GENETIC ASSESSMENT OF PERENNIAL *SESBANIA* SPECIES IN AGROFORESTRY SYSTEMS

by

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A thesis submitted to the University of Edinburgh for the degree of

Doctor of Philosophy.
1994.

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ACKNOWLEDGEMENTS

A large number of people have made this programme possible, and to these I wish to express my sincere appreciation. First of all, I am greatly indebted to my supervisors Dr. D.C. Malcolm, Dr. R.R.B. Leakey and Dr. J. McP Dick for their excellent supervision, encouragement and for the large amount of time they spent correcting and commenting on my writing. I am also grateful to Dr. F. Owino, for his guidance and help in the first two years of the study. I would like to express my sincere gratitude to Dr. Eric Rusten of the Ford Foundation, Nairobi for his effort in securing the funding that enabled me to undertake the programme.

Special thanks go to the technical staff of the Forest department, University of Edinburgh, the Institute of Terrestrial Ecology (ITE), Bush Estate, and the International Centre for Research in Agroforestry (ICRAF) at Maseno and Machakos field stations, who helped me in my field work. Many thanks go to the staff and postgraduates at ITE, ICRAF and Institute of Ecology and Resource Management (IERM), University of Edinburgh, who have made the last 3.3 years such a valuable experience.

I would like to thank the Department of Crop Science, University of Nairobi, Department of Forestry, Moi University at Lessos, for the provision of some equipment used in the study, Kenya Woodfuel Development Programme (KWDP) at Kisii for permission to use their site.

This work was carried out with financial support from Ford Foundation, Nairobi, British council, Nairobi and the International Centre for Research in Agroforestry, Nairobi to whom I am very grateful.

Finally, my deepest appreciation and profound gratitude to my mother Caroline Bagala Kyabwe Oduol for her encouragement throughout my life and for her constant communication that gave me the inspiration and enlightenment to finish this immense task. **"It was a matter of life and death."**

MEMORIAL

In loving memory of my father James Esau Ochieng Oduol.

DEDICATION

To my mother, with love, respect and appreciation.

ABSTRACT.

Key words: Agroforestry, biomass, selection, genetics, multipurpose trees, light, stomatal conductance, nutrients.

The aim of the study was to establish whether clones could be selected for single or multipurpose products by conducting studies involving the evaluation of phenotypic characteristics and their influence on biomass production using Sesbania sesban (L.) provenances and clones.

The study initially examined the extent of genetic variation in phenotypic characteristics and biomass production in S. sesban provenances at Maseno, in Kenya. The study showed that significant differences existed between provenances and that it was possible to select outstanding individual trees in the best provenances for testing on different sites as clones. Significant allometric relationships were established between dry mass, and tree dimensions for the different tree components. Stem diameter at 0.15 m provided a reliable estimation of biomass in the provenances. The provenance repeatabilities (0.31-0.41) and potential genetic gain (40%) highlight the expected returns due to selection.

Plant growth analysis results helped in understanding the growth of young S. sesban clones in the field at Maseno, particularly the distribution of biomass into components. Clones performed similarly in the initial stages of growth and differences were only detected when competition set in. Clone net assimilation ratios were found to be sensitive to moisture stress. Leaf area was found to be the major determinant of clonal differences and was a good indicator of plant growth and productivity.

The results from the genetic variation and productivity study of S. sesban clones grown at Maseno, Kisii and Machakos revealed a differential response of the clones to different environmental conditions. There was genotype by environment interaction in clone heights, biomass production was higher at Maseno and Kisii than Machakos. S. sesban clones differed greatly in absolute biomass but showed similar percentage distribution of dry mass among the different tree components with branches being a major preferred sink. Stem diameter at 0.15 m was more

reliable in predicting biomass for the clone components (R^2 = 0.65-0.74). Different crown forms in S. sesban clones were due to differences in branch lengths and angles. The broad sense-heritabilities of these traits indicate that the genetic components of variance were large enough to permit effective selection for stem diameter, leaf area and crown form.

The results of the predictive test study showed that it is possible to use juvenile physiological growth traits such as percent bud activity following decapitation to improve the selection criteria for genotypes with desirable morphological attributes.

The results from the light interception and stomatal conductance study established those S. sesban clones which captured the most light, regulated water loss and were most productive.

The thesis has demonstrated that; (i) it is possible to select and develop highly productive single-purpose clones for some sites and (ii) it is possible to combine into a single clone, superiority for a product and an environmental service. The results of this thesis have highlighted the potential use of both morphological and physiological criteria for selecting clones of S. sesban with high productivity for agroforestry.

CHAPTER 1

GENERAL INTRODUCTION AND AIMS OF STUDY.

1.1. THE PROBLEM.

The world's forests are declining at a faster rate than replanting them. Forest ecosystems provide both direct and indirect benefits to man. The direct benefits include the provision of several industrial products, wood for construction, food and fuelwood. Indirect benefits on the other hand are the maintenance of soil structure and fertility, prevention of soil erosion and floods (Burley 1987, IUCN 1987). Forest ecosystems also play a vital ecological role, in that they absorb carbon dioxide (CO_2) and release oxygen (O_2) through photosynthesis and thus influence the level of greenhouse gases (NAS 1991).

As the worlds population grows, so does the demand for wood products. The major causes of forest decline are due to the expansion of the agricultural base, in order to produce food to feed the ever increasing human population, provide poles and fuelwood and create settlements through land clearance practices (slash and burn). Man-made hazards such as environmental pollution and climatic changes also contribute to forest destruction (NAS 1991). As a result of deforestation for wood products, these processes have led to severe soil deterioration, erosion and desertification in the tropics (UNESCO/UNEP/FAO 1979).

The removal of natural woody vegetation has accounted for the loss of two billion hectares (ha) of the tropical forests and it is estimated that about 11 million ha, are being lost annually (Wood et al. 1982). The annual wood production from the forest is about 1.5 billion m^3, of which 50% is used for fuel for heating and cooking. This percentage is high in the developing tropics and in Kenya and Nepal for example, is about 71% and 94% respectively (Postel and Heise 1988). With these high demands for wood energy, it is estimated that by the year 2000 about 3 billion

people will face fuelwood shortage (FAO 1985).

The continuous loss of forests on which the human race depends, is very devastating; particularly the potential use for many of the species has not yet been realized. The loss of this genetic diversity, essential for natural evolution and adaptation to environmental change needs to be stopped. In order to reduce the pressure on forest land, it is necessary to explore, identify and assess fast growing tree species with good survival and other commercially important non-timber products that can be used in afforestation and agroforestry. The desired species must meet the farmer's demands and be able to provide the highest level of products and services within a short time.

Natural diversity has been exploited by farmers and scientists to obtain specialised germplasm of crops, animals and trees for modern land use systems. Many current land use systems have been monocultures of cash crops (with high commercial objectives) for both agriculture and forestry. These land use systems have been found to be non-sustainable in the tropics, and have led to serious environmental degradation (NAS 1980). Consequently attempts are now being made to provide rational alternatives for land use which should be economically, environmentally and socially acceptable. Agroforestry, the combination of agricultural crops, animals and tree species raised sequentially or in combination is receiving much attention in most of the developing countries. Agroforestry can rehabilitate degraded land, assist the conservation of species (plant and animal), protect soil and water resources, and also provide the wood income requirements of the people (ICRAF 1982).

The demand for fuelwood has been one of the major causes of deforestation in developing countries (NAS 1980), especially in the dry tropics where trees are the major source of energy. Clear and practical methods to reverse this situation are not yet available. However it is clear that the use of MPT's in agroforestry systems could be highly beneficial.

Research on multipurpose trees (MPTs) has gained prominence due to the ever increasing demand for food and wood products (NAS 1979). Over 2000 species

have been identified for use in agroforestry (Burley and Carlowitz 1984), but hardly any of these has been fully tested to know their real potential in terms of genetic diversity/variation, growth and survival. Similarly, management strategies to optimize their production in plantations or in combination with other crops are not well understood. Thus there is need for exploration, collection, conservation and selection of these species.

Quite often leguminous trees have shown the potential of increasing yield of agricultural crops. They also provide shelter, fuelwood, poles, stakes, fodder, food and nitrogen. Consequently they are being developed for mixed cropping systems (NAS 1979). Sesbania species are among the leguminous trees which are currently receiving attention in agroforestry. They are fast growing, produce high biomass yields and flower early. Consequently relatively rapid genetic progress can be made by breeding and recurrent selection. Sesbania species have wide genetic diversity within their natural populations. This allows their adaptability to a wide range of habitats and their responsiveness to environmental change (Gillet 1963).

1.2. CHOICE OF SPECIES FOR STUDY.

The genus Sesbania consists of about 60 species, which occur in both tropical and subtropical regions. It belongs to the subfamily Papilionoideae, in the family Leguminosae (Evans 1989).

The genus contains two subgenera of economic potential, namely Sesbania and Agati. The sub genera Sesbania is spread world wide and contains species which are used as green manures, for fuelwood and forages (e.g. S. sesban). Thulin (1983) describes S. sesban as follows:

> "S. sesban (L.) Merr. (1912). Shrub or small tree 1-7 m tall; young stems usually +/- pubescent. Leaf-rachis 3-12 cm long including a short petiole. Leaflets 20-50, linear oblong, up to 23 x 5 mm, glabrous or almost so above, +/- pubescent beneath, at least at the margins. Racemes 4-20 flowered up to 15 cm long including a

penducle of up to 4 cm. Calyx c. 5 mm long; lobes broad, acuminate, 0.5-1 mm long. Blade of standard 13-14 x 18-21 mm, cordate at the base; claw 4 mm long; Style glabrous, c. 5 mm long. Pod up to 20(-30) x 0.4 cm, thicker at the centre than at the margin, 20-40 seeded. var. nubica: +/- pubescent, at least at the leaf bases. Filament-sheath 9-13 mm long. Pod 2-3.5 mm wide and with septa between the seeds 4-6 mm apart."

The ecological range of this species is diverse. It is native to Asia (NAS 1980), Africa which represents its centre of diversity (Gillet 1963), Hawaii (Char 1983) and Australia (Burbidge 1965); growing naturally in river valleys, beside swamps, lakes and streams or planted in cropland (Fig. 1.1)

Sesbania sesban was selected for this study because of:- (i) its wide range adaptability, (ii) its ability to provide multiple products and services in a short time, (iii) compatibility with most agricultural crops and (iv) its general acceptability by the farmers.

1.3. PLANT GROWTH AND PRODUCTIVITY.

Biological productivity is a complex interaction between the environment and the genetic constitution of the plant. The anatomical, morphological and physiological (growth and reproduction) diversity which exist in plants, at the genus or species level, is a result of the combination of environmental factors (Rosen 1967). Apart from these environmental factors, both climatic and edaphic there are genetic factors that determine biological productivity. These include, (i) functional or process components, (ii) structural and time components and (iii) the interactions between them (Farmer 1976). Assessment of plant productivity is a very complex process due to variation in phases of growth but can be done by the summation method. This method involves actual measurement of biomass increment over time; as well as the use of allometric relationships based on growth attributes such as diameter, height and yield (Ogawa 1978).

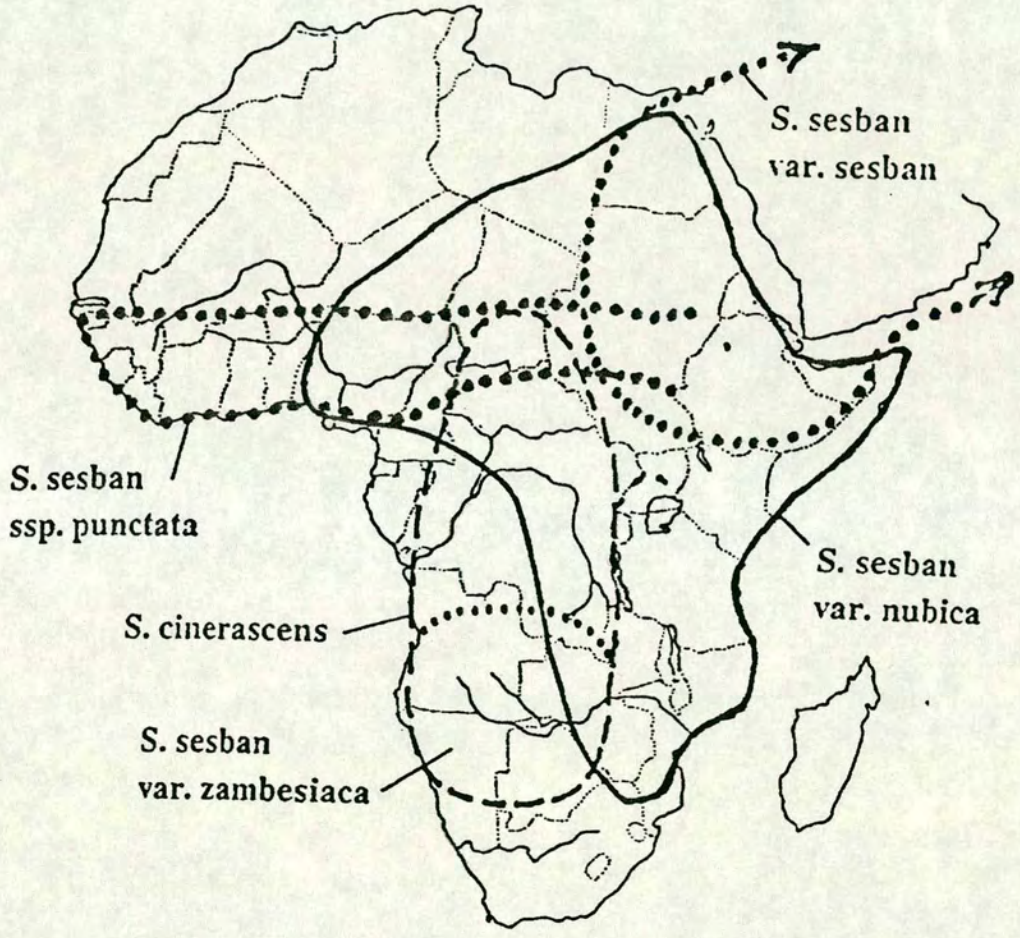

Fig. 1.1. Approximate ranges of some perennial Sesbania species in Africa (after Gillett, 1963)

The rankings of trees with respect to performance changes at different stages of growth. So it becomes necessary to understand tree growth at different phases of development and how it is affected by the local environment. This information can form a basis for predicting productivity and growth limits; as well as for planning of management strategies for the production of different products and services in agroforestry. The variation in shape of the growth curves indicates the relative variation between sites. It allows the investigation of variation to be made earlier, so that future performance can be predicted. However, it is only useful if the productive trees maintain their dominance throughout the rotation (Eis 1986, Howland et al. 1978).

1.4. Plant factors that determine variation, growth and productivity.

Plant growth and productivity varies among tree species. The genetic variation in growth rate and stem volume production has been exploited in tree breeding and selection programmes in order to enhance yield (Dickman and Stuart 1983). Genetic variation and productivity in trees has been demonstrated in poplar clones, where through hybridization, selection and cloning, yields have been enhanced under intensive cultivation from 13 dry Mg ha^{-1} $year^{-1}$ to 27.5 dry Mg ha^{-1} $year^{-1}$ (Heilmann and Stettler 1985).

1.4.1. Metabolic factors.

Factors such as the CO_2 uptake by the leaves for photosynthesis and the dark respiration of plant parts influence plant productivity (Coombs et al 1985). Genetic differences in net photosynthesis and photosynthetic related traits have been demonstrated in trees (Kozlowski and Keller 1966). These variations over time account for the differences in plant productivity (Isebrands and Michael 1986). Inter and intra-specific differences in stomatal conductance have also been used in the selection of high yielding poplar clones (Ceulemans et al. 1978).

1.4.2. Leaf morphology and growth.

Morphological variables such as the number of leaves per plant and plant height affect biomass production. The principal contributors to tree productivity are the photosynthetic tissue (leaf area) and the efficiency of that tissue (leaf efficiency), (Beadle 1987). Leaf area index (LAI) is sometimes used to quantify the photosynthetic area of crops or trees in ecosystems (Beadle 1987). LAI is defined as the ratio of the total leaf surface area to land surface area (Larson and Isebrands 1972). Total leaf surface area is a major determinant of plant productivity, but very difficult to measure under field conditions. Linear relationships exist between gross plant productivity and leaf area duration (Evans 1972). The physiological components known to determine leaf area include the rates of individual leaf growth and production and the duration of this growth. Strong correlations have been reported between stem volume and leaf area (Ridge et al. 1986). McIntosh (1985), for example, reports that basal area at breast height is strongly related to leaf area in spruce. Evidence in poplar clones with regard to correlations between leaf growth rate, leaf size and stem volume suggest that the inheritance of large leaves found in hybrids, may be responsible for their superiority in production (Ceulemans et al. 1984). The correlation between stem volume and leaf growth rate indicates that leaf growth rate may be a useful criterion for selecting high yielding MPTs in agroforestry. Many leaf characteristics are under genetic control (Loomis et al. 1971, Parkhurst and Loucks 1972 and Ceulemans et al. 1984). Thus, it is necessary to examine the relationship between aspects of leaf growth and tree productivity in agroforestry. Several studies have reported strong relationships between tree productivity and leaf area, for example, Zavitkoviski et al. (1974), Isebrands and Nelson (1982), Larson and Isebrands (1972) and Larson et al. (1976), report that high biomass productivity in poplars is related to the large number of leaves with large leaf areas. Telfer (1969) on the other hand, reports that diameter at ground-level is highly correlated in 22

deciduous (tree/shrub) species with both total above ground biomass and to leaf weights. Larson and Isebrands (1972), found strong relations between leaf lamina length, area and dry weight and total plant dry weights. In the same, the yields per unit leaf area increased with increasing leaf area. Thus in a non-destructive way it is feasible to measure leaf area index in the field and correlate it to yield, by using leaf length as an estimate of leaf area.

1.4.3. Allometric factors.

Plant biomass is the mass of plant material developed above and below ground per unit area per unit time (Roberts et al. 1986). It indicates the productivity of a species at a given site.

Dry matter partitioning in plants is very homeostatic in nature and the exact stage of growth when the patterns are formed is not exactly known (Brouwer, 1983). The allocation of photosynthates to above and below-ground components varies throughout the growth period and it can take time before stable ratios are established in trees.

The number, size, depth, orientation and arrangement of roots differs among trees. The differences in morphology, developmental pattern and the sink strength of roots play a key role in the capture of below ground resources, with eventual impact in shoot productivity. Thus survival and adaptation of tree species on different sites can be evaluated through their different biomass productivity. The ratio of shoot to root dry weight (S:R) for a plant is commonly used in physiological and ecological studies as an index of growth pattern (Shepherd et al. 1984).

For shrubs information on and practical methods for estimating biomass is scanty. Allometric factors, such as leaf weight (and area) ratio, dry mass partitioning, specific leaf area, plant heights and diameters and the plasticity of the sink size have been used to study plant productivity. Physiologically, height is an expression of vigour and survival indicates adaptation to the growing conditions of the test location (Morgenstern and Mullin 1990). Height and diameters have been used for

a long time to study tree growth (Eis 1986, Onaka 1950), crown and stem development (Inose 1979, Turnbull 1958) and branch increment (Vatkovskii and Nokivo 1973).

Reliable methods of assessing biomass and the growth rates of MPTs are essential, in order to estimate their total net primary production in agroforestry systems. In forest trees, biomass studies have been done mostly by assessing their productivity and nutrient cycling (Prescott et al. 1989). Several authors (e.g. Whittaker and Marks 1975, Causton 1985, Brown 1976, Freedman 1983, Clough and Scott 1989, Williams and Maclenahen 1984) have reported tree biomass, as estimated by the relationship between weight and some measurable dimension, such as height, diameter, leaf area, leaf weight, *etc.* Non-destructive methods for estimating plant biomass such as these are desirable. Such a relationship should be able to predict the component yields (e.g. stem, leaf, twigs *etc.*) at the different stages of growth, for example at final harvest.

1.4.4. Developmental factors.

The developmental processes of cell division and differentiation, ontogenetic status, as well as the position of the active meristems that control the shoot design and canopy architecture are currently being studied (Korner 1991). The location and activity of meristems determine the growth rate as well as plant morphology. The rate of cell production and maturation generally determines the rate of growth in grasses and forages (Pollock & Eagle 1988). However, there is hardly any information on how these processes operate in trees, under field conditions. Meristematic activity is under strong genetic control and normally is stimulated ontogenetically and by the environment (Kuppers 1985). While studying carbon balance in woody species Kuppers (1985) found Fagus sylvatica L. to be very competitive due to its horizontal branching angles, differential bud activity, leaf positioning and internode lengths.

1.4.5. Variation in structural components.

Knowledge of crown characteristics and the physiology of trees is needed to provide silviculturalists and geneticists with the necessary morphological and physiological criteria for improving biomass production in MPTs.

Crown architecture in trees is composed of the total leaf area, leaf area distribution in the crown, leaf and branch morphology, as well as their orientations. It plays an important role in plant productivity, as it influences the interception of solar radiation and its conversion to biomass (Monteith 1977 and Wang 1988). Crown development depends on the production of apices and branch growth. Branch characteristics such as angle, length, size, number and their distribution determines the crown architecture. Leaf area and the display of leaf area maybe the single most important variable determining stand productivity (Cannell et al. 1987).

The growth form of a tree is determined by branching habit and crown form (Ladipo 1981, Leakey 1986). Rates of height growth and branch production and evolution of crown structure were found to be significantly different in T. scleroxylon clones (Leakey and Ladipo 1987) and to affect tree productivity (Pollard and Wareing 1968, Nelson et al. 1981). Ladipo 1981, determined the branching habit of T. scleroxylon and found that branching was primarily a function of apical dominance and apical control. He showed that early branching studies in small plants could be used to predict the mature performance of this species. Ladipo (1981) reported that high yielding trees had fewer branches per unit of mainstem, while poor field performance was exhibited by those trees which had a high branching frequency. The branching habit is under genetic control in populus (Ying and Bagley 1976), T. scleroxylon (Leakey 1986). The heritability of crown form, shape, branch angle and branchiness has been quantified in populus (FAO 1958, Jankiewicz and Stecki 1976). Sesbania species exhibit morphological features of forking, multistemming and stem crookedness at an early age. It is likely that these can probably be selected against, in order to improve their quality and productivity.

1.4.6. Radiation absorption and dry matter production.

Successful plant growth and reproduction depends on the plant's ability to capture resources from its environment and to compete with its neighbours. Competition between trees and crops for light, water and nutrients is one of the most important limitations in agroforestry (Jackson 1983). Farmers in the tropics have traditionally been managing different plant species (trees/crops) on small plots to maximize productivity and the introduction of trees in crop fields may have both beneficial and negative effects. The variability in canopy architecture among plant genotypes could influence the efficiency of conversion of solar energy into biomass production (Cannell et al. 1988). Studies by Singh et al. 1989, noted significant reductions in Cowpea/Sorghum dry matter yields of between 70-80% when grown in Leucaena leucocephala alleys in the semi arid regions of India. This was attributed to competition for moisture by trees and the shading (30-85%) of the crops in the alleys. Thus, in order to estimate the potential productivity of crops, whether growing alone or in mixtures, it is necessary to know how much photosynthetically active radiation (PAR) is intercepted (Jackson 1983). This is because the amount of biomass produced by a plant (when there are no limits of water and nutrients) is determined by the amount of radiant energy that its foliage can intercept (Linder 1985 and Monteith et al. 1991). The stomata play a major role by controlling the balance between water loss and carbon gain, since if they are closed due to water stress the plant is unable to photosynthesize (Beadle et al. 1987). Effects of water stress on photosynthesis varies among cultivars, but has not been studied in detail in tree species (Tschaplinski and Blake 1989). Studies involving water relations and stomatal resistance are therefore important to the understanding of biomass production in trees (Pezeshki et al. 1982). Currently there is no information on the genetic variation on radiation interception and stomatal conductance in Sesbania species. Studies of canopy dynamics with respect to light interception and water use are an indirect way of evaluating the productivity of tree species for agroforestry.

Total area of leaves and their spatial distribution within the tree crowns are considered to be the two most important aspects influencing light interception with eventual increase in plant productivity (Nobel and Long 1987). Studies by Monteith (1977), Cannell et al. (1987) and Wang (1988), found that accumulated dry matter in trees was linearly related to accumulated intercepted radiation, and that light interception depends on the leaf area index of the canopy structure. Ladipo et al. (1984) looked at clonal variation in rates of photosynthesis in T. scleroxylon and found a relationship with productivity, if respiration losses were taken into account. Agronomists using leaf characteristics, leaf surface area, and light interception, have been able, through physiological studies of crop yield, to incorporate selected morphological and physiological attributes into crop improvement programmes, to maximize yield (Eastin et al. 1969). For example, the crop ideotypes described by Donald (1968), have acute branch angles, offering yield advantages as they occupy less space relative to their mass, and do not compete strongly for light with neighbouring plants of the same ideotype. Considerable efforts are being made to select for erectly branching tree species in order to minimize shading or develop new genotypes with more appropriate crown structures. Phenological studies in trees can also be important in defining canopy characteristics; e.g. Faidherbia albida sheds off its leaves during the rainy season.

