of soil type was significant while interaction effect was significant only at 5% level. Sodium uptake was not affected by level of phosphorus, soil type and their interaction.

4.6 Effects of phosphorus level and soil type on nutrient concentration (% dry matter) in plant roots:

Table 6 summarises the concentration of various nutrients in the plant roots.

4.6.1 Nitrogen:

Nitrogen concentration in plant roots was not significantly affected by phosphorus additions. However, values increased with increasing levels of phosphorus. While soil type significantly ($P/0.01$) affected nitrogen concentration, with S_1 and S_3 plants having higher values than S_2 plants, the interaction effect was not significant.

4.6.2 Phosphorus:

Phosphorus application significantly ($P/0.05$) affected phosphorus concentration in plant roots. Values increased with increasing levels of phosphorus. The effect of soil type on phosphorus concentration was highly significant ($P/0.01$). Values were higher in S_3 and S_1 plants than in S_2. The interaction effect was however not significant.

4.6.3 Potassium, Calcium, Magnesium and Sodium:

Treatment effects on the root concentrations of potassium, calcium, magnesium and sodium were not significant, except for sodium where soil type significantly affected its concentration.

Table 6: Effects of phosphorus level and soil type on nutrient concentration (% dry matter) in plant roots.

Treatment	N	P	K	Ca	Mg	Na
P_0 S_1	2.03c	0.07c	0.56	0.27	0.14	0.03e
P_0 S_2	2.28bc	0.08bc	0.61	0.17	0.14	0.04de
P_0 S_3	2.63abc	0.15ab	0.62	0.28	0.15	0.08bcd
P_1 S_1	2.82ab	0.13abc	0.65	0.20	0.18	0.04de
P_1 S_2	2.05c	0.09bc	0.47	0.18	0.15	0.04de
P_1 S_3	2.66ab	0.16ab	0.81	0.34	0.20	0.14a
P_2 S_1	2.87ab	0.16ab	0.64	0.14	0.17	0.04de
P_2 S_2	2.17bc	0.10bc	0.52	0.23	0.15	0.04de
P_2 S_3	2.75ab	0.16ab	0.57	0.26	0.16	0.10ab
P_3 S_1	2.68ab	0.14abc	0.61	0.24	0.16	0.05cd
P_3 S_2	2.54abc	0.11bc	0.60	0.19	0.14	0.04de
P_3 S_3	2.50abc	0.15ab	0.58	0.27	0.17	0.11ab
P_4 S_1	3.15a	0.21a	0.63	0.23	0.17	0.05cd
P_4 S_2	2.24bc	0.10bc	0.51	0.22	0.13	0.05cd
P_4 S_3	2.54abc	0.19a	0.60	0.28	0.16	0.09bc
SE ± for P	NS	0.01*	NS	NS	NS	NS
SE ± for S	0.09**	0.01**	NS	NS	NS	0.01**
SE ± for P x S	NS	NS	NS	NS	NS	NS

*, **, NS = Significant at P/0.05, P/0.01 and not significant at (P/0.05) respectively.

Means followed by the same letter(s) do not differ significantly at P/0.05 according to Duncan's New Multiple Range Test.

4.7 Effects of phosphorus level and soil type on nutrient uptake by plant roots (mg/pot):

Table 7 shows the uptake of nitrogen, phosphorus, potassium, calcium, magnesium and sodium.

Except for phosphorus, where the application of phosphorus significantly ($P \leq 0.05$) affected uptake, treatment effects and their interactions did not significantly influence nutrient uptake. Generally uptake by plant roots were lower than plant top uptake for all the nutrients investigated.

4.8 Correlation matrix for 24 growth attributes of S. hamata cv. Verano in response to five phosphorus levels and three soil types:

The correlations among 24 growth attributes as affected by phosphorus level and soil type are shown in Table 8. Period from sowing to 50% flowering was positively and significantly associated with 1000 -seed weight but negatively related to numbers of inflorescences and seeds, total plant dry matter yield and uptakes of N, P, K and Mg. The correlations of plant height with stem, seed and total plant yields were significant while those with leaf percentage and plant top concentrations of K and Mg, even though significant, were negative.