Light interception studies are important in agroforestry where trees and crops are grown together as trees and crops have different light requirements. Consequently to maintain their productivity, the management and selection of trees has to be targeted at those ideotypes which can co-exist with crops by minimizing light interception.

1.4.7. Leaf nutrients.

Leguminous trees are used in tropical farming systems due to their ability to maintain soil fertility through nitrogen fixation. They also provide fuelwood, mulch and fodder (Brewbaker et al. 1982). Thus it is necessary to know the concentration

of nutrients in these tissues in order to assess their nutritional quality (Maghembe et al. 1986). Analysis of nutrient content in foliage has been used widely in forestry as a simple, reliable method of assessing nutrient availability and deficiency (Van den Driessche 1974). Studies by Hussein et al. (1990) report nitrogen (N) contents of 4.1% in Sesbania leaves, while Guttenridge (1990) quotes 3.64% N, and Galang et al. (1990) report ranges of 3.79-4.96% N and 0.29-0.37% P. Onim et al. (1987) on the other hand, reports 4.16% N and Rao et al. (1989) report 3.9% N in leaves, 0.4 % N in stems. All these studies with Sesbania report high percentages of foliar nitrogen, showing the potential of this species for mulch and fodder. The amount of foliar and stem nutrients will enable the assessment of how much nutrients are being withdrawn or recycled within the system and how efficiently the available nutrients are being utilised for biomass production.

1.5. ENVIRONMENTAL FACTORS THAT AFFECT PLANT GROWTH AND PRODUCTIVITY.

The increasing pressure on land for growing food crops has constantly changed the availability of sites to marginal land for forestry in the tropics. This creates a need to integrate trees and agriculture on the same piece of land. Trees like all other living organisms respond to the laws of limiting factors, and will not perform well on resource deficient sites. Thus the understanding of climatic, edaphic and biotic effects on trees and their interactions is very crucial if productivity is to be improved or even maintained. Knowledge of the effects of climate and soils on tree growth are needed for productivity prediction as well as for assessing plant limits (Malcolm 1970). The improvement of soil factors through fertilization has enabled the growth of trees in areas where afforestation was not originally possible.

Soil factors that affect tree growth include:-

(i) Parent geological material which determines the soil drainage and the nutrient status of the soils.

(ii) Soil moisture, which influences the nutrient cycling, rooting capacity and the

rates of many soil processes; such as organic matter breakdown, nutrient release and water absorption by the roots.

(iii) Soil depth and rooting depth are related to productivity as they determine the soil volume available to tree roots for water, nutrient and oxygen supply.

Climatic factors such as the amount of rainfall and temperature affect tree growth (Kozlowski 1971), but some of these constraints can be overcome through the selection and development of specific adapted genotypes that can survive in particular silvicultural environments (Zobel 1957, Bey 1974, Saeki and Okada 1971, Heth and Kramer 1975).

1.6. TREE IMPROVEMENT.

Tree improvement is the combination of silvicultural operations and tree breeding skills in order to grow the most valuable wood products, cheaply in the shortest time possible (Zobel and Talbert 1984). To ensure maximum yield, tree improvement must involve intensive forest management practices, such as site preparation or fertilization and the use of genetically superior trees. Substantial improvement in yields and quality of forest trees has been achieved through provenance selection and breeding (Zobel and Talbert 1984).

The basic principles and practices for tree improvement are well documented by Wright (1976) and Zobel and Talbert (1984). The aim is to select a superior phenotype and evaluate its breeding potential through either clonal or progeny tests on representative sites. The elite trees are then mass propagated for afforestation purposes.

The lack of basic information on tree growth has been one of the major constraints to tree improvement (Wright 1981 and Namkoong 1980). This has been due to the longevity of trees and the prevalence of out-breeding (Leakey 1987). The recent global commitment to increased forest productivity to meet wood shortages has stimulated research interest on trees (Daniel 1984). The development of early selection methods has been very useful in some timber species while ineffective

in others (Eldridge 1978, Lambeth 1979, Waxler and Van Buijtenen 1981 and Gibson et al. 1983). Potentially these techniques could be useful for MPTs as they could shorten the period of evaluation and so hasten yields improvements. Tree improvement is complex as it involves selection for several traits. For example, the selection of Eucalyptus spp. for pulp production in Brazil involves several traits (Zobel 1993). Special selection in MPTs is required to match the niche, for example a tree is expected to be grown together with agricultural crops and/or animals.

Significant improvement has been achieved in Leucaena leucocephala wood volume (20% to 30%) through simple selection as reported by Namkoong et al. (1980). However more rapid and greater improvements in MPTs can be achieved by vegetative propagation and clonal selection (Libby 1981, Leakey 1987). Multipurpose trees provide a wide range of products, such as firewood, timber, poles, fodder, fibre, posts and mulch as well as improving human welfare, alleviating energy problems and conserving the environment (Turnbull 1984). The urgent need to improve the quality of multiple products and benefits in MPTs has been highlighted by Venkatesh (1988), Burley (1980), Owino (1992), Simmons (1992) and Chuntanaparb and MacDicken (1992). Strategies of tree improvement revolve around the identification of desired ideotype (Huxley 1985). Some of the traits are described by Rockwood (1984) and Venkatesh (1988). For biomass yield and quality improvement; for example a good timber tree must be tall and erect with a cylindrical stem, without forks, flutes or buttresses and with a minimum taper; while shrubby ideotypes may be preferred for fuelwood. Narrow-crown ideotypes of light density are less competitive and can be planted with crops on borders or in alleys. Such trees allow more light through the crown to reach the intercrop in agroforestry. Broad crown ideotypes may be preferred for windbreaks, fodder, flowers, fruits and seed production. Trees with deep root systems which avoid near-surface competition with agricultural crops are preferred in agroforestry systems.

1.7. ROLE OF VEGETATIVE PROPAGATION.

Asexual or vegetative propagation (cloning) of trees is a useful tool in traditional tree improvement for the production of clonal seed orchards (Libby 1986, Faulkner 1975). More recently these methods have been used, to mass produce superior individuals for clonal forestry/agroforestry. Clonal testing enables the detection at an early age of those clones which perform best, and can help foresters develop early testing methods for forest trees (Libby 1964).
The advantages of vegetative propagation are numerous and are described by Libby (1985), Abdullar (1987), Leakey (1985, 1991).

Vegetative propagation is thus a tool for tree improvement and can be used to:-

i) multiply without altering gene combinations for superior phenotypes from the wild or in plantations for testing on different sites.
ii) capture both additive and non-additive genetic variation in a population.
iii) produce genetically uniform parents which can be used in for mass seed production of selected progenies.
iv) maintain selected clones in 'gene banks' or clonal orchards, where gene recombination can be done through controlled pollination.
v) obtain improved genotypes from hybridization that can be mass produced for scientific and commercial purposes.
vi) obtain good information on genetic x environment interaction (gxe) as well as genetic and environmental covariance between characteristics.
vii) manage the stockplants more easily than the complex management of seed orchards.
viii) producing particular clones for specific sites, for example dry areas, and clones of particular structure and form (ideotypes), to be used to

produce particular products in agroforestry.

ix) screening a large number of clones through multi-trait selection for agroforestry.

The disadvantages of vegetative propagation include:-

i) an increase in risk of pest and disease attack within monoclonal plantations.

ii) a narrowing of the genetic base of the material under investigation through selection of only a few outstanding clones (genotypes).

iii) the risk of producing site specific clones, this calls for a clonal testing over a wide range of environments.

iv) the need for continuous selection of clones in order to achieve genetic improvement and avoid a plateu effect.

Through the selection of desired clones and phenotypes the inherent genetic differences can be observed and measured, thus eventually identifying the desired ideotypes; which will produce different products and benefits in agroforestry.

1.8. METHODS OF VEGETATIVE PROPAGATION.

Several types of vegetative propagation methods exist and they are covered in detail by Hartmann and Kester (1983). In forestry the most commonly used techniques are the rooting of cuttings for operational plantings (Libby 1974, Leakey 1987) and grafting is used to multiply selected genotypes (Dimpflimeier 1954, Bouvarel 1960) and for preserving trees in clonal banks or for seed orchards (Zobel and Talbert 1984). The use of micropropagation techniques is now receiving much attention due to its realized potential for high multiplication rates (McKeand 1981). Most research programmes are trying to understand various uses, values and the problems associated with different methods of vegetative propagation.

Comparisons of growth and form characters between seedlings and vegetative propagules have been reported in douglas fir (Copes 1977), spruce (Roulund 1978, Birot and Nepveu 1979) and radiata pine (Libby and Hood 1976).

1.8.1. Grafting.

Methods of grafting are numerous and are covered fully in several text books (Hartmann and Kester 1983). Grafting has been very successful in temperate species such as oaks (Farmer 1981), pines (Dorman 1976) and is now being attempted in tropical MPTs (Markhamia lutea, Sesbania sesban, Calliandra callothyrsus, Grevillea robusta) by Owino (1992). One of the biggest constraints to tree improvement by grafting is the incompatibility between the stock and the scion (Hong 1975). Incompatibility is due to the relatedness of the materials to be grafted and can easily lead to losses of the selected genotypes, this has been noted in Douglas fir (Duffield and Wheat 1964) and loblolly pine (Zobel and Talbert 1984).

1.8.2. Rooted cuttings.

The rooting of cuttings is one of the most popular methods of vegetative propagation and has been very successful in several tree species (Libby 1977), such as conifers (Cameron 1968) and Eucalyptus spp. (Francelet 1963). Progress in rooting of tropical hardwood species and MPTs has been promising (Rauter 1979, Leakey 1987, 1990, Oduol and Akunda 1988). Physiological, ontogenetic and chronological ageing are some of the constraints to successful rooting of cuttings. Rooting is easy in young trees but very difficult in old trees (Leakey 1983, 1985, Talbert et al. 1982). This is a major hindrance. Trees need to grow to maturity to clearly identify their genetic potential, but by then it has become very difficulty to root them. Secondly the use of old trees can lead to plagiotropic growth (Zobel and Talbert 1984). The variability in rooting dictates the number of genotypes available for planting (Shelbourne and Thulin 1974, Kleinschmit and

Schmidt 1977). However methods are being perfected through research (Leakey 1983, Leakey and Mohammed 1985, Leakey and Longman 1988, Leakey et al. 1982; 1990) in order to ensure successful rooting of trees. For example, it has been found that leaf area, cutting length, carbon and water balance in the cuttings and stock plant management are important factors in rooting (Leakey and Coutts 1989, Ladipo 1981). Leakey et al. 1994 have extensively studied the factors and processes that affect rooting and suggest various ways of improving rooting in tropical trees.

1.8.3. Air layering.

This is a method where roots are generated on an intact plant, such as a branch, by girdling applying hormone and wrapping the treated area in moist media (Kadambi and Dabral 1954). The advantage of air layering is that it produces propagules that can be used directly in seed orchard establishment thus avoiding graft incompatibility (Barnes 1969).

1.8.4. Tissue culture.

This is one of the latest vegetative propagation methods which is still undergoing very intensive investigations but has great potential (Zobel 1977, Sommer and Brown 1979 and Bonga 1980). Tissue culture (in vitro propagation) depends on the induction of growth and differentiation in tissues from woody plants and the regeneration of true-to-type viable plants in selected genotypes (Chen and Ahuja 1993). The plantlets produced in vitro have to be from mature older previously tested and proven trees (Zobel 1981). Like in rooted cuttings, juvenile material is more responsive to in vitro propagation than material from mature trees due to lack of organogenesis (Bonga 1983). Somaclonal variation in plantlets (Larkin and Scowcroft 1981) and difficulties associated with moving the plantlets from the environment in which they were formed to adjust under field conditions are some

of the problems in vitro propagation. This is a very expensive method but methodologies to make it cost effective are being sorted out (Bonga and Darzan 1987).

1.9. AIM OF THESIS.

The aim of the thesis is to establish whether clones could be selected for single or multipurpose products. A series of studies have been undertaken involving the evaluation of phenotypic characteristics and their influence on biomass production in Sesbania sesban (L.) Merr. using provenances and clones. In addition, early growth attributes have been used to develop selection criteria which could be used to predict performance in agroforestry.

The general objectives of the present study were:

a) to examine selection strategies for MPTs notably Sesbania with the aim of increasing their productivity in agroforestry.
b) to select genetically superior clones of S. sesban from existing provenance trials to (i) increase productivity of fuelwood/poles/ fodder and (ii) enhance soil fertility in agroforestry.
c) to develop a method of predicting superior genotypes at an early age which could be used under various agroforestry systems.
d) to develop a long term breeding programme for the selected S. sesban clones, in order to enhance their productivity, conserve and sustain their genetic resources.

These objectives were achieved by:-

i) determination of genetic variation in Sesbania sesban provenances (Chapter 3).
ii) determination of genetic variation and productivity of Sesbania sesban clones selected from provenances for fuelwood, pole and leaf production (Chapter 4).

iii) determination of growth characteristics and form which could be used as indicators of potential productivity for Sesbania sesban clones selected for fuelwood, poles and leaf production (Chapter 5).

iv) establishment of a predictive test for branching in Sesbania sesban clones (Chapter 6).

v) determination whether biomass production in Sesbania sesban clones is directly related to either: (a) light interception or (b) stomatal conductance (Chapter 7).

Materials and methods are described in Chapter 2, while Chapters 3, 4, 5, 6 and 7 commence with a review of relevant literature, experimental designs, results and discussion. Appendix section contains data sets for the experiments.

CHAPTER 2

GENERAL MATERIALS AND METHODS.

2.1. INTRODUCTION.

The experimental sites were located in the districts of Kisumu, Kisii and Machakos in Kenya (Figure 2.1). The sites were chosen to represent areas of land use systems with different climatic conditions. Maseno and Kisii are located in the humid highland zone, while Machakos is located at the interface of the sub-humid and semi-arid zones.

2.2. EXPERIMENTAL SITES.

2.2.1. Maseno site.

Maseno site is located in Kisumu district (Western Kenya) in the bimodal rainfall zone of Kenya (Fig. 2.1). The site is located at Latitude 0° 0° and Longitude 34° 35' East at an altitude of 1520 m above sea level. The site is characterised by a long rainfall season from March/April to June/July and a short rainfall season from September to November, thus giving it a double cropping pattern. The average rainfall is 1750 mm and mean annual temperature 20°C (Jaetzold et al. 1982). The experimental plots were located at KEFRI/KARI/ICRAF field station.

The soils are deep ferralsols and acrisols of light to medium texture, (sandy loam or finer clay) acidic with a pH range from 4.5 to 6.5 and deficient in phosphorus and nitrogen (Jaetzold et al. 1982). The natural vegetation of the area consists of Albizzia and Bridelia spp., Chlorophora excelsa and Maesopsis eminii. This has been replaced by cultivation and settlement. The area is heavily populated with small, intensively managed farms producing food crops and small livestock. Sesbania sesban is found naturally scattered on farms.

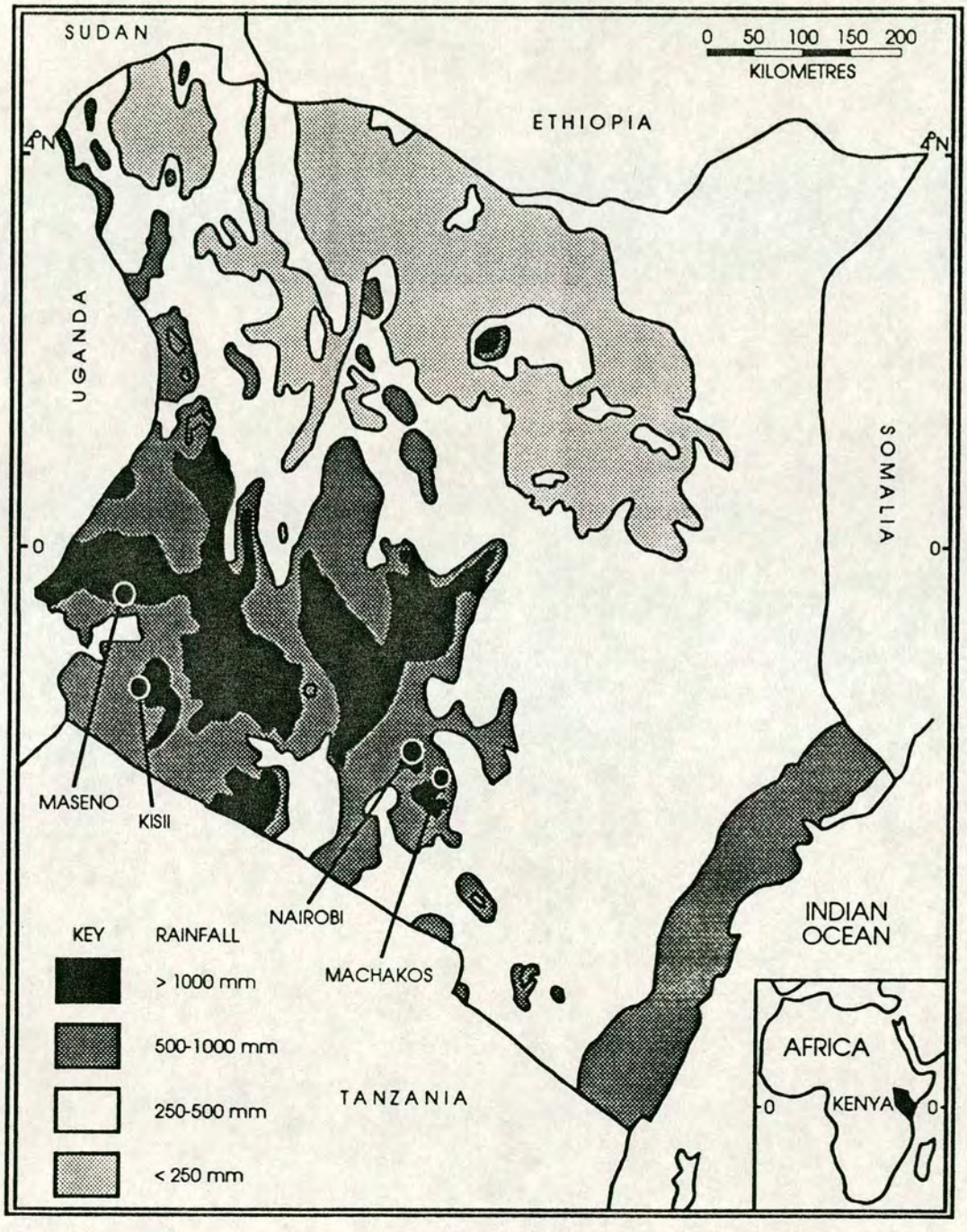

Fig. 2.1. Map of Kenya showing location of experimental sites at Maseno, Kisii and Machakos.

2.2.2. Kisii site.

This site is located in Kisii district of Kenya (South-Western) in the bimodal rainfall zone of Kenya (Fig. 2.1). The site is located at Latitude 0° 41'S and Longitude 34° 47'S at an altitude of 1740 m above sea level. The site is characterised by a bimodal rainfall pattern with long rains from March to July and short rains from September to November with a mean annual rainfall of 2060 mm and mean annual temperature of 19.3°C (Jaetzold et al. 1982). The experimental plot was located at KARI/KWDP field station.

The soils are deep well drained, dark brown reddish and friable clays, classified as nitosols, with a medium to slightly acidic and neutral pH 5.9 (Jaetzold et al. 1982). Kisii district is heavily populated with small, intensively managed farms producing food crops and small livestock. Sesbania is found scattered on farms. The area was formerly part of the tropical moist forest now settled by small scale farmers.

2.2.3. Machakos site.

Located in Machakos district (Eastern Kenya), the site is between Latitude 1° 31'S and 1° 35'S and Longitude 37° 14'E, at an altitude of 1560 m above sea level in the transition area between the sub-humid to semi-arid zones. The rainfall pattern is bimodal, with the long rains from October to January and short rains from March to May, and annual mean rainfall and temperature of 700 mm and 22°C respectively. There is considerable variability in both distribution and total amounts of rainfall received at the site. The soils are deep, well drained, dark, reddish-brown sandy clay, moderately leached, weakly acidic pH 6.0-6.5 with low to medium nutrient levels. Soils are classified as Luvisols (Kibe et al. 1982). The experimental plots were located at the ICRAF field research station.

The natural vegetation in the area is dominated by grasses such as, Eragrostis superba, Cynodon dactylon, Panicum infestum and Themeda triandra and

tree/shrubs of Commiphora africana, Acacia hockii, Lannea rivae, Acacia brevispica, Solanum incanum and Terminalia brownii.

2.3. VEGETATIVE PROPAGATION DETAILS.

In growth analysis and genotype x environment interaction studies, it is necessary to use material as uniform as possible in order to reduce variability (Evans 1972). The plants used in these trials were raised as rooted cuttings, except in the provenance trial where normal seedlings were used. The cuttings were taken from the coppicing stumps of the selected trees of an earlier provenance trial (plus trees/ortets) in the field at Maseno. The plus trees to be vegetatively propagated were selected for their apparent superiority in performance, with respect to stem, branch and leaf dry mass production from the provenance trial (details of clonal selection are described in Chapter 4). Coppicing shoots were collected from the field and brought to the nursery shade. These shoots were cut into single node cuttings of 5 cm length with a pair of leaves in the nursery. The base of the cuttings were dipped into a commercial rooting hormone (Seradix '2' powder containing active ingredient 0.8 percent IBA) to enhance and improve rooting. The cuttings were immediately planted in non-misting propagators (Leakey et al. 1990). The propagators were sprayed with benlate fungicide at the start and fortnightly in order to prevent fungal infection. After 10-14 days the rooted cuttings were transferred into polythene pots (5.5 x 18 cm) and placed in a weaning shed for seven days. The rooted cuttings were hardened in the nursery under full sunlight for another seven days. The rooted cuttings which were obtained directly from field trees (primary clones) after eight weeks from severing were planted at various sites as described in Chapter 4.

Since insufficient number of cuttings were obtained from the field, it required the coppicing shoots in the field to be allowed to regrow. Then more cuttings were collected from these coppices and raised in the nursery as stockplants so that more cuttings could be obtained. Juvenile cuttings were taken from these

stockplants in the nursery, propagated as above and were used in experiments described in Chapter 5 and 6.

2.4. LEAF AREA ESTIMATION.

Leaf area was determined by using a leaf-length measurement method. A non-destructive method for measuring S. sesban leaves was established. Such a method had been used by Wendt et al. (1967) in determining the leaf areas of Prosopis glandulosa whose leaves have the same morphological characteristics as those of S. sesban. The leaves of S. sesban are doubly pinnate with several small linear and oblong deciduous leaflets of various sizes. The leaf areas of S. sesban vary with age, therefore the sampling was done to include leaves of various ages. One hundred leaves from the trees in the field was used initially in the development of the method. The leaves were detached from the tree and the number of leaflets per leaf were counted. Then six leaflets opposite each other were selected as follows-: two leaflets from the top zone, two leaflets from the middle zone and two leaflets from the bottom zone. The length and width of these leaflets were measured along the longest and widest axis and their approximate leaf areas were determined by multiplying the length by width. The average of the six leaflets was obtained and multiplied by the total number of leaflets on the sampled leaf to give the leaf area (Appendix 2.1). The total leaf area per plant was obtained by multiplying the average leaf area by the total number of leaves on the plant. The same leaves after detachment were measured by leaf area meter (Delta T Area Meter, Delta-T Devices Ltd, Cambridge, U.K.), to establish their actual leaf areas. Leaf areas were predicted by using the regression equation $y = a \pm b(x)$ (where a and b are constants) after the data had been subjected to correlation coefficient analysis (Snedecor and Cochran 1967). The regression equation was found to be $y = 1.046 - 0.393(x)$ and a coefficient of determination $r^2=0.93$ ($P \leq 0.001$) was obtained between actual and predicted leaf area. Leaf area was expressed in square metres.

2.5. NUTRIENTS.

This study investigated soil nutrient changes from before planting and after nine months growth of Sesbania sesban clones. Foliar nutrient content changes were determined at 3 and 9 months at Maseno, Kisii and Machakos sites, in Kenya. The soil and foliar samples were analyzed at the soil laboratory in the Institute of Ecology and Resource Management, University of Edinburgh, Scotland.

2.5.1. Soil sampling.

Soil sampling was done at the beginning and at the end of the experiment. Soil samples were collected from ten representative spots in Sesbania sesban plantings at Maseno, Kisii and Machakos. The sampling depth was based on previous root observations of S. sesban where it was found that most of roots were within the 0-50 cm. Soil cores were collected from depths of 0-30 cm and 30-60 cm which were the representative zones for root exploitation. The soils were bulked to ensure a composite sample that was representative of the entire experimental landscape at each site. The soils were placed in labelled water-resistant paper bags and taken to the laboratory. The soils were completely air dried, ground by a pestle in a mortar to pass through a 2.0 mm sieve and stored.

2.5.2. Soil nutrient concentration determination.

Soils were analyzed for soil hydrogen ion activity (pH), loss on ignition (organic carbon), total phosphorus, ammonium nitrogen and nitrate-nitrogen, potassium, calcium and magnesium as per standard procedure described by Jackson (1958) and Allen et al. (1974). Soil pH was measured in water (Soil:fluid ratio 1:2; with 5 minute stirring and 20 minutes to settle) using a pH meter. Ammonium acetate (pH 7) was used to extract for K, Ca and Mg, while KCl was used to extract $N\text{-}NH_4$ and $N\text{-}N0_3$. Nitrogen and P were determined by colorimetric methods using flow

injection analysis (Tecator FIAStar 5032) and K was determined by flame emission while Mg and Ca by atomic absorption (UNICAM 919 AA Spectrometer). The results for N, P, K, Mg and Ca are expressed as mg/100 g^{-1} air dry soil. Loss on ignition was calculated from the weight lost during combustion and expressed as a percentage.

2.5.3. Foliage sampling.

Leaves were collected from the most recent mature upper-crown foliage of three and nine months old trees growing at Maseno, Kisii and Machakos. Three trees (ramets) with average representative diameters for each clone at the site were sampled. The leaves were bulked to represent each clone at each site. The leaves were oven dried at 70°C for 24 hours, ground and stored in labelled bags.

2.5.4. Foliage nutrient concentration determination.

The samples were analyzed for N, P, K, Mg and Ca, according to methods described by Allen et al. (1974). A sample of about 0.1 g of each sample was weighed to four decimal places and digested using 18 M concentrated sulphuric acid plus 100 volume concentrated hydrogen peroxide. These samples were completely digested to break down the organic matter for about 5 hours at 340°C using block digesters till a clear solution was obtained, two blank samples were included as methodology checks. The samples were allowed to cool and transferred 50 cm^3 volumetric flasks and made to volume using distilled water. Colorimetric methods were used to determine N and P contents by using flow injection analysis (Tecator FIAStar 5032) and K was determined by flame emission while Mg and Ca contents were determined by atomic absorption spectroscopy (UNICAM 919 AA Spectrometer). The results were expressed as percentages of oven dry weight.

CHAPTER 3

SESBANIA SESBAN (L.) PROVENANCE VARIATION STUDY.

3.1. AIMS.

Trees exhibit phenotypes (genotype+environmental effects) and characters of widely varying value, some desirable and others not, some of these characters will be passed on to subsequent generations. There is a lack of basic genetic information on the growth and morphological characteristics of many trees. The aim of this study is to show the extent of genetic variation that exists between Sesbania sesban provenances with respect to growth and morphological characters and identify superior, more promising phenotypes to be used in agroforestry.

3.2. INTRODUCTION.

The demand for wood products is increasing, primarily as a result of population growth. This has resulted in the rate of deforestation exceeding the replanting programmes. There is no additional productive land available for forestry and afforestation. In order to cope with the increasing demand foresters have to change from extensive to intensive forest management by using fast growing, highly productive species which optimize yield per unit area of land.

Genetic improvement of forest trees has been achieved through provenance selection (Zobel and Talbert 1984). Provenance in forestry is defined as a population of a species referred to by its locality of occurrence; the place in which any stand of (indigneous or exotic) trees is growing (Callaham 1964, Jones & Burley 1973, Wood & Burley 1976). Provenance studies compare the performance of different origins of trees when grown at one place. The information from provenance tests indicates the amount of genetic improvement which may be

expected through intensive breeding of the species and can also be used to select well-adapted and productive trees for forestry and agroforestry.

Therefore a provenance study is necessary for any species being introduced in any environment, in order to determine whether some of the provenances are better than the local population. Progress on genetically improving most multipurpose trees (MPTs) has not been as dramatic as in timber species and the selection of superior genetic stock for agroforestry still lags behind that of timber species. Most of the trees being considered for agroforestry, still exist in extensive wild populations, whose growth attributes are virtually unknown (Burley and Carlowitz 1984). These populations still offer the opportunity to study natural variation, its magnitude and patterns and their relationships with major environmental variables of likely selective significance.

Sesbania sesban is a leguminous tree of medium size 2-10 m (Evans 1989), establishes easily and has very high productivity. It is among the most prominent tree species being considered in agroforestry, due to its multiple uses and services, which include provision of small sized poles, fodder and mulch (Evans and Rotar 1987, Oduol and Akunda 1989, Onim et al. 1989 and Gutteridge 1990). The natural distribution of Sesbania species in Africa is from sea level to over 2000 m above sea level (Table 3.2), from arid to wet areas and it is widely planted as an exotic (Anon 1986). The wide altitudinal and latitudinal distribution is likely to have a considerable clinal variation resulting in provenance differences in various growth characteristics. Thus we need to know the growth and morphological characters of these provenances in order to get a fully comprehensive knowledge of the species, so that those performing best can be selected to be used in agroforestry. Sesbania species grow fast and show wide phenotypic differences in their growth characteristics (Anon 1987, Owino et al. 1994). Fast growth has been reported for S. sesban in Rwanda attaining a height of 3.86 m after 8 months of growth (Yamoah and Burleigh 1988), Rao et al. (1989) reports heights of 5.25 to 5.61 m for S. sesban with a basal diameter of 9.8 to 12.6 cm after 14 months growth. Dutt and Pathamia (1987) in India have recorded heights of 3.99, 4.35 and 6.75 m after

6, 12, and 18 months growth, Oduol and Akunda (1989) report growth rates under semi-arid conditions in Kenya of 55-73 cm month^{-1} during the wet season and 5-19 cm month^{-1} during the dry season. Gutteridge and Akkasaenji (1985) found S. sesban to be high yielding compared with 15 tree shrubs in Australia while Dutt et al. (1983) report S. sesban to be among the most productive in Thailand. Table 3.1 shows total biomass yields for S. sesban as reported by some authors.

Table 3.1. Sesbania sesban above-ground biomass yields around the world.

Location	Biomass yield	Author (s)	Remarks
California	7 t ha^{-1} yr^{-1}	Brown et al. 1987	After one year under irrigation
Hawaii	428 kg ha^{-1} day^{-1}	Evans and Rotar 1987	Accession trial (period less than a year)
India	27.7 t ha^{-1} yr^{-1}	Rao 1989	After one year
Kenya	7.5 t ha^{-1} yr^{-1}	Oduol and Akunda	After one year (semi-arid environment)
Kenya	4 t ha^{-1} yr^{-1}	Onim et al. 1989	After four years at 1500 plants ha^{-1}

Gore and Joshi (1976) in India report improvement in yields from 19 to 35.1 kg ha^{-1} day^{-1} with application of NPK fertilizer. Sesbania species have been used for fodder for a long time in indigenous farming systems in the tropics due to the high palatability and nutritive quality of their leaves (NAS 1979). The use of Sesbania species leaves as fodder has been reported in India (Patel 1966, Kareem and Sandaraj 1967); in Kenya (Dougall and Bogden 1958); Iraq (Townsend 1974); West Africa (Daliel 1937). Forage dry matter yields of 20 t ha^{-1} year^{-1} have been recorded in Hawaii (Evans and Rotar 1987), 71 t ha^{-1} year^{-1} at Jhansi, India (Gill and Patil 1983) and 9.2 t ha^{-1} year^{-1} in Kenya (Onim et al. 1989). The nutritive value of S. sesban leaves is very high compared with other forages. Several

authors (Gohl 1981, Singh et al. 1980, Robertson 1988, and Onim et al. 1989) report high crude protein values ranging from 19.4% to 26.4% S. sesban leaves. High dry matter digestibilities above 66.5% for S. sesban leaves are reported by Singh et al. (1980) while Onim et al. (1989) in their studies report dry matter digestibilities of 74.3% and crude protein of 26.0% in S. sesban leaves and for Leucaena leucocephala leaves 57.7% dry matter digestibility and 21.3% crude protein. This superior nutritive quality of Sesbania species indicate that it can be used as a protein supplement in low quality dry season forages in order to sustain livestock weight.

Applying green leaves (green manuring) is a practice of growing a suitable leguminous crop and burying it while green at the appropriate time in the soil in order to improve its productivity (Rao 1985). It is also the easiest way of supplying readily decomposable organic matter in soils. Sesbania species have been used as green manure in Asia where the fields are small and intensively managed (NAS 1979). Increase in rice yields of between 20-40% have been achieved by green manuring (Sivaraman 1958). Sesbania species can fix up to 600 kg ha^{-1} of nitrogen per year (Onim et al. 1987). However it should be noted that the advantage of green manured crop is proportional to the biomass added and its nutrient content, especially nitrogen. This emphasises the importance of proper selection of plant material with high forage production of high nutrient contents.

All these studies indicate the potential Sesbania species have to provide fodder for animal feed, woody stem for cooking fuel and construction. The ability of Sesbania species to grow on a wide range of soil conditions has expanded its utility compared to other legumes (Evans and Rotar 1987, Brewbaker 1986). Sesbania species can tolerate soil salinity, alkalinity, flooding and waterlogging as well as surviving under acidic conditions (Evans and Rotar 1987). This genus in developing countries can be grown on less favourable sites where agricultural productivity is low and can be used to rehabilitate these lands and at the same time provide high quality fodder and wood fuel. Although widely grown, the material used has never been selected. This has been due to the lack of systematic research to examine

the extent of the genetic components with respect to (phenotypic variation) productivity of this species.

A successful afforestation programme is dependent on the correct choice of species, using the best provenance of the species (Barnes et al. 1984). Therefore, in April 1990 studies were initiated to explore the genetic variation of S. sesban provenances at Maseno, Kenya with the following objectives:

(i) To determine the genetic variation in growth attributes among S. sesban provenances and how these attributes could be used to predict the productivity of this species.

(ii) To select genetically outstanding individuals to form clonal seed orchards as part of a breeding population.

3.3. MATERIALS AND METHODS.

3.3.1. Experimental site.

The provenance trial was conducted at KEFRI/KARI/ICRAF field station at Maseno, Kisumu in the bimodal rainfall zone of Kenya. Site details are described in Chapter 2. The Sesbania sesban provenance trial was located in plots on a former pasture with low shrub and bushes on a flat land with a slope less than 3%.

3.3.2. Provenance source details.

The germplasm used in this study were obtained from International Livestock Centre for Africa (ILCA) gene bank, collected from Ethiopia, Kenya and Tanzania (Otieno et al. 1987, Mengistu 1989), Nitrogen Fixing Tree Association (NFTA) Hawaii and Commonwealth Scientific and Industrial Research Organisation (CSIRO) Australia. These consisted of 75 Sesbania sesban provenances whose

details are presented in Table 3.2. The provenances are coded according to sources as follows: Australia (CS), Burundi (BR), Ethiopia (ET), Hawaii (HW), Kenya (KN), Mali (ML), Niger (NI) and Tanzania (TZ). Provenance KN60 from Kakamega in Kenya was included as a local control. The provenances will be referred to in the text by their respective code numbers.

Table 3.2. Information of the Sesbania sesban provenances.

Prov. code	ILCA number	Country	Location	Altitude (m)	Rainfall (mm)
BR74	15525	Burundi	Not available		
CS72	15077	Australia	Not availabe		
CS73	15079	Australia	Not available		
ET1	10375	Ethiopia	06°06'N 37°06'E	1200	900
ET2	10379	Ethiopia	06°25'N 37°22'E	1925	900
ET3	10521	Ethiopia	06°50'N 37°45'E	1925	1300
ET4	10639	Ethiopia	07°45'N 36°34'E	1640	1657
ET5	10865	Ethiopia	08°44'N 39°02'E	1900	866
ET6	13491	Ethiopia	06°08'N 37°35'E	1860	1500
ET7	2000	Ethiopia	07°10'N 38°40'E	1750	1000
ET8	9043	Ethiopia	07°04'N 38°30'N	1680	970
ET9	9164	Ethiopia	08°00'N 38°45'N	1550	700
HW62	15018	Hawaii	Not available		
HW63	15019	Hawaii	Not available		
HW64	15020	Hawaii	Not available		
HW65	15021	Hawaii	Not available		

Prov code.	ILCA no.	Country	Location	Altitude (m)	Rainfall (mm)
HW66	15022	Hawaii	Not available		
HW67	15023	Hawaii	Not available		
HW68	15024	Hawaii	Not available		
HW69	15025	Hawaii	Not available		
HW70	15036	Hawaii	Not available		
HW71	15037	Hawaii	Not available		
KN58	13144	Kenya	00°35'N 34°34'E	1450	1900
KN59	ENDEB	Kenya	01°01'N 34°50'E	1920	1045
KN60	KKGS	Kenya	00°20'E 34°40'E	1585	1918
ML75	9265	Mali	Not available		
NI61	13887	Niger	12°15'N 02°23'E	270	600
TZ10	1179	Tanzania	06°21'S 37°15'E	680	543
TZ11	1180	Tanzania	06°10'S 36°10'E	900	543
TZ12	1188	Tanzania	08°05'S 37°47'E	1520	626
TZ13	1189	Tanzania	09°25'S 34°45'E	1300	672
TZ14	1190	Tanzania	08°46'S 34°23'E	1060	672
TZ15	1191	Tanzania	08°46'S 34°23'E	1050	672
TZ16	1193	Tanzania	08°56'S 33°28'E	1060	672
TZ17	1194	Tanzania	08°56'S 33°28'E	1180	883
TZ18	1195	Tanzania	08°56'S 33°28'E	1550	1154
TZ19	1198	Tanzania	09°00'S 33°00'E	1380	1000
TZ20	1200	Tanzania	09°00'S 33°00'E	1350	1000
TZ21	1201	Tanzania	08°00'S 32°00'E	810	800
TZ22	1203	Tanzania	08°00'S 32°05'E	800	800
TZ23	1215	Tanzania	04°55'S 29°40'E	780	976

Prov. code	ILCA no.	Country	Location	Altitude (m)	Rainfall (mm)
TZ24	1221	Tanzania	04°53'S 29°38'E	1120	977
TZ25	1228	Tanzania	01°51'S 31°39'E	1200	972
TZ26	1229	Tanzania	01°11'S 31°44'E	1110	2040
TZ27	1231	Tanzania	01°20'S 31°49'E	1090	2040
TZ28	1233	Tanzania	01°25'S 31°49'E	1100	2040
TZ29	1238	Tanzania	02°38'S 31°19'E	1280	972
TZ30	1256	Tanzania	04°02'S 35°46'E	1400	1074
TZ31	1259	Tanzania	04°02'S 35°46'E	1000	1074
TZ32	1261	Tanzania	02°45'S 36°15'E	940	1074
TZ33	1262	Tanzania	02°45'S 36°15'E	920	1074
TZ34	1264	Tanzania	02°45'S 36°05'E	940	808
TZ35	1265	Tanzania	03°50'S 35°55'E	910	800
TZ36	1275	Tanzania	09°40'S 35°50'E	600	1400
TZ37	1276	Tanzania	09°40'S 35°50'E	600	1400
TZ38	1281	Tanzania	04°22'S 38°03'E	400	1000
TZ39	1282	Tanzania	04°22'S 38°03'E	400	1000
TZ40	1284	Tanzania	04°22'S 38°03'E	400	1000
TZ41	1285	Tanzania	04°38'S 38°05'E	400	1000
TZ42	1286	Tanzania	04°38'S 38°05'E	400	1000
TZ43	1287	Tanzania	04°46'S 38°05'E	400	610
TZ44	1288	Tanzania	04°28'S 38°12'E	390	610
TZ45	1289	Tanzania	04°55'S 38°14'E	385	610
TZ46	1290	Tanzania	05°00'S 38°30'E	350	610
TZ47	1291	Tanzania	05°05'S 39°04'E	220	1321
TZ48	1292	Tanzania	05°10'S 38°15'E	235	1321

Prov. code	ILCA no.	Country	Location	Altitude (m)	Rainfall (mm)
TZ49	1293	Tanzania	04°33'S 37°41'E	625	553
TZ50	1295	Tanzania	04°33'S 37°41'E	625	553
TZ51	1296	Tanzania	04°33'S 37°41'E	625	553
TZ52	1297	Tanzania	04°33'S 37°41'E	625	553
TZ53	1298	Tanzania	04°33'S 37°41'E	625	553
TZ54	1299	Tanzania	04°33'S 37°41'E	625	553
TZ55	1300	Tanzania	04°34'S 37°19'E	410	1230
TZ56	1302	Tanzania	04°33'S 37°41'E	840	859
TZ57	1303	Tanzania	04°33'S 37°41'E	700	859

3.3.3. Provenance collection philosophy.

The International Livestock Centre for Africa (ILCA) undertook a range wide collection of Sesbania species, the site description and collection details are described in detail by Otieno et al. (1987) and Mengistu (1989). The methodology used was based on principles described by Lazier (1984). The main purpose of these collections was to sample adequately the population by incorporating the entire range of genetic diversity. Briefly the seeds were collected in an area and bulked to provide the provenance collection.

3.3.4. Experiments management and field design.

The seeds were sown in seed trays and after germination (5-6 days) pricked out into polythene bags (5.5 X 18 cm). After eight weeks on 13th April 1990 the seedlings were planted in the field on a site prepared by deep ploughing, in order to minimise weed growth. The plots were kept weed free throughout the

growth period so that the provenances could express their full genetic potential. The provenance trial was planted in a 12 X 7 alpha (α lattice incomplete block) design, with 3 replications. The layout was row plots of 8 trees with a spacing of 1.5 m between plots and 1 m within rows. Each of the 3 replicates consisted of 12 blocks with 7 plots per block (each plot represented a provenance). A single guard row was planted at 1.5 m perimeter around the whole experiment (Fig. 3.1). The provenances were investigated for their general survival and performance.

3.3.5. Assessment of the trial.

Due to various morphological expressions of MPTs (erect, shrubby, single and multi-stems) and the necessity of producing in agroforestry multiple products and services from a single tree species, several characteristics were assessed. The measured characteristics will enable a full understanding of the genetic variation and identify the growth factors that can be used to compare and predict the productivity of this species. The trees were assessed for the following traits: (i) growth of individual trees was determined by measuring the height (m) to the tip (current active growing bud) of tallest shoot, (ii) root collar diameter (cm) at 10 cm above ground level, (iii) number of primary and secondary branches were counted, (iv) crown diameter (m), a measure of competition in trees, was assessed by measuring the crown diameter twice at right angles and calculating the average. Phenological observations of flowering, podding and incidence of pest and disease were also assessed to indicate the reproductive potential and disease resistance of this species and are reported elsewhere (Oduol in preparation). All linear measurements were expressed to the nearest centimetre. Destructive sampling was done at 8 months of age to determine above-ground biomass by thinning the plots from 8 to 4 trees. Twelve trees of each provenance were harvested (height, root collar and crown diameters, number of primary and secondary branches were

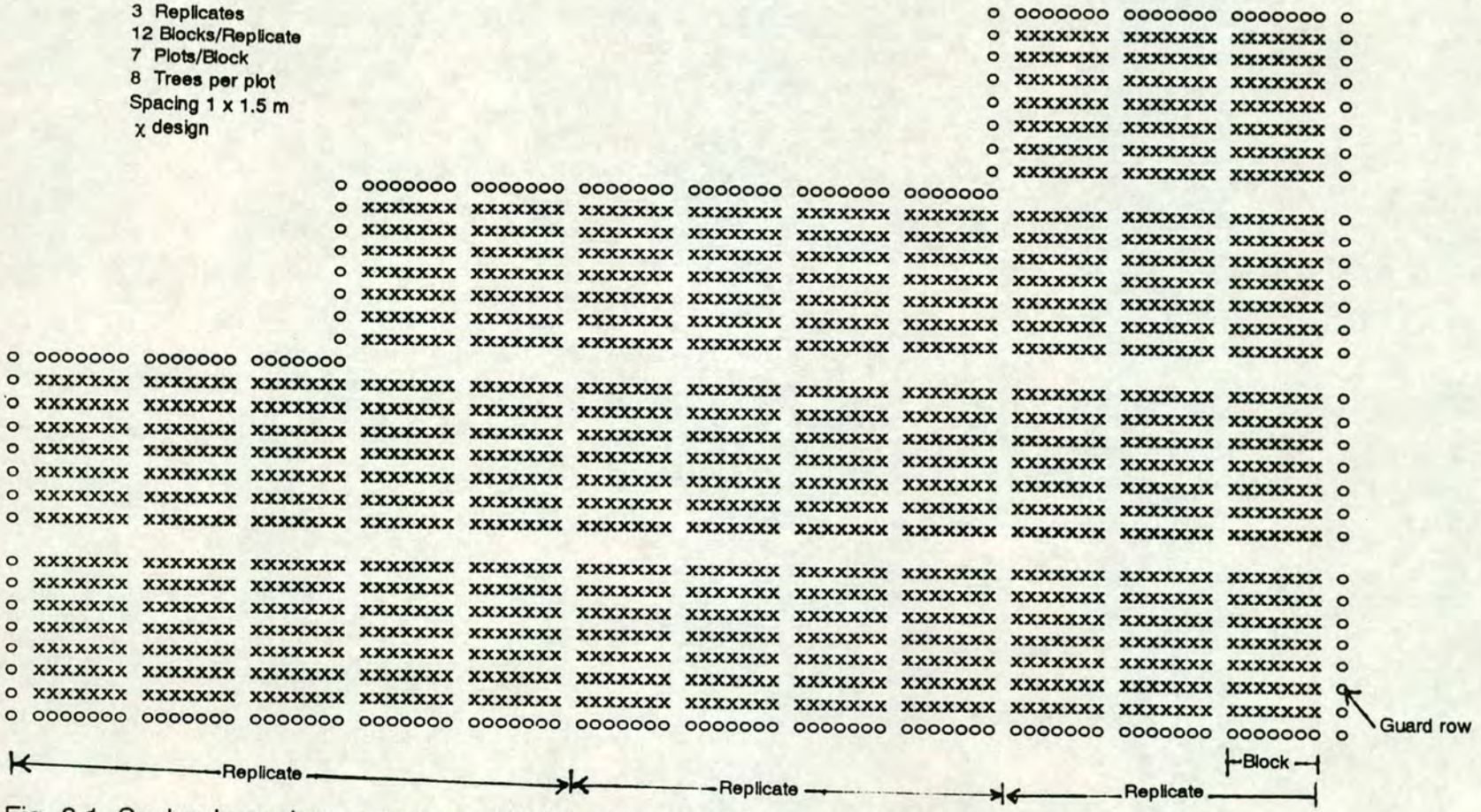

Fig. 3.1. Sesbania sesban provenance trial field layout at Maseno, Kenya.

recorded at time of harvest). The harvested trees were partitioned into stem, branches and leaves in order to understand the allometry of the species, these were oven dried at 105°C for 48 hours and the dry weights were recorded. Tree volume was estimated using the following formula:-

Volume (m^3) = 3.142*d^2*H/40000, where d^2 is root collar diameter (cm) at 10 cm. and H is tree height (m).

3.4. DATA ANALYSIS.

The data was analyzed using both SAS and GENSTAT programmes on the microvax computer system at the Institute of Terrestrial Ecology (ITE) at Bush Estate near Edinburgh. The General Linear Model (GLM) procedure in SAS for the analysis of variance of the un-balanced experiments (Barr et al. 1979) was used. Means between provenances were compared using standard errors. The following model was used in the analysis:

$$Yij = \mu + \alpha i + \beta i + \Sigma ij$$

Where: Yij = The plot mean of provenance "i" in block "j".

μ = The true experimental mean.

αi = The effect of provenance "i".

βj = the effect of block(replicate) "j"; "j" = 1,r.

Σij = the random or residual error of observation "Σij".

Correlations were tested to determine the relationship between height, root collar diameter with stem, leaf, branch and total biomass. Variance components were obtained by the VARCOMP procedure in GENSTAT. Principal component analysis (PCA) was used to delineate the morphological differences between provenances. The pattern of differentiation was projected into a two-dimensional space in order to visualise the differences clearly.

3.5. RESULTS.

3.5.1. Primary growth assessment.

The results of the assessment are given in the form of individual analysis using the general linear model (GLM) procedures in SAS. The GLM summaries of variance ratios, significance levels as well as provenance means, standard deviations and coefficients of variations for the assessed traits are presented in Table 3.3. Provenances were significantly different ($P \leq 0.001$) in all the traits assessed (height, root collar diameter, crown diameter, number of primary and secondary branches, branch frequency, stem weight, branch weight, leaf weight and total above ground dry weight). Significant differences were also observed between replicates for crown diameter and stem weight at $P \leq 0.05$ and secondary branches at $P \leq 0.001$ (Table 3.3). Blocks within replicate differences were observed for height ($P \leq 0.001$), crown diameter ($P \leq 0.05$) and branch number ($P \leq 0.01$).