Whereas the relationships between leaf dry matter yield and plant top and total plant yields, 1000 - seed weight and seed yield were positive and significant, that between leaf percentage and these parameters, where significant, were negative. Similarly correlations between leaf dry matter yield and plant top N, P, K and Mg uptakes were strong and positive but those between leaf percentage and these elements were strong mostly in terms of concentration rather than uptake except in the case of K.

Table 7: Effects of phosphorus level and soil type on nutrient uptake by plant roots (mg/pot).

Treatment	N	P	K	Ca	Mg	Na
P_0 S_1	40.0	2.0b	11.0	5.0	3.0	1.0
P_0 S_2	60.0	2.0b	16.0	4.0	4.0	1,0
P_0 S_3	60.0	3.0ab	14.0	6.0	3.0	2.0
P_1 S_1	70.0	3.0ab	16.0	5.0	4.0	1.0
P_1 S_2	70.0	3.0ab	16.0	6.0	5.0	1.0
P_1 S_3	60.0	4.0ab	19.0	3.0	5.0	3.0
P_2 S_1	70.0	3.0ab	14.0	3.0	4.0	1.0
P_2 S_2	80.0	4.0ab	18.0	8.0	5.0	2.0
P_2 S_3	70.0	4.0ab	14.0	6.0	4.0	3.0
P_3 S_1	70.0	3.0ab	16.0	6.0	4.0	1.0
P_3 S_2	90.0	4.0ab	20.0	6.0	5.0	1.0
P_3 S_3	50.0	3.0ab	12.0	5.0	3.0	2.0
P_4 S_1	80.0	5.0ab	16.0	5.0	4.0	1.0
P_4 S_2	80.0	4.0ab	16.0	8.0	4.0	2.0
P_4 S_3	70.0	5.0a	16.0	7.0	4.0	2.0
SE ± for P	NS	0.4*	NS	NS	NS	NS
SE ± for S	NS	NS	NS	NS	NS	NS
SE ± for P x S	NS	NS	NS	NS	NS	NS

*; NS = Significant at $P \leq 0.05$, and not significant at $P \leq 0.05$, respectively.

Means followed by the same letter(s) do not differ significantly at $P \leq 0.05$ according to Duncan's New Multiple Range Test.

Table 8: Correlation matrix for 24 growth attributes of *S. hamata* cv. Verano in response to five phosphorus levels and three soil types.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	1																							
2	.04																							
3	-.45	.10																						
4	-.70	.30	.42																					
5	-.50	.55	.32	.59																				
6	-.59	.26	.30	.64	.51																			
7	-.38	.10	.52	.34	.22	.40																		
8	-.55	.55	.36	.62	.67	.63	.37																	
9	-.60	.53	.49	.68	.70	.67	.61	.93																
10	.15	-.44	.14	-.29	-.45	-.17	.59	-.48	-.26															
11	-.20	.26	.12	.40	.32	.25	-.20	.36	.27	-.52														
12	-.16	.05	.36	.02	.24	-.19	.34	.06	.18	.19	-.08													
13	-.43	.14	.51	.35	.43	.28	.52	.31	.46	.15	.02	.86												
14	.48	-.49	-.48	-.51	-.72	-.33	-.22	-.56	-.58	.37	-.21	-.37	-.47											
15	-.52	.50	.32	.58	.97	.54	.29	.65	.71	-.38	.28	.22	.43	-.59										
16	-.61	.53	.49	.72	.71	.68	.54	.92	.98	-.33	.45	.16	.45	-.58	.72									
17	-.25	-.20	.43	-.02	-.05	.22	.50	-.07	.10	.52	-.38	.29	.41	-.06	.03	.03								
18	-.19	-.27	.39	-.02	-.07	.15	.30	-.10	0	.37	-.21	.23	.28	-.02	-.01	-.03	.74							
19	-.11	-.47	.35	-.19	-.31	-.04	.44	.38	-.20	.76	-.44	.36	.36	.15	-.24	-.25	.72	.64						
20	-.26	-.42	.19	.07	-.15	0	.11	-.24	-.16	.34	.16	-.01	-.01	.11	-.14	-.11	.21	.28	.49					
21	-.52	.19	.58	.37	.38	.57	.76	.52	.69	.24	-.13	.30	.56	-.35	.45	.62	.78	.50	.39	.03				
22	-.39	.07	.57	.33	.32	.49	.65	.40	.54	.27	-.05	.29	.48	-.29	.40	.50	.65	.77	.42	.11	.79			
23	-.57	.07	.66	.40	.31	.50	.86	.46	.66	.38	-.12	.43	.65	-.33	.37	.60	.63	.45	.59	.21	.86	.74		
24	-.63	.31	.55	.65	.52	.62	.58	.73	.83	-.13	.32	.18	.47	-.45	.54	.84	.11	.05	0	.25	.58	.47	.69	1