Ranking of S. sesbania provenances by their means and standard deviations for primary growth characteristics of height, root collar diameter, crown diameter, number of primary and secondary branches, branch frequency and volume are presented in Figures 3.2 to 3.7.

Height growth of trees varied significantly between provenances ($P \leq 0.001$, Table 3.3). Provenance HW63 from Hawaii ranked first with a height of 4.87±0.81 m, followed by provenance ET6 from Ethiopia with 4.60±0.09 m, these heights were significantly superior to the local provenance KN60 which ranked 6th with a height of 4.26±0.21 m. Low heights were recorded in provenances CS72 and CS73 both from Australia with 1.98±0.23 and 1.64±0.07 meters respectively (Fig. 3.2). Fifty four percent of the tested

Table 3.3. Results of General linear model showing variance ratios, significance levels, means, standard errors and coefficients of variations, for Sesbania sesban provenances after 8 months growth at Maseno, Kenya.

Source	df	Ht (m)	Rcd (cm)	Crdi (m)	No. Br. (count)	Br. freq. (no)	No. secbr (count)	Stem wt. (kg)	Branch wt. (kg)	Leaf wt. (kg)	Total dry wt. (kg)	Volume (m^3)
Replicate	2	3.54ns	1.13ns	4.01c	1.34ns	1.15ns	33.63a	3.35c	1.18ns	2.88ns	1.85ns	1.04ns
Block(rep)	33	2.29a	1.28ns	1.65c	2.14b	2.25a	1.30ns	0.95ns	0.72ns	1.01ns	0.78ns	3.27a
Provenance	74	7.40a	5.28a	5.44a	5.92a	2.59a	3.85a	5.87a	3.58a	6.27a	4.75a	5.05a
Mean		3.64	3.69	2.76	54	15.25	124	0.56	0.66	0.2	1.42	0.004
Se		0.81	1.09	0.68	12	1.62	103	0.39	0.61	0.2	1.12	0.001
C.V. %		17	24	20	17	18	71	57	83	78	67	60

Ht = Height.
Rcd = Root collar diameter .
Crdi = Crown diameter .
No. Br. = Number of primary branches.
Br. freq. = Branch frequency.
No. secbr. = Number of secondary branches.
Stem wt. = Stem weight.
Branch wt. = Branch weight.
Leaf wt. = Leaf weight.
a = significant at $P \leq 0.001$.
b = significant at $P \leq 0.01$.
c = significant at $P \leq 0.05$.
ns = not significant.

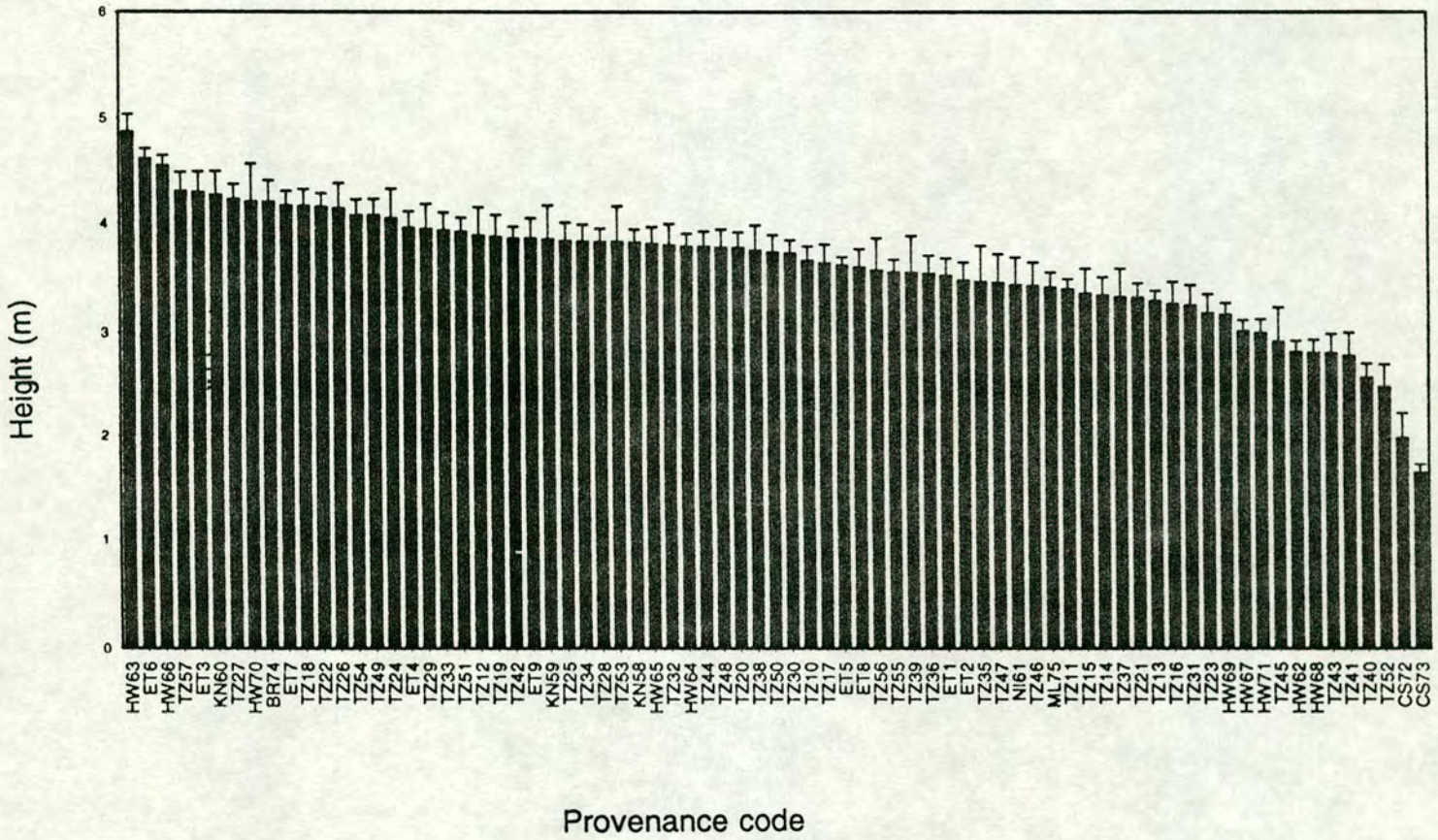

Fig. 3.2. Variation in height (m) among Sesbania sesban provenances after 8 months growth, at Maseno, Kenya.

provenances had heights above the mean of 3.64±0.81 m (Fig. 3.2).

Significant differences were also observed in root collar diameters ($P \leq 0.001$, Table 3.3). This trait is closely linked to height and the trends were almost similar to that of height. Figure 3.3 illustrates the mean root collar diameters for the provenances whose overall mean was 3.69±1.09 cm (Table 3.3). Provenance BR74 from Burundi ranked first with 5.06±0.22 cm followed by ET7 from Ethiopia with 4.97±0.24 cm while the local provenance KN60 ranked 19th with 4.06±0.4 cm. Low root collar diameters were recorded in provenances CS72 and CS73 from Australia with 2.14±0.19 and 1.53±0.06 cm respectively (Fig. 3.3).

Crown diameter among provenances was significantly different at $P \leq 0.001$ (Table 3.3). The widest crown diameter of 3.58±0.20 m was recorded in provenance BR74 from Burundi, followed by TZ28 from Tanzania with 3.58±0.15 m while the local provenance KN60 had a crown diameter of 3.09±0.2 m ranking 13th (Fig. 3.4). Provenances CS72 and CS73 from Australia had the smallest crown diameters of 1.74±0.21 and 0.93±0.11 m respectively (Fig. 3.4). Fifty percent of the provenances had crown diameters greater than the average of 2.77±0.09 m.

Number of primary branches on the main stem were significantly different between provenances ($P \leq 0.001$, Table 3.3). The highest number of primary branches were in provenance HW63 from Hawaii with 75±3 branches while lowest branch numbers were recorded in provenances CS72 and CS73 from Australia with 33±4 and 20±3 branches respectively. The local KN60 provenance had 57±2 branches ranking 27 (Fig. 3.5). About forty-two percent of the provenances had number of branches more than the average of 54±12 branches per stem.

Branch frequency which is the total number of primary branches divided by the tree height was highest in provenance HW68 and HW71 both from Hawaii with 18.4±7 and 18±0.7 branches per meter respectively. Provenance KN60 had 13.6±4 branches per meter ranking 69th, while low branch frequencies were

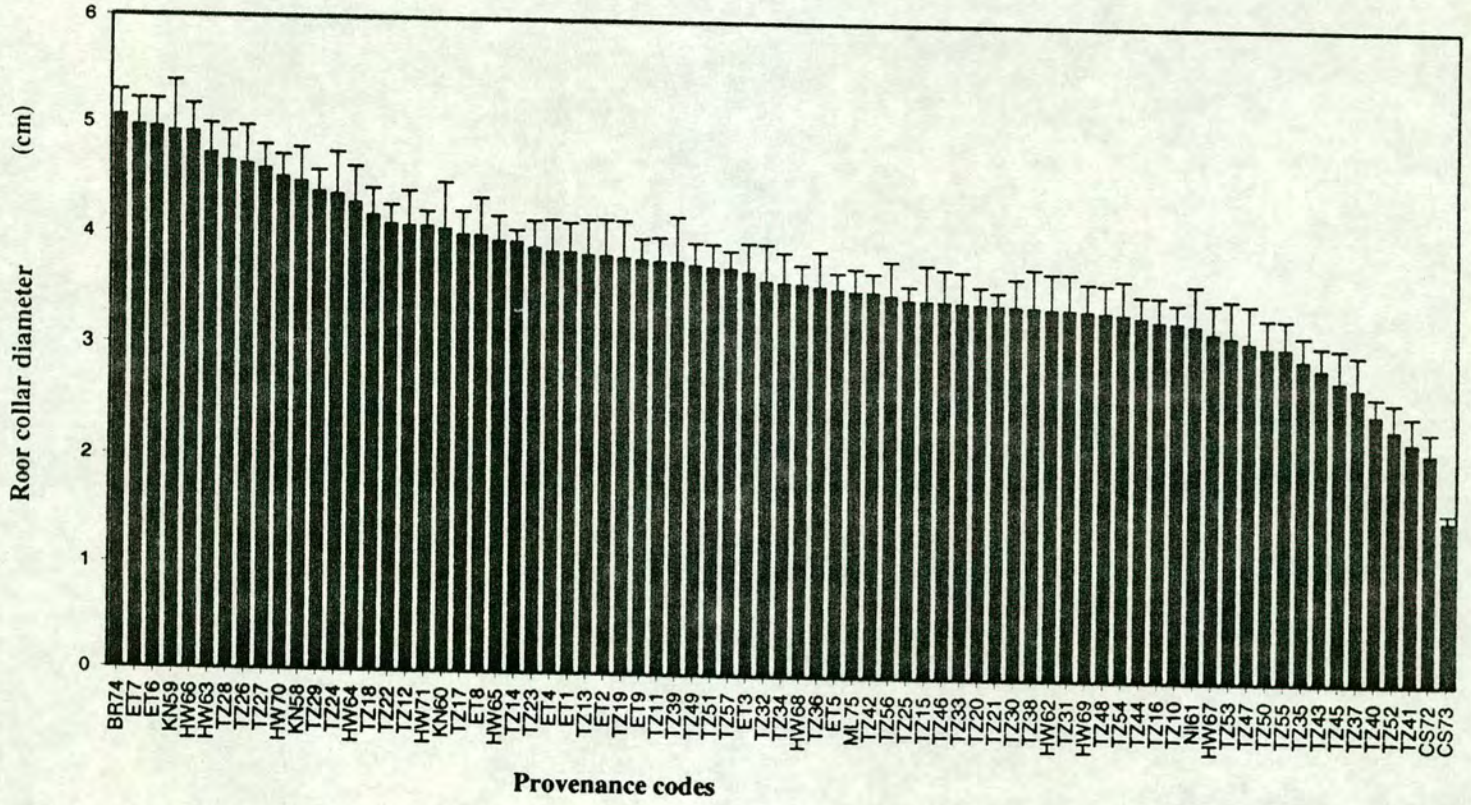

Fig. 3.3. Variation in root collar diameter (cm) among Sesbania sesban provenances after 8 months growth, at Maseno, Kenya.

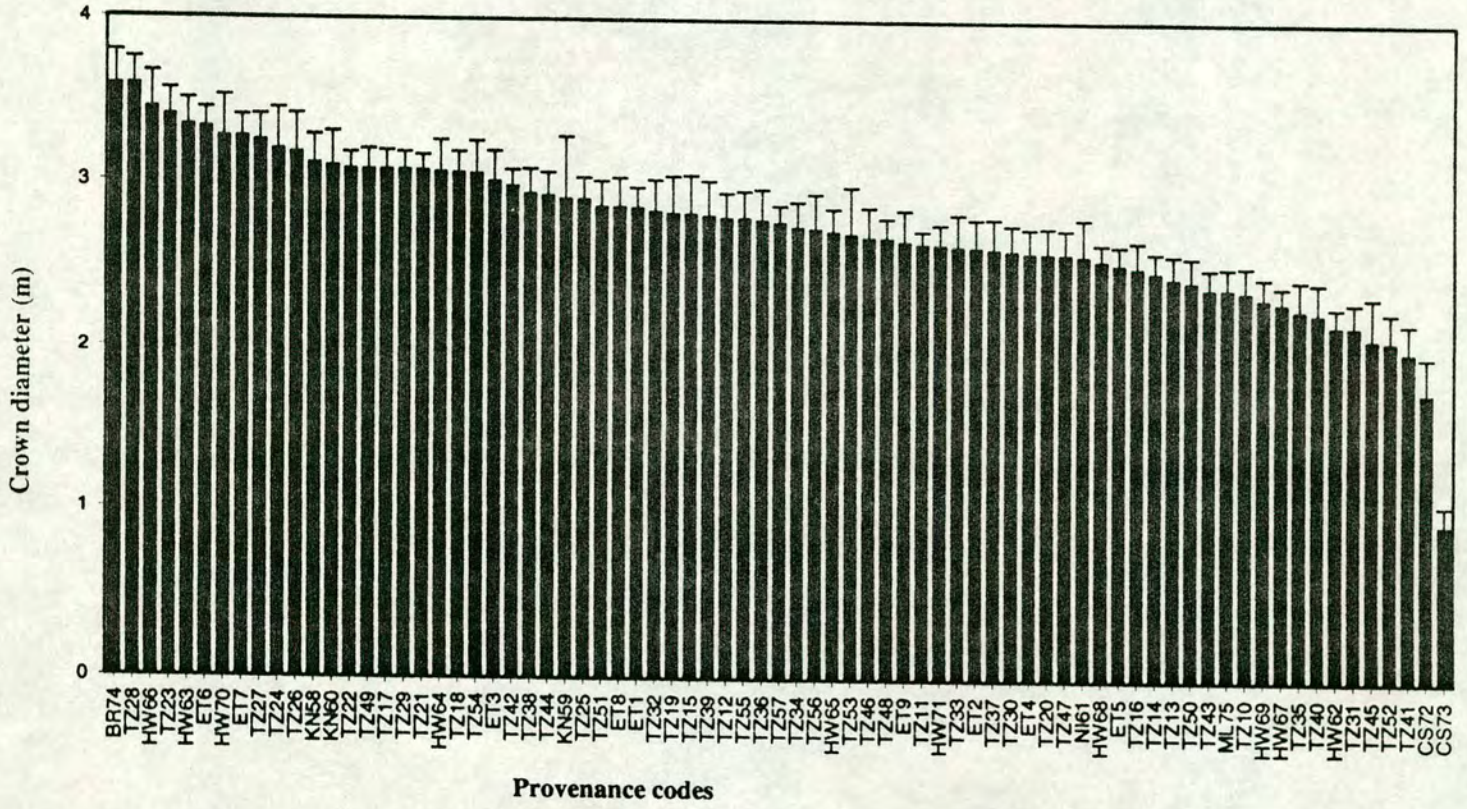

Fig. 3.4. Variation in crown diameter (m) Sesbania sesban provenances after 8 months growth, at Maseno, Kenya.

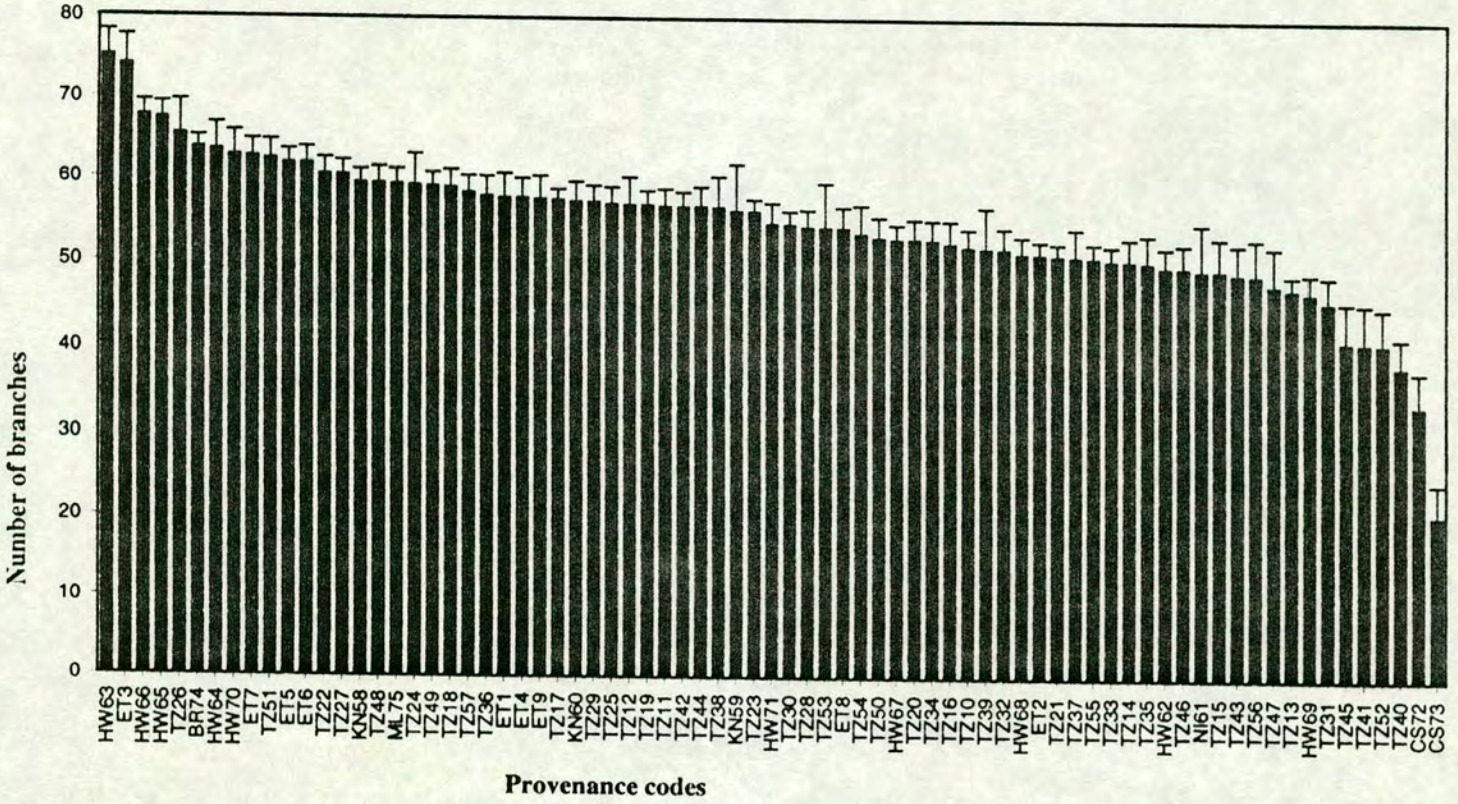

Fig. 3.5. Variation in number of primary branches among Sesbania sesban provenances after 8 months growth, at Maseno, Kenya.

recorded in provenances TZ33 from Tanzania and CS73 from Australia with 12.9±0.3 and 12.4±2.1 branches per meter respectively (Fig. 3.6). Forty-four percent of the provenances had more branches per meter than the average of 15. The number of secondary branches were highest in provenance TZ49 from Tanzania with 259±44 per tree and lowest in CS72 and CS73 from Australia with 25±12 and 6±3 secondary branches per tree respectively (Fig. 3.7).
Tree volume (m^3) was significantly different among provenances ($P \leq 0.01$) with a mean 0.004±0.001 m^3 (Table 3.3). Provenance ET6 from Ethiopia ranked first in volume with 0.0094 m^3 followed by HW66 from Hawaii with 0.0090 m^3. The local provenance KN60 had a volume 0.0065 m^3 ranking 12th while lowest volumes were recorded in provenances CS72 and CS73 with 0.0008 and 0.0003 m^3 respectively (Fig. 3.8).

3.5.2. Yield assessment.

The total above-ground biomass (dry mass $tree^{-1}$) of stem, branch, leaves was significantly different between provenances ($P \leq 0.001$, Table 3.3). Provenance ET6 from Ethiopia had the highest total dry mass of 2.96±0.28 kg $tree^{-1}$, followed by BR74 from Burundi with 2.88±0.33 kg $tree^{-1}$. The local KN60 provenance ranked 16th with 2.01±0.33 kg $tree^{-1}$ other provenances HW63, HW64, HW66, HW70, ET7, TZ22, TZ24, TZ26, TZ27, TZ28, TZ29, KN58 and KN59 from Hawaii, Ethiopia, Tanzania and Kenya had dry mass $tree^{-1}$ greater than the local KN60 provenance (Table A3.1). Provenances CS72 and CS73 from Australia had the lowest dry mass of 0.19±0.08 and 0.18±0.09 kg $tree^{-1}$ respectively. Thirty provenances had higher dry mass $tree^{-1}$ than the average of 1.42±1.12 kg $tree^{-1}$.
Provenance ET6 ranked first in stem mass with 1.19±0.09 kg $tree^{-1}$, followed in second position by BR74 with 1.09±0.13 kg $tree^{-1}$ while KN60 provenance ranked 13th with 0.79±0.12 kg $tree^{-1}$. Low stem weights were recorded for provenance CS72 and CS73 with 0.10±0.03 and 0.06±0.03 kg $tree^{-1}$

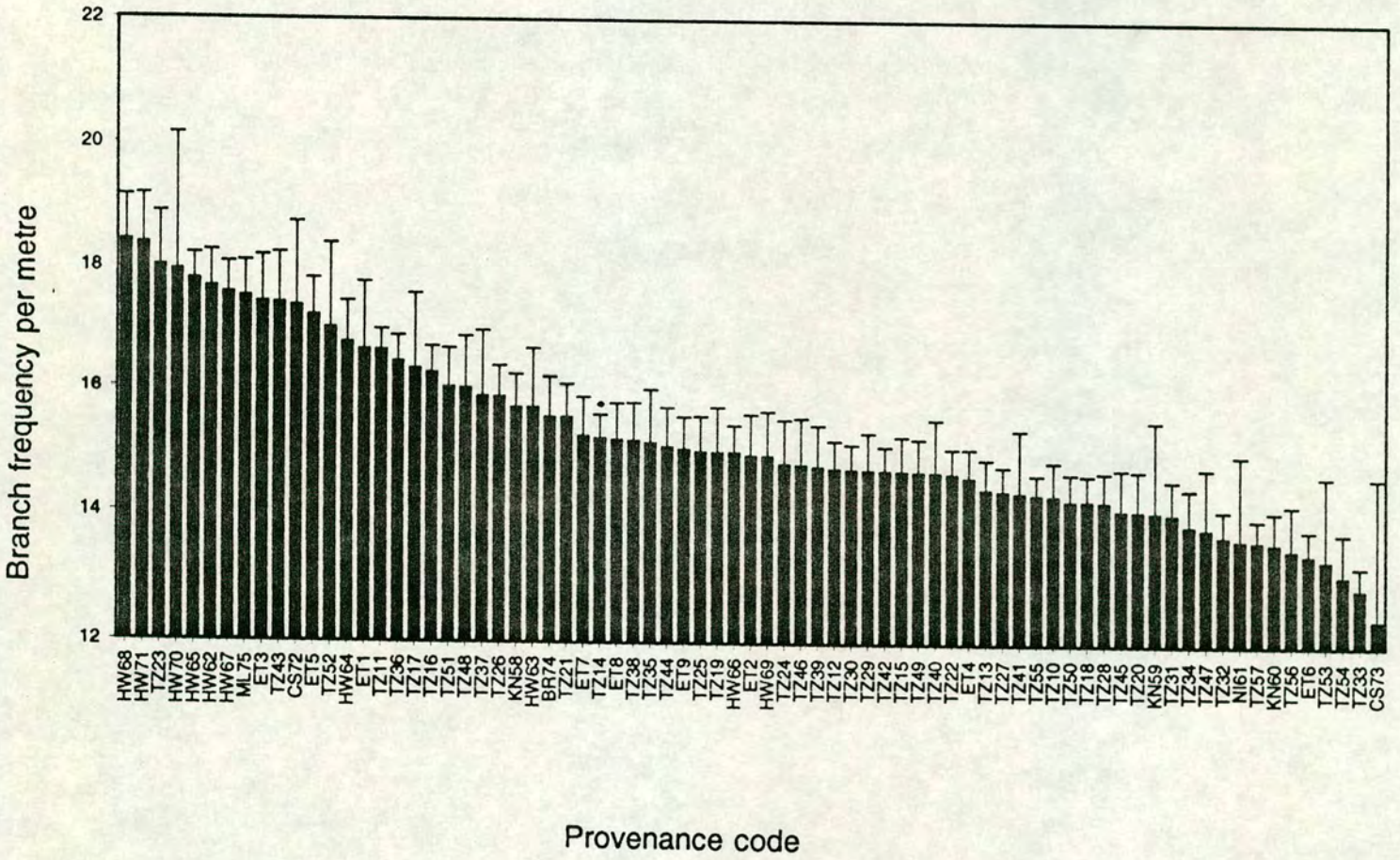

Fig. 3.6. Variation in branch frequency per meter among Sesbania sesban provenances after 8 months growth, at Maseno, Kenya.

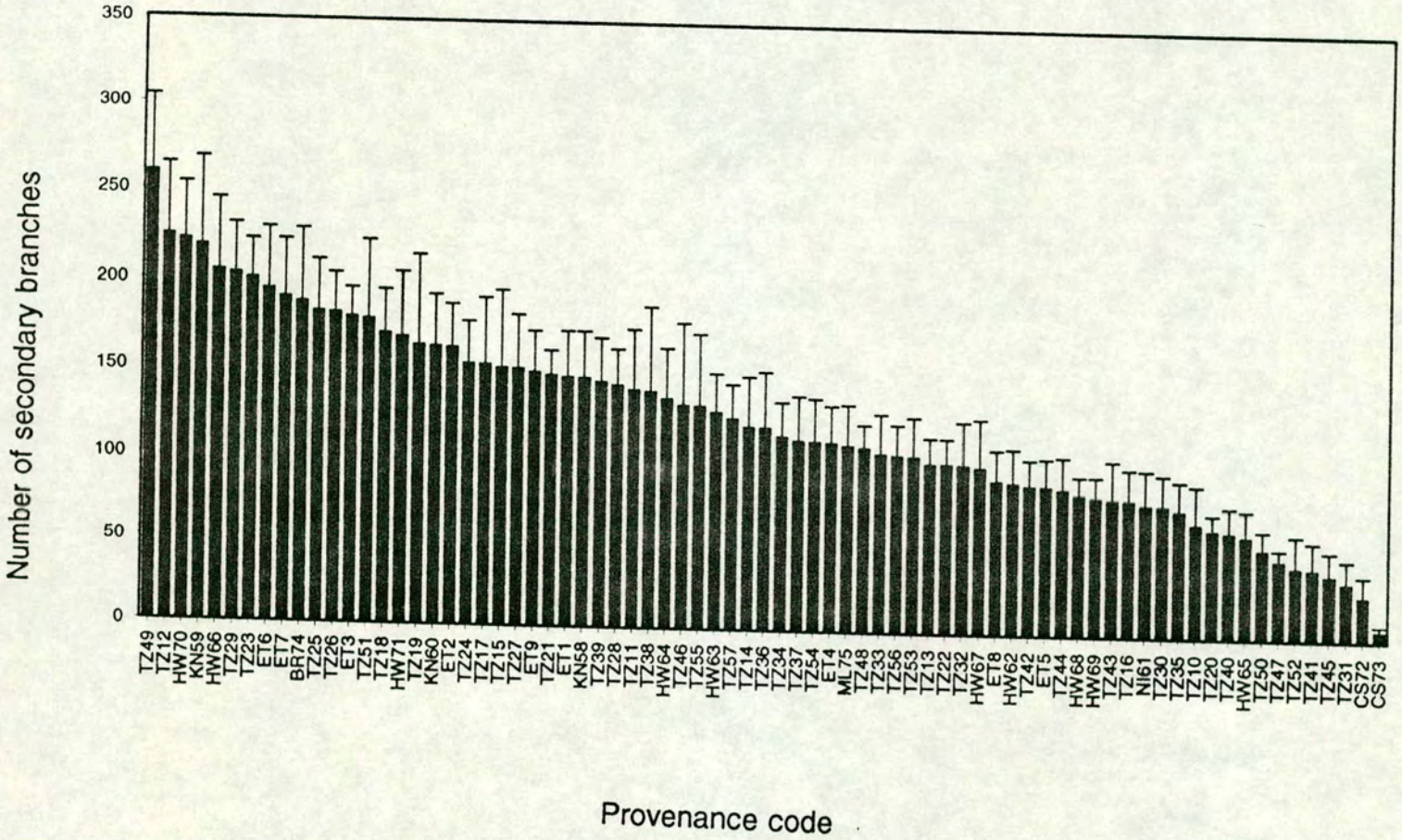

Fig. 3.7. Variation in number of secondary branches among Sesbania sesban provenances after 8 months growth, at Maseno, Kenya.

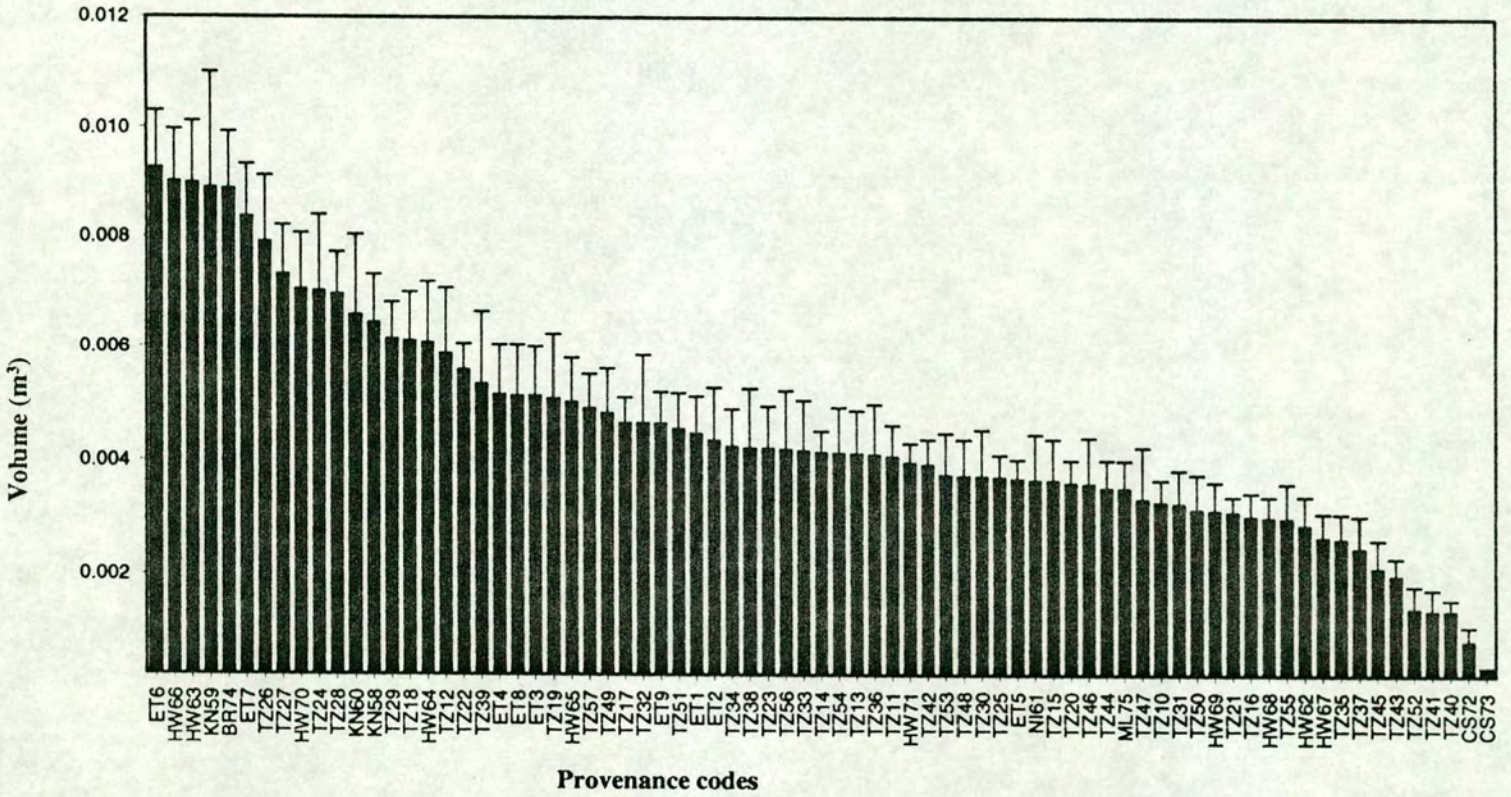

Fig. 3.8. Variation in volume (m^3) among Sesbania sesban provenances after 8 months growth, at Maseno, Kenya.

respectively. About forty-two percent of the provenances registered higher stem mass above the average of 0.56±0.39 kg tree^{-1} (Table A3.1).

Branch dry mass between provenances were significantly different ($P \leq 0.001$, Table 3.3), with provenance KN59 from Kenya having the highest branch mass of 1.55±0.44 kg tree^{-1} followed by BR74 in second position with 1.28±0.17 kg tree^{-1}, the KN60 provenance ranked 21st with 0.83±0.22 kg tree^{-1}. Low branch weights were recorded in provenances CS72 and CS73 with 0.08±0.04 and 0.05±0.03 kg tree^{-1} respectively. Forty-five percent of the provenances had higher branch weights than the average of 0.66±0.61 kg tree^{-1} (Table A3.1).

Assessment of leaf biomass showed significant differences between provenances ($P \leq 0.001$, Table 3.3). Provenances ET7 and ET6 both from Ethiopia ranked first and second with 0.61±0.09 0.53±0.04 kg tree^{-1} of leaf dry mass respectively. The KN60 provenance ranked 10th with 0.38±0.007 kg tree^{-1}. Provenances TZ43 and CS73 from Tanzania and Australia had the lowest leaf mass of 0.04±0.01 and 0.03±0.01 kg tree^{-1} respectively (Table A3.1).

3.5.3. Branch analysis.

Branching data was subjected to further critical evaluation in order to give a picture on its influence on tree form. Studies by Leakey and Ladipo (1987) have shown that branching in Triplochiton scleroxylon had an influence on tree form and yield. The branch frequency (number of primary branches divided by tree height) and branchiness index defined as the ratio of branch biomass to total above-ground biomass (Ceulemans et al. 1990) was used. The results of the present study show clearly that there was no correlation between provenance height and branchiness index ratio (Table 3.7). On ther other hand there was a negative correlation (-0.23) between height and branching frequency (Table 3.7). Provenance TZ23 which ranked first in branchiness index (Table A3.1) was also among those with the highest number of secondary branches where it ranked sixth (Fig. 3.7) but had a relatively low height ranking 63 (Fig. 3.2). In terms of volume those provenances

with less branch density and branchiness index tended to have higher volumes (Table A3.1). The regressions between branch frequency and height and total dry weight were very poor with r^2 of 0.07 and 0.01 respectively. Therefore it is apparent that branching has an influence on tree performance. None of the 16 provenances with the highest branchiness ratios (Table A3.1) appears in the top ten provenances ranked with respect to height (Fig. 3.2). Thus branching pattern studies leading to a predictive test are worth pursuing in provenance studies of this species.

3.5.4. Dry matter distribution.

The distribution of dry matter into stem branch and leaf components among provenances was determined in order to know the pattern of allometry at 8 months. Dry matter allocation is very important in agroforestry, as it indicates the potential components which a tree can produce. Figure 3.9a shows dry matter distribution for stem, branch and leaf in kg tree^{-1} while figure 3.9b shows the average percentage distribution of dry matter by mass into stem, branch and leaf for each provenance. The overall mean percentage for all provenances for stem was 43.89±13.24%, branch 42.29±12.86% and leaf 14.21±7.8%. It is apparent that dry matter allocation differed among provenances, for example provenance ET6 from Ethiopia had maximum total dry mass of 2.96±0.28 kg tree^{-1} of which stem mass formed 40%, branch mass 41% and leaf mass 17% and provenance ET7 also from Ethiopia had 2.72±0.38 kg tree^{-1} of which 35% was stem mass, 42% branch mass and 22% was leaves. Provenance KN59 from Kenya had 2.66±0.66 kg tree^{-1} of which 29% was stem mass, 58% branch mass and 15% leaf mass and provenance KN60 had total dry mass of 2.01±0.39 kg tree^{-1} of which 39% was stem, 41% branch and 19% leaf mass. These provenances (ET6, ET7, KN59 and KN60) represented the high dry mass category. The middle or average weight category was represented by provenance TZ57 from Tanzania which had dry mass of 1.43±0.19 kg tree^{-1}

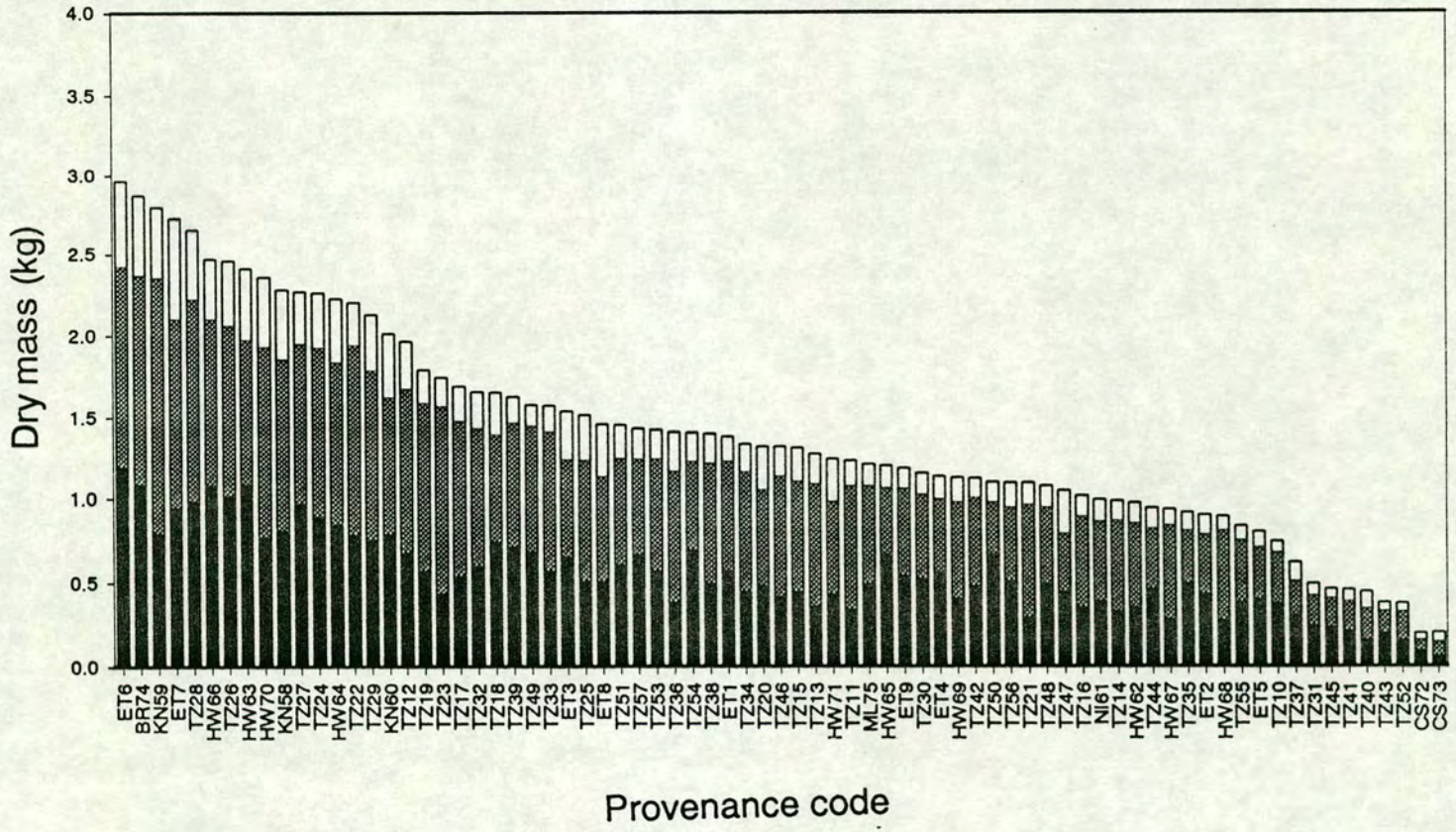

Fig. 3.9a. Variation in total dry mass (kg) of components of stem ■, branch ⊠ and leaf □ of Sesbania sesban provenances after 8 months growth, at Maseno, Kenya.

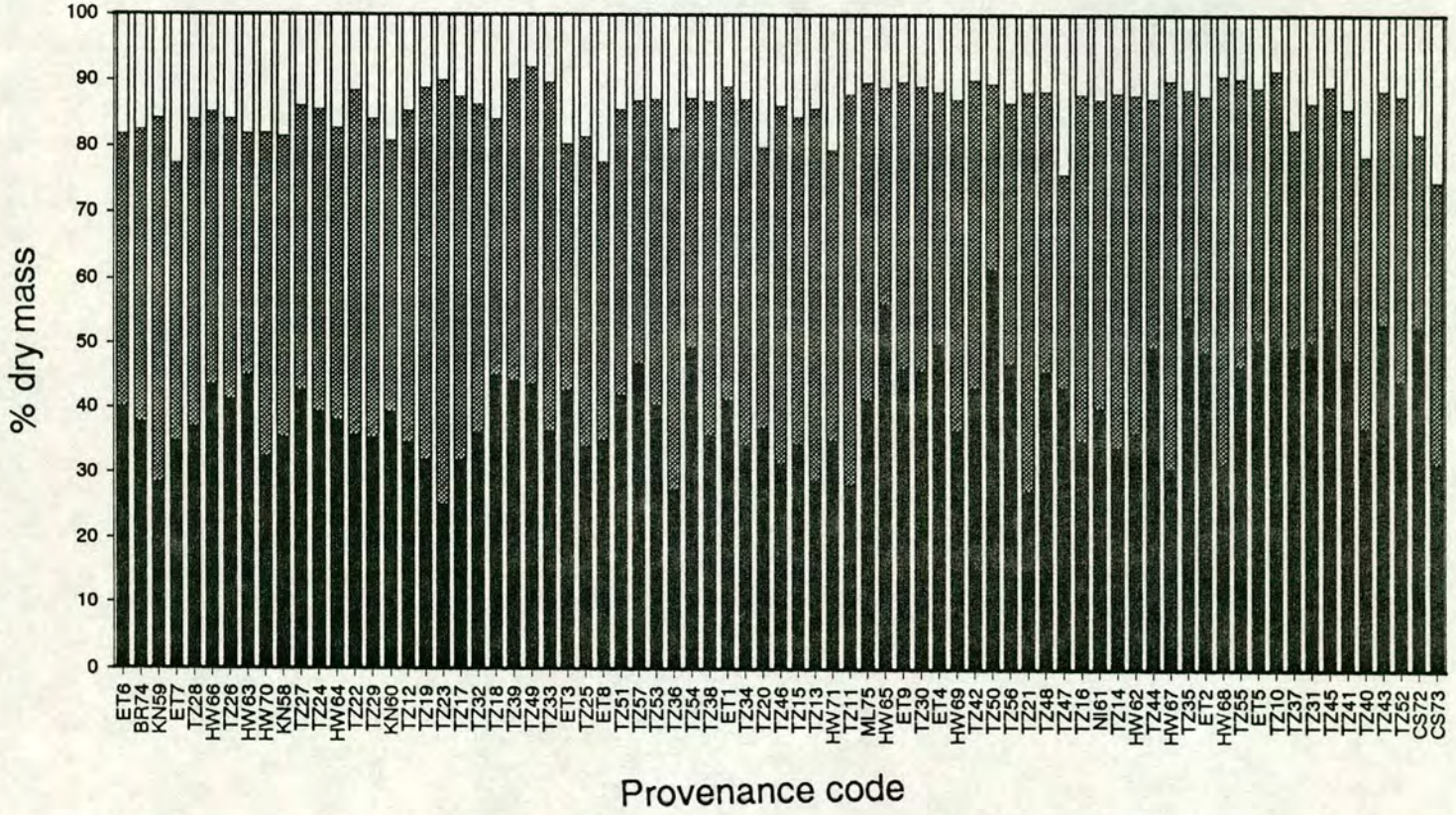

Fig. 3.9b. Variation in percentage distribution of dry mass of components of stem ■ , branch ⊠ and leaf □ of Sesbania sesban provenances after 8 months growth, at Maseno, Kenya.

composed of 47% as stem mass, 47% branch mass and 12% leaf mass. The lowest ranking provenances in dry mass were from Australia, CS72 which had 0.19±0.08 kg tree^{-1} of which 52% was stem mass, 26% branch mass and 16% leaf mass, and provenance CS73 had 0.18±0.09 kg tree^{-1} of which 33% was stem mass, 44% branch mass and 27% leaf mass.

In terms of dry matter investment into components, there is no clear pattern between those provenances with higher and lower dry mass. Even though Figure 3.9b shows some tendency for an increase in proportion of stem dry mass as total dry mass dropped among some provenances. The allometric relationships between stem, branch and leaf and above-ground dry mass to an independent variable of stem diameter at 10 cm was determined and the results are presented in Table 3.4. These strong regressions indicate that stem diameter at 10 cm is a strong predictor of biomass in S. sesban provenances.

Table 3.4. Regression equations relating stem, branch, leaf and above-ground dry mass (kg) to stem diameter at 10 cm of Sesbania sesban provenances after 8 months growth at Maseno, Kenya.

Variable	Regression equation	R^2
Stem mass	Y = -0.52 + 0.29x	0.65
Branch mass	y = -0.92 + 0.42x	0.56
Leaf mass	Y = -0.28 + 0.13x	0.50
Above-ground mass	Y = -1.73 + 0.85x	0.68

* Significant at P≤0.001.

3.5.5. Genetic parameters.

Genetic values at the provenance mean level were calculated using the model for analysis of one trait at the site based on provenance means.

$$Y_{ij} + \mu + \alpha_i + \beta_i + \Sigma_{ij}$$

Where: Y_{ij} = provenance mean (plot mean)

μ = general mean

α_i = effect of replication

β_i = effect of provenance

Σ_{ij} = random error of the plot mean - a combined effect of within-replication, environmental heterogeneity and within plot and genetic variation.

The estimated components of variance were obtained using VARCOMP procedure in GENSTAT and measures of repeatability (r) for the provenances were calculated and are presented in Table 3.5. Repeatability (r) is the ratio of the between individual component to the total phenotypic variance. It measures the proportion of the variance of single measurements that is due to permanent or non-localized differences between individuals, both genetic and environmental (Falconer 1989).

$$r = \frac{\delta^2 \text{ prov}}{\delta^2 \text{ prov} + \delta^2 \text{ e}}$$

where: δ^2 prov = is the variance component of provenance.

δ^2 e = is the error variance component

r = repeatability.

Since the provenances were grown under the same environmental conditions their phenotypic mean values will be equal to the genetic values of their particular genotypes, if there is no within site variation. In this case the phenotypic value is an expression of the genotypic value expressed by the repeatability (Falconer 1989). The high phenotypic mean repeatabilities of the provenances for height of 0.41, root collar diameter 0.31, crown diameter 0.32, primary branches 0.36, secondary branches 0.19, stem weight 0.33, branch

Table 3.5. Variance components, provenance mean repeatabilities for height, diameter, root collar diameter, crown diameter, number of primary and secondary branches, stem, branch, leaf and total dry weights.

Source	df	Ht	Rcd	Crdi	Br	Secbr	Stemwt	Branchwt	Leafwt	Total dry weight
Provenance	74	0.263	0.371	0.146	52.59	1598	0.053	0.079	0.013	0.355
Error	772	0.383	0.805	0.306	91.13	6566	0.105	0.290	0.025	0.912
Repeatability		0.41	0.31	0.32	0.36	0.19	0.33	0.21	0.34	0.28

Ht = height (m).
Rcd = root collar diameter (cm).
Crdi = crown diameter (m).
Br = number of primary branches (count).
Secbr = number of secondary branches (count).
Stemwt = Stem weight (kg).
Branchwt = Branch weight (kg).
Leafwt = Leaf weight (kg).

weight 0.21, leaf weight 0.34 and total dry weight 0.28 (Table 3.5), indicate how repeatable the performance could be, and can be used to predict future performance such as the potential response expected.