Positive or negative values greater than 0.29 and 0.38 are significant at $P < 0.05$ and $P < 0.01$ respectively.

1 Days to 50% flowering
2 Plant height
3 Number of branches
4 Number of inflorescences
5 Number of seeds per pot
6 Number of nodules per pot
7 Leaf dry matter yield (g/pot)
8 Total stem dry matter yield (g/pot)
9 Plant top dry matter yield (g/pot)
10 Leaf percentage
11 Root dry matter yield (g/pot)
12 1000-nodule weight (g/pot)
13. Nodule dry matter yield (g/pot)
14. 1000-seed weight (g/pot)
15. Seed dry matter yield (g/pot)
16. Total plant dry matter yield (g/pot)
17. Plant top N conc. (%Dm)
18. Plant top P conc. (% Dm)
19. Plant top K conc. (% Dm)
20. Plant top Mg conc. (% Dm)
21. Plant top N uptake (mg/pot)
22. Plant top P uptake (mg/pot)
23. Plant top K uptake (mg/pot)
24. Plant top Mg uptake (mg/pot).

Root yield was significantly but negatively related to plant top N and K concentrations but not to their uptake.

There was a significant and positive association between the number of inflorescences and the number of seeds as well as seed yield, but the number of inflorescences was negatively associated with 1000-seed weight.

CHAPTER FIVE:

DISCUSSION

5.1 Soils:

The 0.84 to 1.06% organic carbon content of the experimental soils was slightly higher than that reported for most West African Savanna soils (Jones and Wild, 1975). Whereas the nitrogen contents of the essentially sandy loam Samaru and Sokoto soils were within the low level characteristics of most Savanna soils (Jones, 1973), the value for Jos soil was much higher. Only Sokoto soil recorded phosphorus within the critical value of 13.5 to 17.5 ppm credited to Samaru soils (Monehansyah, 1977). Although the calcium, magnesium, potassium and sodium requirements of Verano stylo have not been determined in Nigeria, the lack of response of most field crops to these elements in the Savanna region suggests their probable presence in adequate amounts.

5.2 Plant morphological attributes:

In both Samaru and Jos soils that were more deficient in available phosphorus, the addition of phosphorus caused a reduction in days to 50% flowering and increases in the number of branches and nodules. Without phosphorus, plants grown on Sokoto soils flowered earliest and had the highest number of nodules presumably because the soil contained the highest amount of phosphorus. Jos soil plants grew tallest probably because of the higher soil cation exchange capacity, organic carbon and nitrogen contents. In addition, Jos soil was more clayey, implying greater moisture retention which would be important particularly in the upper soil layer where most of the roots are concentrated. It was not immediately