3.5.6. Repeatability of response.

Selection differential is expressed by the deviation of the observed provenance mean from the overall population mean. Genetic values for the provenances for height, root collar diameter and total dry weights were estimated for different selection intensities and are presented in Table 3.6. Height and root collar diameter were used as they are strongly correlated with yield variables. The provenance mean which is the phenotypic expression of that provenance among others at this site, under the prevailing environmental climatic conditions is considered to be the true genotypic value. The response values are equivalent to the genetic values of the parents (Falconer 1989). From the repeatabilities for provenance means and the repeatability of response values it is apparent that improvement through selection can lead to gains. For example using stem diameter at 10 cm with a repeatability of 0.31, predicted gains of 15%, 26% and 40% will be achieved from selecting the best 50% (37), 25% (18) and 5% (4) provenances respectively.

3.5.7. Correlations.

Correlation analysis between characters was used to investigate the way in which they are related. In the case of provenance evaluation and selection, correlations at provenance mean level (phenotypic values) was used, giving phenotypic correlations between characters. A summary of significant and non-significant correlations are presented in Table 3.7. Numerous significant correlations existed between measured and environmental variables. The altitude of provenance origin was significantly correlated with 11 variables while

Table 3.6. Estimates of prediction response for height, root collar diameter and total dry weight for Sesbania sesban provenance at different intensity of selection using repeatabilities.

Variable	Proportion selected (%)	Intensity of selection (i)	Mean of selected	Selection differential (S)	Expected response (R)
Height	5	1.16	4.58	0.94	0.38
Mean = 3.64	10	0.98	4.44	0.80	0.33
r = 0.41	25	0.71	4.22	0.58	0.24
	50	0.48	4.03	0.39	0.16
Root collar diameter					
Mean = 3.69	5	1.17	4.97	1.28	0.40
r = 0.31	10	1.09	4.88	1.19	0.37
	25	0.76	4.52	0.83	0.26
	50	0.44	4.17	0.48	0.15
Total dry weight					
Mean = 1.42	5	1.23	2.80	1.38	0.39
r = 0.28	10	1.12	2.68	1.26	0.35
	25	0.81	2.33	0.91	0.25
	50	0.45	1.92	0.50	0.14

Selection differential (S) = Population mean - Mean of selected.
Prediction response (R) = Repeatability (r) x selection differential (S).
Intensity of selection = selection differential/standard deviation of the trait.

Table 3.7. Phenotypic correlations between 15 variables among 75 Sesbania sesban provenances after 8 months at Maseno, Kenya.

Trait	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1. Altitude (m)														
2. Rainfall (mm)	0.37c													
3. Height (m)	0.42b	0.46b												
4. RCD (cm)	0.62a	0.59a	0.77a											
5. Crown diameter (m)	0.34c	0.53a	0.82a	0.84a										
6. No. of primary branches	0.47a	0.39c	0.85a	0.78a	0.80a									
7. No. secondary branches	0.45b	0.22d	0.61a	0.74a	0.75a	0.63a								
8. Volume (m^3)	0.57a	0.64a	0.81a	0.95a	0.82a	0.75a	0.71a							
9. Stem mass (kg)	0.41b	0.62a	0.85a	0.85a	0.81a	0.75a	0.64a	0.94a						
10. Branch mass (kg)	0.44b	0.46b	0.63a	0.85a	0.78a	0.59a	0.76a	0.85a	0.78a					
11 Leaf mass (kg)	0.53a	0.64a	0.66a	0.83a	0.73a	0.59a	0.64a	0.87a	0.85a	0.83a				
12. Total dry mass (kg)	0.48a	0.59a	0.77a	0.91a	0.84a	0.69a	0.74a	0.94a	0.93a	0.95a	0.92a			
13. Branchiness index	0.18d	-0.06d	0.09d	0.33b	0.34b	0.33c	0.43a	0.15d	0.03d	0.51a	0.12d	0.29b		
14. Branch frequency	0.08d	-0.12d	-0.23c	0.06d	0.02d	0.27c	0.09d	-0.09d	-0.16d	-0.03d	-0.08d	-0.09d	0.25d	
15. Leafyness	0.21d	0.32c	-0.05d	0.05d	-0.02d	-0.10d	0.03d	0.15d	0.09d	0.12d	0.45a	0.18d	-0.23c	-0.24b

RCD = root collar diameter
Branchiness index = ratio of branch mass to total dry weight
Branch frequency = number of primary branches divided by tree height.
Leafyness = ratio of leaf mass to stem+branch mass.
a = significant at P≤0.001.
b = significant at P≤0.01.
c = significant at P≤0.05..
d = not significant..

rainfall for the provenance origin was significantly correlated with 10 variables. Number of primary branches was significantly correlated with 13 variables. Branch weight, leaf weight and total dry weight were each significantly correlated with 12 variables while stem weight, number of secondary branches and volume were each significantly correlated with 11 variables. Height and root collar diameter were significantly correlated with 10 and 9 variables respectively. Crown diameter was significantly correlated with 8 variables. Branchiness index 6, branch frequency 3 and ratio of photosynthetic (leaf weight) to non-photosynthetic tissue (stem + branch weights) 4 variable. Negative significant correlations at $P \leq 0.05$ occurred between height and branch frequency ($r = -0.23$), branchiness index ratio and photosynthetic to non-photosynthetic ratio 9 (leafiness), ($r = -0.23$). The lack of correlation between height and branchiness index and a negative correlation between height and branch frequency indicates that branching in these provenances has an effect on tree performance, this is also reflected in the lack of correlations between branch frequency and volume or total above ground dry weight. The genetic reflection of these correlations at provenance level is indicated by the phenotypic provenance means as well as the high repeatability values indicated earlier.

3.5.8. Multiple regression.

Multiple regression analysis was used to determine the effect of independent variables on the dependent variables and results are presented in Table 3.8 (detailed multiple regressions are presented in Table A3.2).

Table 3.8. Multiple regression of stem, branch, leaf and above-ground dry mass (kg) and 5 independent variables (height, root collar diameter, crown diameter, number of primary and secondary branches), for Sesbania sesban provenances after 8 months growth at Maseno, Kenya.

Dependent Variable	Regression equation	R^2
Stem mass	Y = -0.89 + 0.21xi + 0.18xii	0.75
Branch mass	Y = -1.04 + 0.23xii + 0.23xiii - 0.007xiv	0.65
Leaf mass	Y = -0.36 + 0.09xii + 0.08xiii	0.54
Above-ground mass	Y = -2.25 + 0.58xii + 0.55xiv + 0.15xi	0.75

xi = height (m)
xii = root collar diameter (cm)
xiii = crown diameter (m).
xiv = number of primary branches (count).
xv = number of secondary branches (count).

Regressions are normally used in estimating biomass in forestry by development of a mathematical relationship between mass produced for a whole tree or tree component and one or more of the tree dimensions measured. Since there were several variables assessed and different products sought the following independent variables of height, diameter, crown diameter, number of primary and secondary branches and dependent variables of stem weight, branch weight, leaf weight and total dry weight were used in the analysis. Height and root collar diameter can be used in the regression equation for estimating stem weight as they had higher coefficients of determination (r^2) of 0.75. Branch weight can be estimated by parameters of root collar diameter, crown diameters and branch number with r^2=0.66, while leaf weight can be determined by using root collar diameter and crown diameter, with r^2 = 0.54. Total dry weights can be predicted by using height, root collar diameter and number of branches with a r^2=0.75. Thus it is apparent that some traits can be used to predict more than one dependent variable.

3.5.9. Principal component analysis.

Principal component analysis (PCA) was used to investigate the correlations between large number of variables measured in order to identify those variables causing the greatest variation in the provenances (Gittins 1968, Burley and Burrows 1972). Principal component analysis has been used to investigate forest site-growth relationships (Malcolm 1970, Hunter and Gibson 1984) and in ecological studies (Gittins 1968). The mathematical transformations in principal component analysis extracts the components so that they are independent of each other, the first component accounts for a maximum variation of the variables, the second component the maximum variation left after the removal of the first component. The coefficients of correlation were used to calculate principal components and the percentages of total variation accounted for by these components are presented in Table 3.9. The calculated transformations were then plotted graphically to illustrate the pattern of variation between provenances (Figs. 3.10, 3.11). The first principal component accounted for 80.07% of the total variation, composed largely of height, root collar diameter, stem weight, branch weight, leaf weight, total dry weight, primary branches and crown diameter. The second principal component accounted for 7.63% of the total variation, and the main contributor was the number of primary branches, while the third principal component accounted for 5.12% of the total variation with secondary branches being the main contributor.

Table 3.9. Percentage of total variation accounted for by the principle component.

Component	Percentage of total	Cumulative percentage of
1	80.07	80.07
2	7.63	88.26
3	5.12	93.35
4	1.97	95.35
5	1.86	97.21
6	1.46	98.67
7	1.07	99.74

Figure. 3.10 shows plots of PCA 1 and 2, the best sized provenances in terms of volume, total dry weight, diameter, crown diameter and height are zoned together (A), while good medium sized provenances which are less branchy are zoned together (B) while provenances of average size are also zoned together (C). Figure 3.11 shows plot of PCA 1 and 3, provenances with less branchiness index zoned together (A). Very shrubby with high branchiness index provenances are zoned together (B) while provenances of average performance are zoned together (C). The worst performing provenances in both plots (Figs. 3.10 and 3.11) are zoned together (D). The first principal component was mainly attributed to the primary growth characteristics of the plants (size) while the second and third principal component were concerned with the secondary growth attributes of the plant.

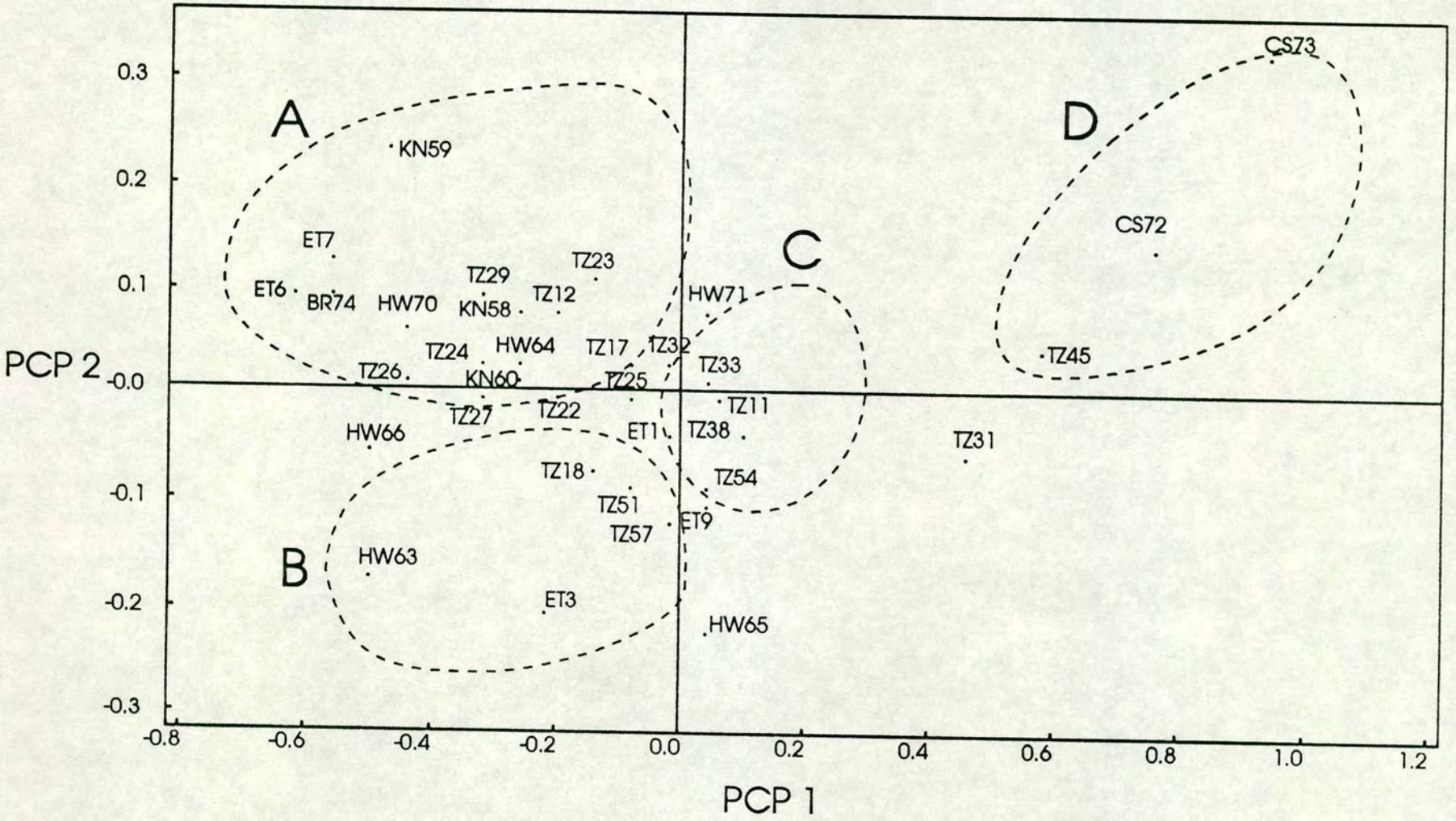

Fig. 3.10. Relationship between the first two principal components of 75 Sesbania sesban provenances at Maseno, Kenya.

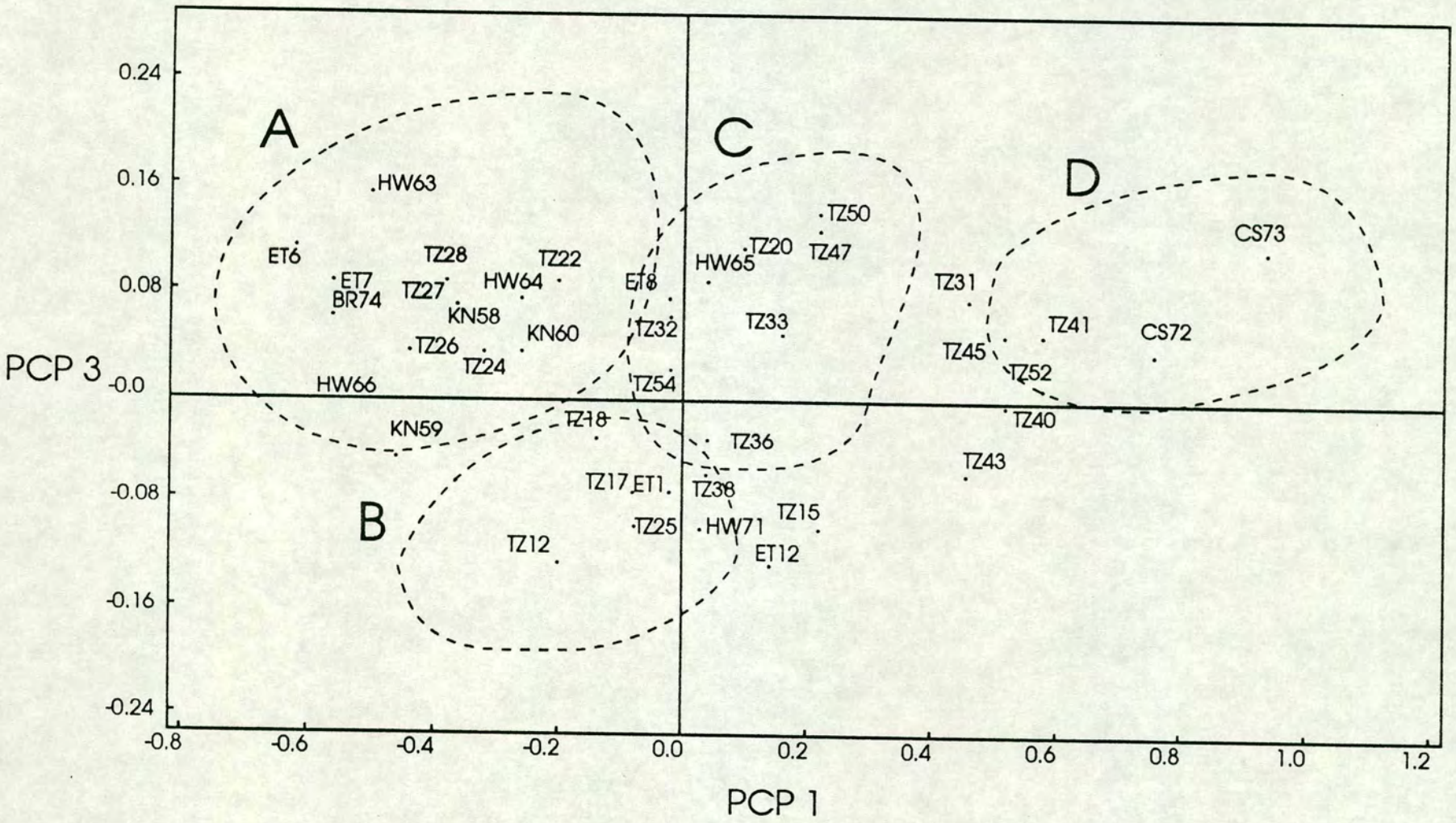

Fig. 3.11. Relationship between the first and third principal components of 75 Sesbania sesban provenances at Maseno, Kenya.

3.6. DISCUSSION.

The results of these Sesbania sesban provenance trials at Maseno, have shown that there is great genetic variation in the species. Provenance means in the assessed traits indicated that the top performers tended to came from high altitude and high rainfall areas (r=0.42). This is not surprising since Maseno is a high altitude area (1500 m) and high rainfall zone (1750 mm). Provenances from low rainfall areas among the top performers tended to have more secondary branches (TZ51, TZ49, TZ12 and TZ29). Using volume as an indicator of provenance productivity, the following 24 provenances (selection based on volume mean±1SD) are recommended for further evaluation in the high rainfall areas of Kenya; provenance BR74 from Burundi, ET3, ET4, ET6, ET7 and ET8 from Ethiopia, HW63, HW64, HW65, HW66 and HW70 from Hawaii, TZ12, TZ18, TZ19, TZ22, TZ24, TZ26, TZ27, TZ28, TZ29 and TZ39 from Tanzania and KN58, KN59 and KN60 from Kenya. Some provenances ranked highly in more than one variable, for example ET6 from Ethiopia, had all the characteristics required in agroforestry of good height (ranked 2), stem weight (ranked 1) leaf weight (ranked 2) and ranked first in total dry weight. Such a provenance can be manipulated through management to produce different products. Some provenances (*e.g.* CS72 and CS73) were consistently poor in all assessed traits, thus eliminating themselves at this stage of evaluation. Provenance ET7 performance was unique, the morphology of the parent was described as a low creeping vine having a height of 1 metre and crown diameter of 4 metre (Anon 1987), but on this site it expresses its self phenotypically as a tree with a mean height of 4.16±0.13 m and ranked first in leaf weight (0.61±0.09 kg tree^{-1}). This provenance might have been heavily browsed at the place of origin or was on a relatively poor site. These top ranked provenances are very interesting from a breeding point of view, as gains can be achieved by selection based on individual phenotypic values. Performance with respect to height (range 1.64-4.87 m) is in agreement with other authors who obtained similar results for height growth in S. sesban. For example Yamoah and

Burleigh (1988) and Dutt and Pathamia (1987) report heights of 3.86 m in Rwanda and 3.99 m in India respectively for S. sesban.

The repeatabilities and potential genetic values indicate how much the variation is due to genetic variation and highlight the expected returns due to selection. However this expected genetic gain cannot be relied on unless the different measurements made have equal variances and represent the same character genetically (Falconer 1989). On the other hand this first performance by the provenances may have been due to the good environment which is not carried through to the subsequent performances. But the results indicate how repeatable the values can be on similar sites. Thus selection of clones from those provenances which rank high will definitely lead to greater genetic gains in this species at this site. Since S. sesban is fast growing and it more or less expresses its full genetic potential within one year, the conclusions made at this stage will be justified. But selection of clones from this population to be planted on similar or different sites should encompass a wide range of environmental conditions in order to get broadly adapted trees. Genotype x environment interaction is known to be expressed more strongly in clones than in provenances (Kleinschmit 1983) as clones show significant differences in their ecological stability.

The significant differences in branching among provenances needs further evaluation. Provenances with higher branchiness index and branch density tended to be poor performers in terms of height and total dry weight. Similar results were found by Leakey and Ladipo (1987) in T. scleroxylon where trees with more branches per unit stem tended to be of low stem height and root collar diameter. Studies by Leakey and Ladipo (1987) found that branching affected tree yield, and could be used as a selection criteria. This is confirmed by the negative correlation between height and branch frequency in the present study. Thus there is need to select against branching in S. sesban clones for poles and to develop a predictive test using young plants (Leakey 1991).

The presence of variation in productivity among and within S. sesban provenances indicates that selection is possible, for fuelwood, poles and fodder. Despite the

wood being soft and of low density, the provenances produce high woody biomass in a short time, which could be used as quick and hot burning fuel. The favourable conditions at the site resulted in high fodder yields, with high protein contents making S. sesban leaves suitable as high quality feed supplement to ruminants. The lack of significant correlations between the ratio of photosynthetic to non-photosynthetic tissue shows how leaves are subjected to seasonal fluctuations and that other assessments should be considered to evaluate this trait. The correlation and regression analysis indicated strong inter-relationships among the independently measured variables. These variables can be used in the prediction of dependent variables of stem weight, branch weight and leaf weight. The results are in agreement with those of Brown (1976), Freedman (1983) and Telfer (1969) and show that the allometric relationship with stem diameter as an independent variable is a good model for predicting plant biomass and its components. In the next set of trials only one of those closely related variables will be measured in the field. The similarity among provenances in allocating dry matter between components (Figs. 9a and 9b) indicated that they are adaptable to this site and have a common growth pattern. This may have been due to the juvenility of the trees which were growing freely with minimal competition, as the canopies were just starting to interlock. Further investigation of dry matter allocation after canopy closure is necessary in order to determine whether the trend persists. The earlier analysis could not explain how the nine measured variables were correlated and the way in which the provenances could be discriminated from each other. The principle component analysis has shown that the variables measured are not independent. Two broad groups can be sorted out, one in which height, diameter, crown diameter, stem, leaf and total dry weights (plant size) and the second group by, the branching habit of the plants, represented by primary and secondary branches (indicator of shrubbiness). The variables of height and root collar diameter link these two groups as they are strongly correlated with most of the assessed variables. This result is good for breeding as improvement in one of these traits will lead to subsequent improvement in other traits. The first three

components accounted for 93% of all the variability contained in the 9 variables (plant growth), The third component accounted for 5.12% of the variability and cuts across almost all provenances. This third component with emphasis on mode of branching is very interesting because it affects tree form which is correlated with volume, thus this third component may be of value in helping to predict the tree form among provenances. The classification of provenances based on the first three components would be adequate and the strong inter-correlations that exist among variables suggests that only a few need to be measured (height and root collar diameter) in order to identify the differences between provenances.

In conclusion and based on the results obtained so far from the General linear model analysis, ranking of provenances, attempted estimate of genotypic values it is apparent that:-

i) Significant differences between provenances have been shown for all assessed characters and that S. sesban has an ecotypic variation making selection at provenance level worthwhile.

ii) Further tests on different sites are necessary to obtain the clones with the best genotype by environment interaction (Chapter 4).

CHAPTER 4

GENETIC VARIATION AND PRODUCTIVITY OF SESBANIA SESBAN CLONES.

4.1. AIMS.

When trees are grown over a wide range of environments their relative performance varies in unpredictable ways. It is also very difficult to predict tree productivity over several environments due to their longevity and the various number of growth phases they undergo throughout their rotation. Thus there is need to understand the inherent genetic variation and genetic processes in trees as well as environmental factors that influence tree productivity. This can be achieved by characterising the differences between standing-tree measurements, dry mass yields in genetically uniform material tested in various environments.
The aim of this study is to determine the growth and yield potentials of Sesbania sesban clones under different environmental conditions and make use of the growth attributes in predicting their productivity.

4.2. INTRODUCTION

Fast growing multipurpose trees (MPTs) are being recommended for short rotation forestry under intensive management (NAS 1980). However, for most of these MPTs there is hardly any information available on their growth and development in various environments (Zohar et al. 1988). Thus there is need to monitor the growth of these trees at a range of sites and in association with other crops. The knowledge gained through investigations will lead to the development of good management practices for MPTs (planting density, coppicing regimes, harvesting rotation) in order to optimize yields in agroforestry.
The survival and adaptability of trees depends on the genetic variation of the

species (Zobel et al. 1960). The variability between individual trees is unknown, but may be due to the differences in the environment in which they are growing, genetic differences are due to the interactions between the tree genotypes and their environment. Through genetic tests on a broad range of sites it is possible to evaluate both morphological and physiological portions of the variation in trees which are due to genetic effects and environmental effects (van Buijtenen 1992). Clonal trials on several sites can give estimates of the magnitude of the total genetic and environmental variation from which predictions may be made of the amount of genetic gain to be expected in tree improvement programmes.

4.3. GENOTYPE BY ENVIRONMENT INTERACTION.

Genotype interactions between the environment (g x e) is the differential response of genotypes (species, provenances, families or clones) to different environmental conditions (Zobel and Talbert 1984, Venkatesh 1988). For a true g x e to occur there must be a difference in genotype ranks relative to each other in different environments.

With the recent shift in forest practices to intensive management in short rotations (afforestation in marginal areas and introduction of new trees in farmers fields - agroforestry) there is a likelihood of creating new artificial habitats for trees where they have never thrived before. It is also very difficult to predict the environmental conditions over the growth period of trees, which calls for the requirement of genotypes to be adapted to a wide range of environments (Hanson 1970, Matziris and Zobel 1976). The puzzling question to foresters now is how to select the best genotypes and how will these selected genotypes perform in the new and variable environments. Genotype by environment studies help to ascertain the range of possible sites over which the best selected genotypes can be planted profitably and achieve greater genetic gains (Zobel and Kellison 1978). Studies have been conducted on the effects of interaction in tree growth (Binet 1963, King 1965, Burdon 1971) and also on species adaptability for a wide and specific

environments (Squillance 1969, Shelbourne 1972). Conclusions from these studies, for a successful tree planting programme require the determination of environmental conditions where the genotype is to be planted.

Genotype by environment interaction is very important in genetic variation studies as it is used in the estimation of genetic parameters. These can be used to direct the selection strategy for genetically well buffered genotypes which will perform well under a wide range of environments (Venkatesh 1988). For example when trees are planted on one site the additive genetic variance and the g x e interaction is confounded. This can lead to over estimation of expected gains in the selected genotypes to be planted on a different site. The best genotypes chosen at this site may not perform well on another site, this will result in less genetic gains in the non-test environment. It can lead to economic disaster as planting trees is a long-term investment. To get sound economic returns it is necessary to start with the correct genotypes. The location of genetic tests on several sites exposes the genotypes to different climatic and edaphic factors. Performance will be different, so that those genotypes which exhibit little interaction are selected.

Most of the causes of g x e interaction are more often related to edaphic factors rather than climatic factors (Shelbourne 1972). Genotypes may interact in both growth and quality characteristics, and the responses to selection for these traits will be greater when they are under strong additive genetic control rather than under non-additive genetic control (Stonecypher et al. 1973). Most of the adaptability variations in trees are strongly inherited in an additive manner. Thus the development of trees that are high yielding and broadly adapted on several sites will lead to high genetic gains (Kellison and Sprague 1971), which can be captured through vegetative propagation (Leakey 1987).

4.4. MORPHOLOGICAL EVALUATION.

4.4.1. Growth, form and above-ground biomass production.

Tree parameters related to growth, productivity and morphometric studies have been conducted extensively in temperate species (Kozlowski 1964, Farmer 1976, Jannke and Lawrence 1965, Kramer and Kozlowski 1979 and Cahalan 1981). There is little information available on the growth pattern and architecture (morphology) of tropical trees, except for a study by Tomlison and Gill (1973), Hallé et al. (1978) and Bisht and Toky (1992).

There is need to study factors that determine tree form, such as rates of height growth, numbers and relative lengths of branches, their direction of growth and how these affect productivity. These factors are very important in agroforestry where the main objective is to increase the productivity of a tree and crops. The increase in tree productivity apart from inherent genetic factors depends on the spacing as well as the efficient utilization of the available resources (Cannell 1988, Harper 1985). Dry matter production in trees is as a result of biomass production of its shoots, their (shoot) arrangement and how the biomass is partitioned into various tree components. In order to improve tree productivity we need to understand tree architecture and the amount of biomass produced (Farmer 1976, Rook et al. 1985).

Apart from direct yield studies there is also need to develop non-destructive methods for assessing biomass during the growth of MPTs. Easily assessed traits such as height and stem diameters have been used to estimate the potential biomass yields in trees (Causton 1985, Stewart et al. 1989, Whittaker and Marks 1975, Stewart et al. 1992). The use of linear models has been recommended by Brewbaker (1987) and Hawkins (1987). Multipurpose trees in their early stages of development often exhibit multiple stems. Usually one or two develop into dominant stems. Since most of the MPTs are fast growing and normally harvested for fuelwood when young (between 0.5-3 years), the developed equations will hold

true. Generally there is a lack of biometric relationships equations for MPTs in different environments.

4.4.2. Root morphology and below-ground biomass production.

Plants having different rooting patterns co-exist successfully in mixtures by sharing soil moisture and nutrients. The size, type and efficiency of the rooting system depends on its competitive ability and determines the success of an individual species in any given habitat. There is need to know the structure and development of tree root systems in order to understand their exploitation of ecological niches. This is a requirement so that proper silvicultural decisions can be implemented in order to optimize yields in agroforestry (Huxley 1983, Von Maydell 1987).

There is more information available on the aerial components of trees than on rooting habits (Hosegood and Howland 1966). This can be attributed to the difficulty in excavating roots, their non-uniformity in size and distribution and to the physical problems of separating roots from soil.

In traditional agroforestry systems in the tropics, the trees are grown together with crops and on pasture lands. For sustainability, this assumes that trees being deep rooters will exploit deeper horizons and so should not compete with crops. It is also believed that trees will improve the physical and chemical properties of the soil (Kang and Juo 1986, Sanchez et al. 1985, Sanchez 1987, Nair 1984).

Extensive studies on the root biomass production and fine root dynamics of temperate zone species have been done (Harries et al. 1978, Roberts 1976, Moir and Bacheland 1969) but few studies have been attempted for tropical trees (Berish 1982, Prasad and Misra 1984, Shukla and Ramandkrishan 1984, Jonsson et al. 1988, Toky and Bisht 1992 and Heal 1993). Tropical trees have been described as shallow rooters (Roberts 1952, Whitmore 1975), but these studies did not involve detailed investigations and were merely based on wind throws and soil pit excavations.

Sesbania sesban and other trees and shrubs, are being mixed with agricultural

crops in agroforestry, but their interactions below ground are not known. Studies relating to the rooting characteristics of these species are necessary in agroforestry in order to understand the below ground interactions with crops and their overall effect on yield. The competition of tree feeder roots with agricultural crops for available moisture and nutrients is highly undesirable in agroforestry as it can lead to reduction in crop yields (Gichuru and Kang 1990).

Tree growth and development of roots in shape and pattern is directly affected by external factors, such as soil type, soil moisture, slope, planting techniques (Kozloswki 1971). The plasticity of roots to their environment influence results in different characteristics, as shown by Kerfort 1963. However, about 30% of the genome of higher plants is associated with rooting characteristics (Zobel 1975).

Since little information is available on the inheritance of rooting patterns of tropical trees and shrubs, this study was undertaken to answer the following questions.

1) What are the general features of the root system of Sesbania sesban clones?

2) How does the rooting pattern of Sesbania sesban clones vary under different environmental conditions?

3). What are the (intra-specific) variations in the form of root systems due to modifications by site?

4.4.3. Soil and foliar nutrient concentration.

Most tree planting programmes in agroforestry are for the supply of fuelwood, browse; provision of cover to protect the soil from erosion (NAS 1980) and to enhance nutrient cycling (Sanchez 1979, Nair 1984, Young 1987, Lundgren and Nair 1985, Sanchez et al. 1985).

Nutritional problems in the soils are normally associated with un-favourable soil conditions, such as acidity, salinity, shallowness, flooding and low organic matter. The uptake of nutrients by trees is a complex process due to the physiological processes involved and the symbiotic role of mycorrhizas. Studies involving soil and tree nutrient concentrations (Steinbeck 1966) and the responses of trees to

nutrients (Walker and Hatcher 1965, Curlin 1967, Ingestad and Lund 1986) have led to improvements in tree performance on sites previously not used for afforestation. Large differences exist in concentrations and total amount of nutrients in the leaves of trees. It is worth finding out whether these differences are genetically controlled, so that only those trees with high growth rates and nutrient uptake can be selected for nutrient poor sites. Agroforestry systems are intended to enhance the sustainability through the enhancement of in soil nutrients and improved physical properties. However there is very little published information to support this (Sanchez 1987). Sanchez et al. (1985) recommended the assessment of soil properties over time, in order to ascertain the beneficial effects of trees in agroforestry. Sesbania sesban productivity is variable on different sites used in agroforestry for soil improvement. It is therefore necessary to examine (i) soil fertility differences between sites at different times, to determine whether there are changes in soils associated with tree planting and (ii) seasonal variations in leaf nutrient concentrations so see if these are associated with tree productivity.

4.5. SELECTION OF CLONES.

The trees worthy of cloning are those that can grow best with high productivity on a chosen site. Clonal selection is useful at identifying outstanding genotypes for single or multiple traits which are important for a breeding programme or can be immediately deployed as superior genotypes for direct use (Libby 1990). Selecting ideotypes in agroforestry is very complex. Apart from performance they have to be compatible with the agricultural crops as well as targeted to the harvest index (Wood 1990). Multi-trait selection is relatively easy for those characteristics relating to the production of a single product (eg. yield, nutritive value and palatability of fodder), but it is unlikely the individual clones can be selected for the superior production of more than one timber, fodder, gum etc. product, although superiority for a product and an environmental service may perhaps be combined into a single clone.

The screening in the provenance study (Chapter 3) indicated that certain provenances perform better than others at the Maseno site and that great variability exists between provenances, giving great scope for improvement. However, selection of clones from these provenances would perhaps lead to further dramatic gains, if this genetic variation can be captured by vegetative propagation (Leakey 1991). Barnes et al. (1980) showed in pines that selection of the best phenotypes in one provenance could be twice as productive as those in another provenance with the same mean. It is worth testing whether this is true in Sesbania. The selected provenances/clones (plus-trees) for this study should encompass a wide range of diversity and take into consideration all the growth characteristics that contribute to yield as well as the intended use. This is important because they will be tested on different sites to check their physiological adaptability under those environmental conditions (genotype x environment interaction). Straight or multi-stemmed, small sized trees with intensively branching crowns will be preferred for fuelwood. For poles straight stems with less branching are required while for fodder or mulch trees with fairly rounded crown, dense foliage, accessible height, ability to retain the leaves during dry season and good resprouting potential are desired.

Clones sought for the next set of trials are those that can produce poles, fuelwood and fodder. These were selected as highly productive single-purpose clones for use in agroforestry. Agroforestry has two main features namely sustainability and polyculture where clones can play a very significant role. Agroforestry is associated with small scale farmers whose sole purpose is to be self-sufficient, by growing a variety of crops, animals and trees in close or intimate mixtures. Large monocultural farming systems have been found to be economically and ecologically detrimental in the tropics. So the development of highly productive single purpose clones to be deployed in mixtures will reduce detrimental effects of cropping and improve sites in terms of nutrients and soil characteristics while utilizing the available space optimally.

The objective of this study was to examine growth, morphology and yield potential

of Sesbania sesban clones, when grown under different environmental conditions, and use the growth attributes to predict their productivity.

The hypotheses tested in this study were:

(i) Sesbania sesban clones selected for fuelwood would produce more branch and stem dry mass.

(ii) Sesbania sesban clones selected for poles will produce more stem dry mass.

(iii) Sesbania sesban clones selected for leaf will produce more leaf dry mass.

4.6. MATERIALS AND METHODS.

4.6.1. Experimental sites.

The genotype by environment interaction study was conducted on three sites in Kenya (i) KEFRI/KARI/ICRAF field station at Maseno, (ii) KARI/KWDP field station at Kisii and (iii) ICRAF field research station at Machakos. Site details are described in Chapter 2 while climatic factors of rainfall and temperature for the period of study are shown in Figure 4.1.

4.6.2. Clone selection details.

Genotypes with the following phenotypic characteristics were selected for; (i) poles - straight stems, higher stem dry weight with less branching; (ii) fuelwood - higher stem plus branch weights and (iii) leaf/fodder -higher leaf weights. The selected clones details are presented in Table 4.1 while their summary statistics are presented in Table 4.2. It can be noted that the plus-trees selected for fuelwood had a high proportion of their biomass allocated to branch weight of 58%, while those selected for poles had a high proportion of biomass in the stem of 43%.

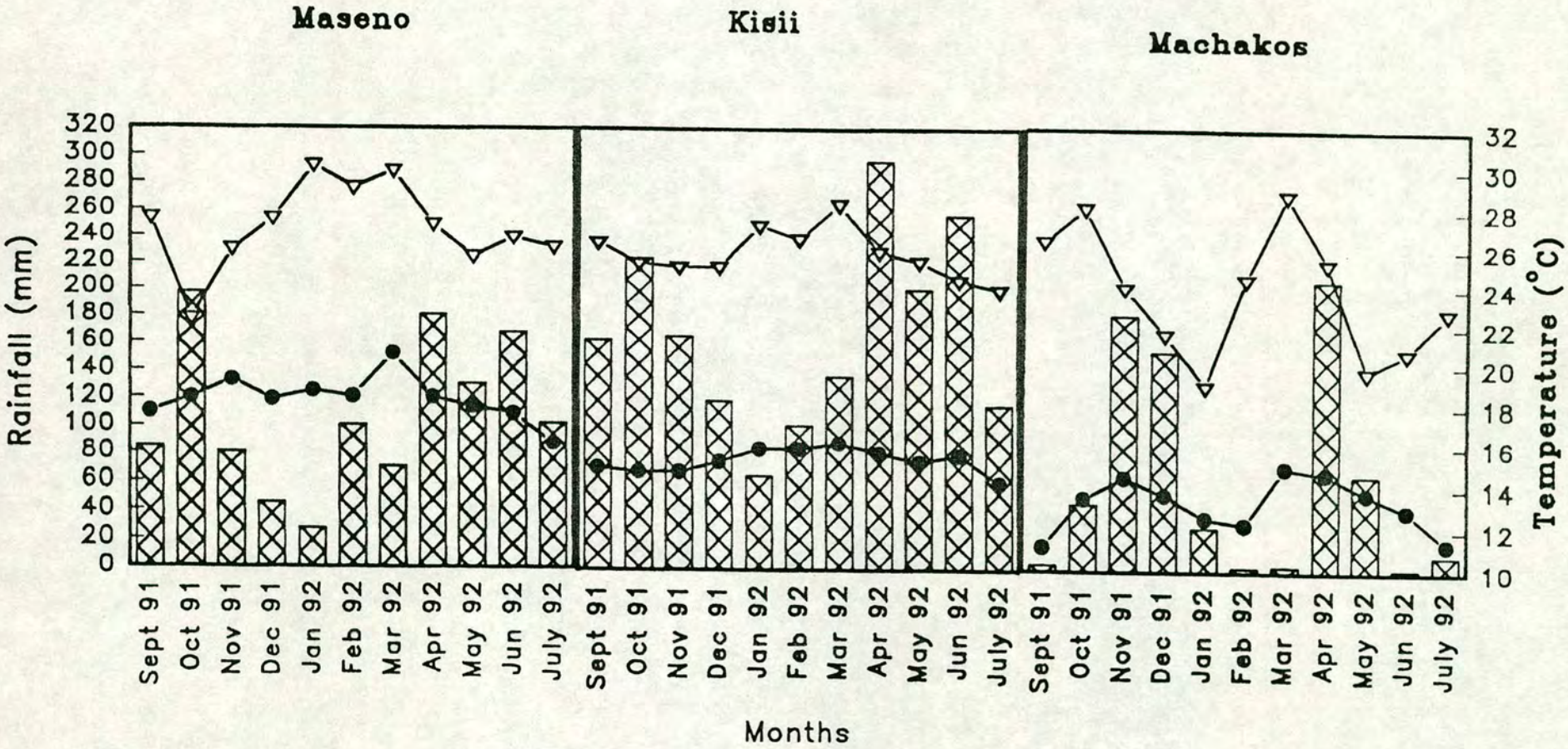

Fig. 4.1 Mean monthly maximum (▽) and minimum (●) temperature and rainfall (▨) at Maseno, Kisii and Machakos, Kenya, during the experimental period.

Table 4.1. Showing sources of the selected Sesbania sesban clones used in Genotype by environment interaction study at Maseno, Kisii and Machakos.

Clone code	Provenance Code	Country of origin	Product selected for	Altitude (m)	Rainfall (mm)
F3	TZ38	Tanzania	Fuelwood	400	1000
F6	TZ32	Tanzania	Fuelwood	940	1074
F10	TZ33	Tanzania	Fuelwood	920	1074
F11	TZ12	Tanzania	Fuelwood	1520	626.4
F13	TZ46	Tanzania	Fuelwood	350	610.8
L4	KN60	Kenya	Leaf	1585	1918
L5	TZ28	Tanzania	Leaf	1100	2040
L6	HW63	Hawaii	Leaf	-	-
L7	TZ47	Tanzania	Leaf	220	1321
L9	HW66	Hawaii	Leaf	-	-
P2	TZ35	Tanzania	Poles	910	808.8
P4	HW63	Hawaii	Poles	-	-
P7	TZ39	Tanzania	Poles	400	1000
P8	TZ39	Tanzania	Poles	400	1000
P9	HW63	Hawaii	Poles	-	-

Table 4.2. Summary statistics of plus-trees selected for fuelwood, poles, leaves from S. sesban provenance trial at Maseno, Kenya compared with all provenance mean.

Product	Height (m)	Root collar diameter (cm)	Stem dry mass (kg)	Branch dry mass (kg)	Leaf dry mass (kg)	Total dry mass (kg)
Fuelwood (n=5)	4.75(0.52)	5.77(0.44)	1.33(0.13)	2.71(0.25)	0.65(0.06)	4.69(0.16)
Poles (n=5)	5.36(0.62)	4.73(1.19)	1.77(0.14)	1.80(0.44)	0.57(0.07)	4.14(0.40)
Leaf (n=5)	4.39(0.42)	5.12(0.50)	1.26(0.54)	1.54(0.59)	0.82(0.12)	3.62(1.02)
Clone mean (n=15)	4.83(0.66)	5.21(0.90)	1.45(0.45)	2.02(0.67)	0.68(0.13)	4.15(0.77)
Prov. trial mean (n=75)	3.64(0.81)	3.69(1.09)	0.56(0.39)	0.66(0.61)	0.2(0.2)	1.42(1.12)

Figures in parenthesis are standard deviations.

Plus-trees selected for fodder had 25% of the biomass in the leaves. Trees selected for fodder thus had a 10% more leaf than those for poles (14%) and fuelwood (14%). The clones were selected from different altitudinal and rainfall zones in order to have a broad base (Table 4.1). Five top ranked clones were selected for each category (poles, fuelwood and fodder). Further selection of more clones from these ranges is required for a clonal breeding programme in agroforestry.

4.6.3. Experimental management and field design.

The plants used in the trial were raised as rooted cuttings (see Chapter 2 for propagation details). The cuttings after about eight weeks from the time of collection were planted on the three sites, Maseno and Kisii on 21/10/92 and Machakos on 26/10/92 in a randomized block design (Table 4.3). The plots were kept weed free (by hand) throughout the experimental period. The spacing was 2.5 x 2.5 m in a 5 x 3 array (15 cloned individuals from 15 ortets were planted with a single ramet per clone randomized in each block as single tree plots). The gaps for missing trees were planted with different Sesbania sesban clones of the same size in order to give equal competition. A single guard row was planted around the perimeter of the whole experimental area at each site. The total experimental area was about 0.12 ha for Maseno, 0.07 ha for Kisii and 0.12 ha for Machakos. The unbalanced structure was accentuated by poor rooting ability of the material obtained from the field. This might have been due to maturation effects or the physiological status of the coppice shoots as some did not show vigour at the time of collection.

Table 4.3. Experimental details of the Sesbania sesban clone trials analyzed.

Site	Altitude (m)	Rainfall (mm)	Clones tested	Number of blocks	Design	Plot size tree rows
Kisii	1740	2060	13	6	RBD	5x3
Maseno	1500	1750	15	10	RBD	5x3
Machakos	1560	700	15	10	RBD	5x3

4.6.4. Assessment of the experiment.

The trees were monitored from the second month in the field for growth, morphological characteristics and biomass production. Physiological parameters of light interception and stomatal conductance were measured in nine month old trees at Maseno and Machakos. The results are reported in Chapter 7.

4.6.5. Growth characteristics.

The following growth characteristics were assessed at the three sites after two, four, six and eight months after planting in the field.

i) Height of the mainstem from ground-level to the apical bud, was measured using height measuring rods to the nearest cm.

ii) Root collar diameter at 0.15 m was measured in centimetres using vernier calipers. For multi-stemmed clones, a consolidated diameter for all the erect shoots at 0.15 m was estimated by using the following equation:

$$D = \sqrt{(d_i^2 + d_{ii}^2 + \ldots + d_n^2)}$$

Where: d_i, d_{ii} ... d_n, are stem diameters at 0.15 m for stems.

iii) Crown diameter was measured in metres by taking two measurements between the longest and shortest axes of the crown edge using a tape measure. Crown diameter was calculated as the average of the two measurements and expressed to the nearest cm.

4.6.6. Measurements of crown characteristics.

Crown characteristics were assessed in order to determine whether there were any differences between Sesbania sesban clones during tree development.
At the end of February and end of June 1992 (representing growth after four and eight months), detailed measurements of branch characteristics were made on three representative trees for each of the fifteen Sesbania sesban clones at each of the sites. To reduce variability, the chosen trees had a basal diameter near to the overall clone mean of the experiment. The height of the selected trees was measured. Based on the tree height each tree was divided into three zones, namely lower, middle and upper zone. In each zone four primary branches were selected and marked by paint, after which the following measurements were made on the marked branches at four and eight months.
i) Length of primary branch (branches directly originating from the main stem) was measured using a tape measure to the nearest cm.
ii) Diameter of primary branch was measured in centimetres at 1 cm from the point of branch attachment to mainstem and recorded to the nearest mm. using a vernier caliper.
iii) Branch angles of origin and angle of termination from the vertical axis of the stem to the lateral branch was measured, by using a protractor, as described by Nelson et al. 1981 and Burk et al. 1983 and values expressed to the nearest degree (°).
iv) Number of leaves per branch were counted.
v) Leaf area per branch was estimated by randomly sampling ten leaves per tree and determining their leaf areas. Leaf area per branch was obtained by multiplying

the average leaf area of the sampled leaves by the number of leaves per branch and expressed in square metres.

vi) Number of primary branches per crown zone were counted.

vii) Crown diameter (m) at lower, middle and upper zone was measured and expressed to nearest cm.

4.6.7. Yield assessments.

At the end of the experiment, after nine months field growth (July/August 1992), three trees were selected for destructive sampling. The limited number of trees sampled was due to the difficulty in excavating root systems, which is also labour intensive and expensive. The trees represented a variety of normal stand conditions. The sample trees varied in height from 3.98 to 5.83 m, and were healthy and symmetrical dominants and codominants. The entire root system (about 95%) of the tree was excavated manually. The trees were in a monocultural plantation at a spacing of 2.5 x 2.5 m. These were clones propagated by cuttings. The trees selected were measured, destructively sampled and separated into component parts to determine both above and below ground biomass yields. Above ground biomass yield (kg) was partitioned into stem, branch and leaf. During digging the horizontal spread of roots were measured and roots of various diameter classes, in vertical distribution (0-10, 10-20, 20-30, 30-40 and >40 cm) were also counted. The roots which originated from the main root irrespective of the size were described as primary roots, while secondary roots originated from the primary roots. However, where the main root was not distinct, the most prominent and central root was considered as the mainroot. Root angles (°) were measured for primary and secondary roots with respect to main root and primary roots, respectively. Below ground biomass was separated further into lateral root biomass consisting mainly of primary and secondary roots and vertical root biomass consisting of the stump and the tap-roots. For comparison between clones the following ratios were estimated root/shoot, root/crown spread (horizontal root

spread / crown diameter).

All mass estimates were based on oven dry mass at 105° for 24 hours.

4.7. DATA ANALYSIS.

The data was analyzed using Statistical Analytical System (SAS) on the Unix system at the Institute of Terrestrial Ecology Bush Estate. The General Linear Model (GLM) for the analysis of un-balanced experiments (Barr et al. 1979) was used to explore the variation in each character, for combined sites and single site analysis. PROC VARCOMP with the REML method was used to estimate the variance components corresponding to the different effects (site, block, clone, clone by site interaction and error). Correlations were tested to determine relationships between growth and yield parameters. Due to the unbalanced nature of the experiment, clone averages are expressed as least square means (Lsmeans) for each clone per site. The listing of the individual clones in order of ranking does permit some overall comparison between sites. Means between clones were compared using the Least Significant Difference (LSD) test at $P \leq 0.05$. The following models were used for analysis:

a) For single site (environment).

$$X_{ik} = \mu + \alpha_i + \gamma_k + e_{ik}$$

Where:

X_{ij} = is the plot mean of variable X of the kth replication of the ith genotype.