clear why the Jos soil based plants still required more phosphorus for height maximisation than Samaru and Sokoto soils that had lower and higher initial phosphorus levels, respectively. The reliance of seed production on phosphorus is reflected in the highest number of seeds produced by plants grown on unfertilized Sokoto soils. However, phosphorus application aims at overall plant productivity. Consequently the clayey Jos soils which responded well to phosphorus fertilizer and utilized this in producing the greatest seed numbers is of agronomic significance. It might be suggestive of the potential of the Jos area as a Verano seed production centre. Phosphorus and soil were expected to have affected inflorescences and seed numbers produced equally; but inflorescence size and therefore flowers/inflorescence were not measured, hence seed number x seed size perhaps might be a more important factor for consideration.

The fact that plants grown on all the three soil types responded to phosphorus application as revealed in the various growth attributes examined confirmed earlier observations that Samaru soils were deficient in available phosphorus (Enwezor and Moore, 1966). The results also indicated that phosphorus fertilization could speed up growth and time to maturity of the legume in these Savanna ecological zones with characteristic short rainfall duration.

5.3 Plant dry matter yield:

Without added phosphorus fertilizer, Sokoto soils accounted for the highest, and Samaru soils the lowest leaf, main stem, seed, plant top, nodule and total plant (above + below - ground) dry matter yields while Jos soils supported the highest branch, total

stem and root yields. Although phosphorus application increased total plant and plant component dry matter yields, root yield tended to be the least affected and even registered lower values in some instances such as at 60 and 180 kg P_2O_5/ha (Sokoto soil) than without phosphorus. It would therefore appear that above and below-ground Verano stylo parts responded differently to this element and that it was made greater use of in building up the top portion normally available for animal consumption. Abdullahi (1981) observed at Shika that dry matter yield increases occurred when perennial stylo (S. guianensis) cultivars were phosphorus fertilized.

The responses to phosphorus obtained were largely consistent across yield components and proportional to the physical and chemical characteristics of the soils. For the Samaru soils, the highest yields at 180 kg P_2O_5/ha did not differ significantly from the lower values at other phosphorus rates. Fertilizer phosphorus had little effect on Jos soil in terms of leaf yield. However, with regards to most other plant component yields, addition of 120 kg P_2O_5/ha to Jos soil tended to be adequate but then remarkable yield increases were recorded again at 240 kg P_2O_5/ha. The suggestion would be that the lower rate be applied for forage yield and the higher rate for seed production. Pasture improvement and development programmes in Nigeria have so far depended essentially on imported seed. Local seed production should cut down on costs, especially foreign exchange, and in turn justify expenditure on use of the fertilizer doses. Predominantly sandy Sokoto soil was credited with the highest level

of available phosphorus. Nevertheless plants grown on it responded to phosphorus, even if to a less magnitude than was observed for Samaru and Jos soils. The indications were that phosphorus at the rate of 60 kg P_2O_5/ha should suffice for Sokoto soils while this amount might be the minimum required to support Samaru soil grown Verano pastures.

Seed size was actually depressed by added phosphorus except for Sokoto soil in which application of 120 kg P_2O_5/ha resulted in 1000 - seed weight values higher than that without fertilizer. Consequently the objective of phosphorus application should be to increase seed number rather than seed weight. Similarly, leafiness or leaf percentage was relatively unaffected by phosphorus application. Jos soil supported plants with the least leaf percentage. Greater leaf retention by Samaru and Sokoto soils than Jos soil would indicate the appropriateness of the latter for leafy forage production. Leaf yield is a function of leaf number and leaf size or weight per leaf.

5.4 Nutrient concentration and uptake in plant tops and roots:

Generally increasing levels of phosphorus increased the concentration and uptake of essential elements in the plant. Andrew and Robins (1969) and Jones (1974) reported increases in the concentration of nitrogen and phosphorus in the plant tops of S. guianensis as a result of addition of phosphorus fertilizer. According to Milford and Minson (1965), the minimum required nitrogen (N) content of tropical hays is about 1.12% (7.0% crude protein). For other nutrients such as phosphorus, potassium, calcium, magnesium and sodium, the requirements are 0.12%, 0.40%, 0.20%, 0.20% and 0.08% respectively (Boudet, 1975). The values

obtained for nutrients other than sodium in the present study are well above these minimum requirements. It would seem that, for any of these soils, addition of phosphorus up to 240 kg P_2O_5/ha (P_4) will be beneficial in view of meeting nutrient requirements of ruminants.

The increasing levels of these nutrients with increasing levels of phosphorus is expected since phosphorus is a very important element in proper root development. Phosphorus is also important in nitrogen fixation and nodulation, hence its significant effect on nitrogen concentration and uptake.

Days to 50% flowering, important dry matter yield components, nutrient concentration and uptake which rose in value as phosphorus level increased were all significantly interrelated. This suggested that any of the attribute involved could be predicted from the other provided the values are (dependent or independent) component were made available.

From the above discussion, it can be conclusively recommended that Jos soils are suitable more for seed than for forage production of Verano stylo with application of 240 kg P_2O_5/ha (or above) since the soil was low in phosphorus and responded well to its application. Samaru and Sokoto soils, however tended to be more appropriate for forage rather than for seed production, with applications of 180 and 60 - 120 kg P_2O_5/ha, respectively. This experiment was conducted in a glasshouse under semi - controlled conditions. Field experiment should be undertaken to confirm further, the validity and relevance of the above recommendations for the various ecological zones.

CHAPTER SIX:

SUMMARY AND CONCLUSION:

A pot experiment was conducted in a glasshouse at the Institute for Agricultural Research, Samaru (11° 11'N, 07° 30'E and 686 m, above sea level) between June and September, 1989 to determine the effects of five phosphorus application levels viz. 0, 60, 120, 180 and 240 kg P_2O_5/ha and three soil types sampled from sites at Samaru, Jos and Sokoto in the Northern Guinea Savanna, Montane and Sudan Savanna zones, respectively, on the growth of Caribbean stylo (Stylosanthes hamata cv. Verano).

Most of the plant growth attributes examined, were significantly affected by phosphorus. These included number of days from sowing to 50% flowering; numbers of inflorescence, seeds, branches and nodules; components of plant top dry matter yield; and plant nutrient composition and uptake. For Samaru and Jos soils, phosphorus reduced days to 50% flowering and increased branch and nodule numbers. Without phosphorus, plants established on Sokoto soils flowered earliest and produced the highest number of seeds and nodules. This was explicable in terms of this soil being richer in phosphorus than either Samaru or Jos soil. While phosphorus application increased yields of the total plant (above and below ground) and plant top (leaf + stem + seed), yield of the root component appeared the least affected and was even lower, for example, at 60 and 180 kg P_2O_5/ha than without phosphorus. Phosphorus thus tended to play a greater role in increasing plant top growth and development.

The study suggested that Jos soil was suitable for seed production and could require up to 240 kg P_2O_5/ha for this purpose, or half this rate if it would be used for forage production. Samaru

and Sokoto soils supported plants with greater leaf retention. The suggestions were that they would be appropriate for forage production, with applications of 180 and 60 - 120 kg P_2O_5/ha, respectively.

Nitrogen (N), phosphorus (P), potassium (K) and magnesium (Mg) concentrations reached maximum levels at 180 kg P_2O_5/ha whereas between 120 and 180 kg P_2O_5/ha was required to bring the uptake of these nutrients to the highest levels. N, P, K, Ca and Mg concentrations as obtained in this study were above the minimum required for the maintenance of ruminant liveweight. The conclusions were that Verano seed production would be best in the Jos area while the plant could be grown for forage in the Samaru and Sokoto environments. Extensive field trials would be necessary to validate the results of this glasshouse experiment.

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