μ = is the grand mean overall replicates and genotypes.

α_i = is the genetic contribution of the ith genotype.

γ_k = is the contribution of the kth replication.

e_{ik} = is the residual variation of the kth replication of the ith genotype.

b) For combined sites (environments).

$$X_{ijk} = \mu + \alpha_i + \gamma_{k(j)} + \epsilon_j + g_{ij} + e_{ijk}.$$

Where :

X_{ijk} = is the plot mean of variable X of the kth replication of the ith genotype in the jth environment.

μ = is the grand mean overall replications, genotypes and environments.

α_i = is the genetic contribution of the ith genotype.

$\gamma_{k(j)}$ = is the contribution of the kth replication in the jth environment.

ϵ_j = is the environmental contribution of the jth environment.

g_{ij} = is the genotype-environment interaction of the ith genotype in jth environment.

e_{ijk} = is the residual variation of the kth replication of the ith genotype in the jth environment.

4.8. RESULTS.

The GLM summaries of variance ratios, significance levels, clone means and standard errors and coefficient of variation for the assessed growth variables are presented in appendix Tables A4.1 to A4.18, while trends in growth are in Figures 4.2 to 4.31.

4.8.1. GROWTH VIGOUR.

The results for combined site analysis (Maseno, Kisii and Machakos) for height, root collar diameter (0.15 m) and crown diameter for Sesbania sesban clone groups and individual clones after eight months growth are presented in Table A4.1. The effects of sites and clones are large. Significant differences were observed between clone groups for height ($P \leq 0.001$). Significant differences were

also observed between sites and clones for height, root collar diameter and crown diameter ($P \leq 0.001$) while clone by site interaction was not significant for root collar diameter and crown diameter after eight months (Table A4.1). Mean height for clones groups were 3.84±0.58, 4.33±0.47 and 3.66±0.46 m for clones selected for fuelwood, poles and leaves respectively. While mean height for clones for combined sites was 3.97±0.14 m, for root collar diameter was 4.78±0.27 and for crown diameter was 3.58±0.14 m (Table A4.1). The GLM results for S. sesban clones and groups for height, root collar diameter and crown diameter for single sites at eight months are presented in Tables A4.2. Variation in growth with time for height, root collar diameter and crown diameter for the three experimental sites are presented in Figures 4.2 to 4.4. The Figures are categorised for the sites of Maseno, Kisii and Machakos and for clones selected for fuelwood, poles and leaves. The time is indicated as months after the start of the experiment in the field.

4.8.1.1. Height.

At Maseno, mean height for clone groups were 4.41±0.51, 4.81±0.37 and 4.17±0.33 m for clones selected for fuelwood, poles and leaves respectively. Height growth followed a linear pattern (Fig. 4.2). Height growth rates at this site between two and six months was 0.32±0.09 m month^{-1} while between six and eight months was 0.40±0.12 m month^{-1}. Some clones tended to rank higher than others in height growth, for example F6 and F10 in clones selected for fuelwood (Fig. 4.2), P4 and P2 in clones selected for poles (Fig. 4.2) and L6 for clones selected for leaves (Fig. 4.2).

At Kisii, mean heights for clone groups were 3.86±0.55, 4.34±0.69 and 3.25±0.75 m for clones selected for fuelwood, poles and leaves respectively. Height growth for S. sesban clones was also linear but with two distinct groupings (Fig. 4.2). Growth rate for height among clones at Kisii was greater between two and four months with 0.57±0.21 m month^{-1}, dropping to 0.24±0.16 m month^{-1} between four

and six months and 0.22±0.16 m month^{-1} between six and eight months. Clones F10 and F3 selected for fuelwood (Fig. 4.2), clones P4 and P2 selected for poles (Fig. 4.2) and L7 in clones selected for leaves (Fig. 4.2) had their growth curves completely separated from others and had relatively greater heights.

Mean heights for clone groups at Machakos were 3.25±0.22, 3.86±0.44 and 3.58±0.31 m for clones selected for fuelwood, poles and leaves respectively. Height growth for S. sesban clones followed a sigmoid pattern of growth (Fig. 4.2) with clone means very close to each other, except for the clones selected for poles at two months (Fig. 4.2). The growth rates for height between two and four months was 0.54±0.14 m month^{-1}, dropping between four and six months to 0.14±0.12 m month^{-1}, and virtually ceasing thereafter (0.006 m month^{-1}). F10 in clones selected for fuelwood (Fig. 4.2), P4 and P2 in clones selected for poles (Fig. 4.2), L4 and L6 in clones selected for leaves (Fig. 4.2) had greater heights at this site.

The comparison of clones within sites in height growth reflects the habit of growth, for most of the clones, e.g. clones P4, P2 and F10 were tall, while clones P8, L9 and L5 were relatively squat, at least up to the time of harvest.

4.8.1.2. Root collar diameter.

At Maseno, the mean root collar diameter curve for clones was almost exponential. Growth rates increment in root collar diameter was greatest between two and four months with 0.55±0.06 cm month^{-1} while between four and six months was 0.52±0.06 cm month^{-1} and between six and eight months was 0.50±0.07 cm month^{-1}. Clones F3, F6 and F10 tended to have greater diameters among clones selected for fuelwood (Fig. 4.3), while P4 and P2 had greater diameters in clones selected for poles (Fig. 4.3), while clones selected for leaves L5, L6 and L7 tended to have greater root collar diameters (Fig. 4.3).

At Kisii, mean root collar diameter for S. sesban clones also increased in a similar pattern like Maseno. Root collar diameter growth rates among clones was greatest between two and four months, with 0.64±0.13 cm month^{-1}, dropping to a steady

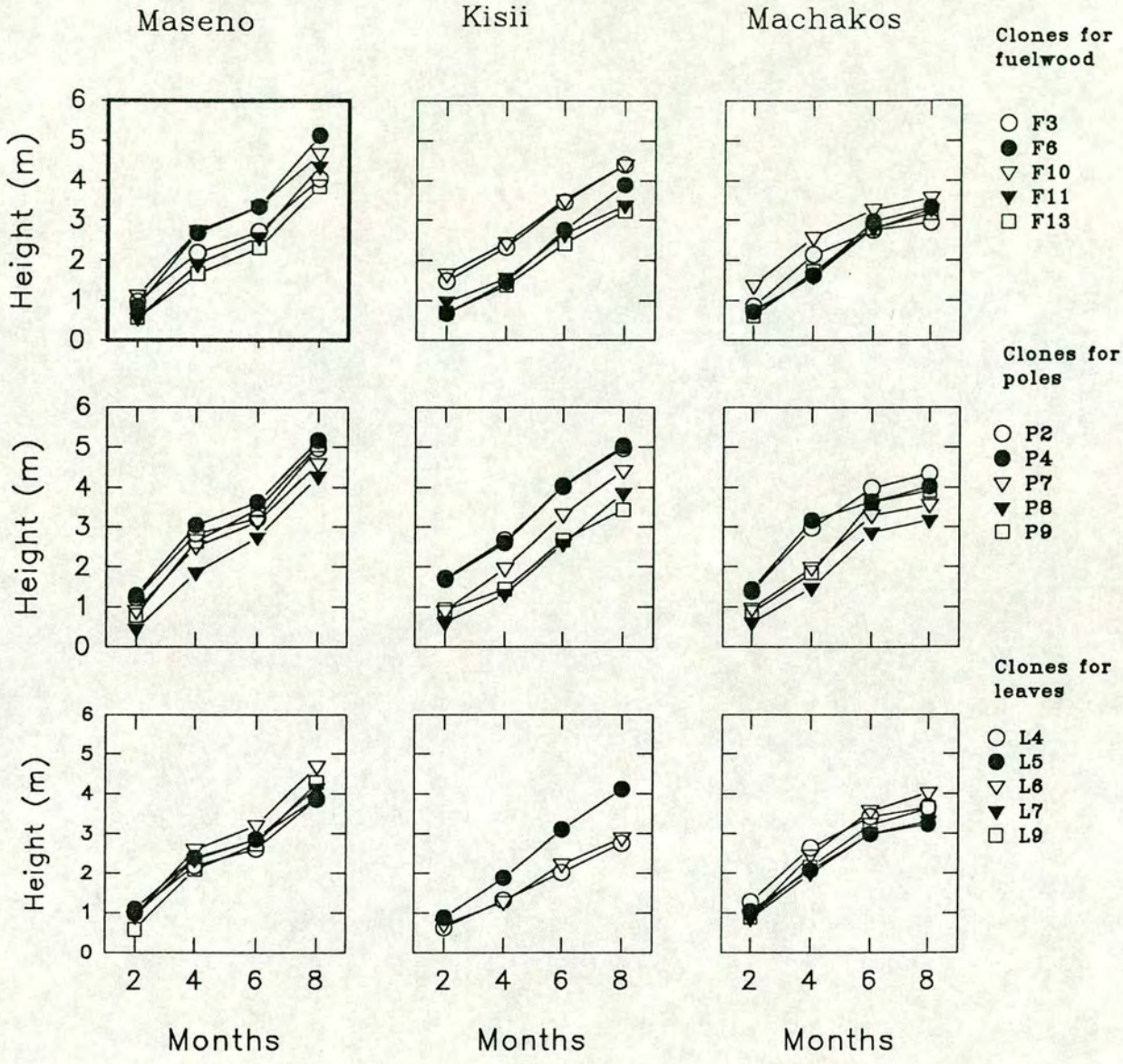

Fig. 4.2. Variation with time in height growth (m) of Sesbania sesban clones at Maseno, Kisii and Machakos, Kenya.

Clones selected for fuelwood (F), poles (P) and leaves (L).

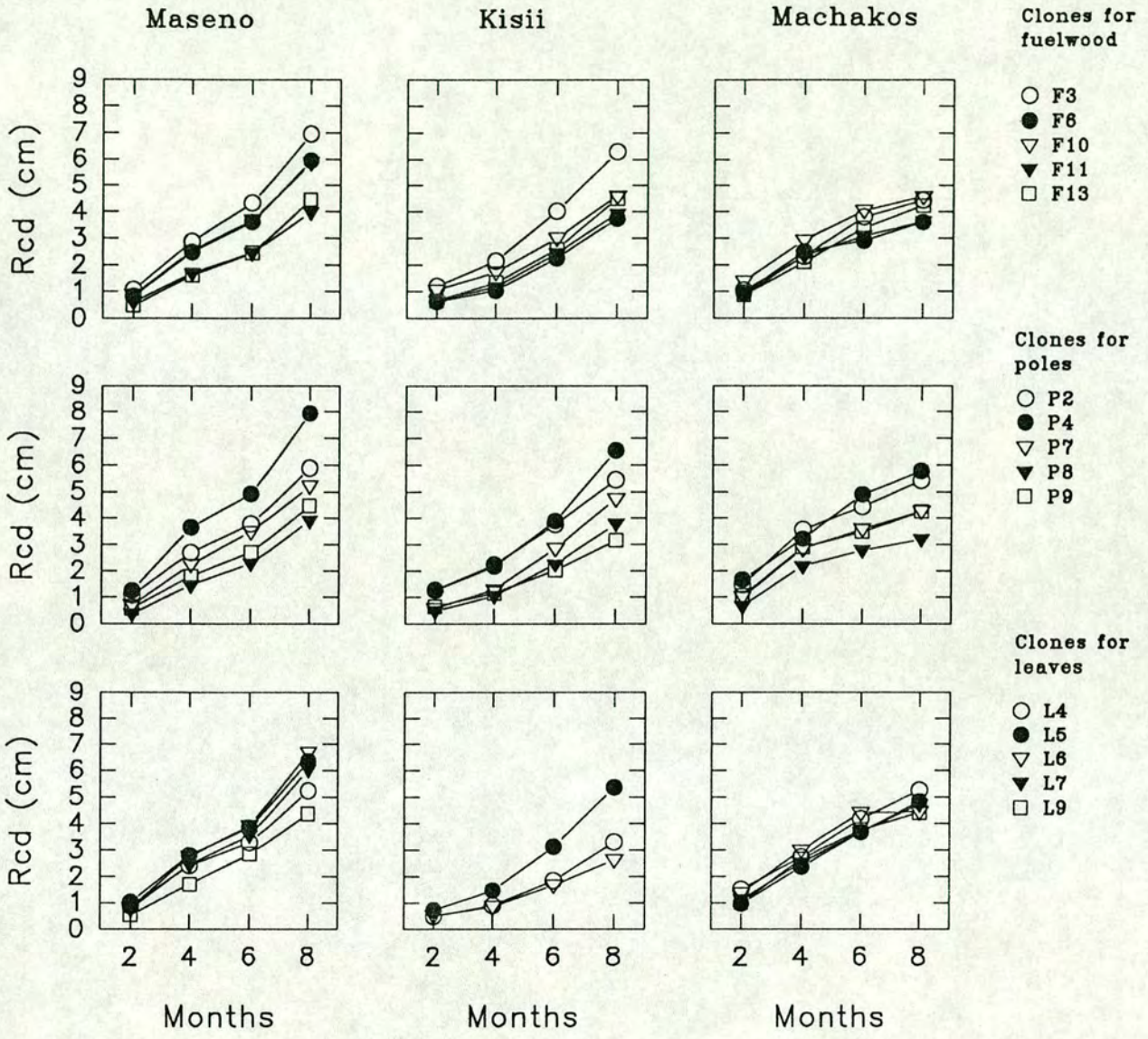

Fig. 4.3. Variation with time in root collar diameter (cm) growth of Sesbania sesban clones at Maseno, Kisii and Machakos, Kenya. Clones selected for fuelwood (F), poles (P) and leaves (L).

growth rate of 0.42±0.09 cm month^{-1} between four and eight months. Clones F3 and F10 tended to have greater root collar diameter among clones selected for fuelwood (Fig. 4.3), while among clones selected poles, P4 and P2 (Fig. 4.3) had relatively greater root collar diameters. Among clones selected for leaves, L7 had greater root collar diameter (Fig. 4.3).

At Machakos, root collar diameter had a sigmoid curve. Growth rates in root collar diameter between two and four months was 0.52±0.11 cm month^{-1} dropping to 0.36±0.09 and 0.34±0.03 cm month^{-1} between four to six and six to eight months, respectively. Overall there was no clear separation for those clones selected for fuelwood and leaves (Fig. 4.3) with respect to root collar diameters, while in clones selected for poles, P2 and P4 tended to have greater root collar diameters (Fig. 4.3).

4.8.1.3. Crown diameter.

At Maseno, the crown diameter growth curves for clones selected for fuelwood and poles showed clear separation (Fig 4.4). The growth rate in crown diameter for clones between four and six months was 0.21±0.05 m month^{-1}, this dropped to 0.12±0.06 m month^{-1} between six and eight months. Clones F3, F6 and F10 among clones selected for fuelwood (Fig. 4.4) and P2, P4 and P7 among clones selected for poles (Fig. 4.4) tended to have greater crown diameters while in clones selected for leaves there was no clear separation in the growth curves (Fig. 4.4).

At Kisii, crown diameter curves were distinctive among clones (Fig. 4.4). Growth rate in crown diameter for clones between four and six months was 0.22±0.06 m month^{-1} and between six and eight months was 0.21±0.05 m month^{-1}. Clone F3 and F10 had greater crown diameters among clones selected for fuelwood (Fig. 4.4). While P2, P4 and P7 among clones selected for poles and L5 and L7 among clones selected for leaves had greater crown diameters (Fig. 4.4).

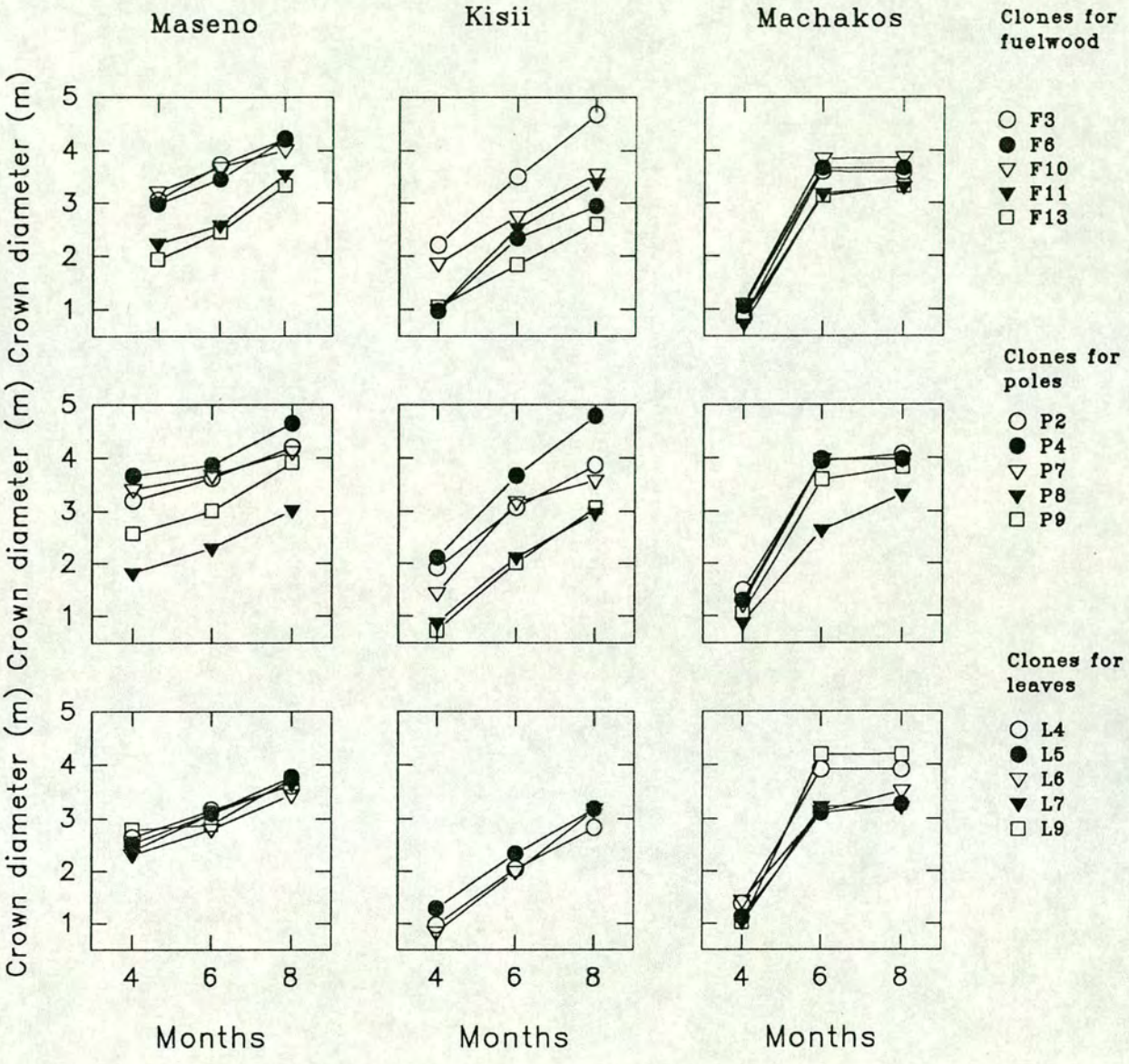

Fig. 4.4. Variation with time in crown diameter (m) growth of Sesbania sesban clones at Maseno, Kisii and Machakos, Kenya.

Clones selected for fuelwood (F), poles (P) and leaves (L).

At Machakos, mean crown diameter growth rates for clones between four and six months was 1.25±0.03 m month^{-1}, dropping to 0.04±0.01 m month^{-1} between six and eight months. Clones F3, F6 and F10 among clones selected for fuelwood, P2, P4, P7 and P9 in clones selected for poles and L4 and L9 in clones selected for leaves had greater crown diameters (Fig. 4.4).

There was a general increase in crown diameter at Maseno and Kisii between times of measurement, while at Machakos crown diameter growth drastically dropped between six and eight months, a factor attributed to the dry period at the site.

The general performance of clones was slightly better at Maseno site than at Kisii and Machakos, as the clones at Maseno tended to have relatively greater heights, root collar diameters and crown diameters.

4.9. Correlation among characters.

Phenotypic correlations between final growth measurements (at eight months) and earlier measurements of the same characters were examined. Correlations for combined sites (Maseno, Kisii and Machakos) at the individual tree level are presented in Table 4.4 (all correlations were significant at $P \leq 0.001$). Heights (HT), root collar diameters (RCD) at 0.15 m and crown diameter (CW) were positively correlated with earlier measurements. Phenotypic correlations for height increased with age from 0.67 between height at 2 and 8 months to 0.86 between height at 6 and 8 months. The highest correlation for heights was between 4 and 6 months ($r=0.92$, Table 4.4). Correlations for root collar diameters increased with age from 0.67 between 2 and 8 months to 0.90 between 6 and 8 months. The highest correlation for RCD was between 4 and 6 months ($r=0.93$, Table 4.4). Phenotypic correlations for crown diameter followed the same trend increasing from 0.74 between 4 and 8 to 0.85 between 6 and 8 months. The highest correlation was between CW at 4 and CW at 6 months ($r= 0.93$, Table 4.4). The phenotypic correlations between variables tended to increase with age.

Table 4.4. Sesbania sesban clonal phenotypic correlations on individual tree basis for height, root collar diameter and crown diameter development from 2 to 8 months of age in the field at three sites, Maseno, Kisii and Machakos in Kenya.

Trait	1	2	3	4	5	6	7	8	9	10	11
1. HT at 2 months		0.75a	0.77a	0.80a	0.69a	0.72a	0.79a	0.73a	0.67a	0.76a	0.67a
2. RCD at 2 months			0.69a	0.86a	0.78a	0.58a	0.81a	0.71a	0.39a	0.67a	0.53a
3. HT at 4 months				0.74a	0.76a	0.92a	0.73a	0.77a	0.75a	0.67a	0.69a
4. RCD at 4 months					0.77a	0.66a	0.93a	0.74a	0.50a	0.84a	0.84a
5. CW at 4 months						0.67a	0.75a	0.93a	0.50a	0.63a	0.74a
6. HT at 6 months							0.68a	0.72a	0.86a	0.69a	0.71a
7. RCD at 6 months								0.75a	0.56a	0.90a	0.66a
8. CW 6 months									0.62a	0.65a	0.85a
9. HT at 8 months										0.67a	0.70a
10. RCD at 8 months											0.72a
11. CW at 8 months											

HT = Height (m).
RCD = Root collar diameter at 0.15m (cm).
CW = Crown diameter (m).
Degrees of freedom for all combinations 311.
a = significant at P≤0.001.

4.10. Variance components and broad sense heritability estimates (H^2).

Variance components were estimated for clone, clone by site interaction and error following a VARCOMP with REML (restricted maximum likelihood) analysis. Ratios of total genetic to phenotypic variance (broad-sense heritability) and their standard errors, coefficients of phenotypic and genotypic variation were calculated for data at 8 months.

Broad-sense heritability (H^2) was estimated according to Falconer (1989). For combined sites:

$$H^2 = \frac{\delta^2_c}{\delta^2_c + \delta^2_{cs} + \delta^2_e}$$

and for single sites:-

$$H^2 = \frac{\delta^2_c}{\delta^2_c + \delta^2_e}$$

where: σ^2_c = clone variance

σ^2_e = error variance

σ^2_{cs} = clone by site interaction

Standard errors for broad-sense heritability were estimated according to Swiger et al. (1964) and Becker (1967).

Coefficient of phenotypic variation was calculated by dividing the phenotypic standard deviation by the phenotypic mean (δ_p/x_p).

Coefficient of genotypic variation was calculated by dividing the product between phenotypic standard deviation and square root of heritability by the phenotypic mean ($\delta_p\sqrt{h}/x_p$).

Where : δ_p = phenotypic standard deviation

x_p = phenotype mean

$h = \sqrt{H^2}$ (broad-sense heritability)

Table 4.5. Clone means, range of clone means, variance components, broad-sense heritabilities (H^2), standard errors (±), coefficients of phenotypic and genotypic variation for height, root collar diameter and crown diameter for Sesbania sesban after 8 months growth at Maseno, Kisii and Machakos, Kenya.

Trait	Test mean	Range of means	Clone variance	Clone x site variance	Error variance	H^2	Standard error for H^2	coefficient of phenotypic variation	Coefficient of genotypic variation
Combined sites									
Height (m)	3.97	3.27-4.70	0.126	0.080	0.50	0.18	0.01	0.18	0.07
RCD (cm)	4.78	3.93-6.72	0.620	0.128	1.917	0.24	0.05	0.29	0.14
Crown width (m)	3.58	2.77-4.26	0.111	0.047	0.497	0.17	0.01	0.19	0.08
Maseno site									
Height (m)	4.48	3.86-5.17	0.178		0.316	0.36	0.03	0.12	0.07
RCD (cm)	5.41	3.91-7.94	1.161		1.783	0.39	0.03	0.25	0.15
Crown width (m)	3.85	3.02-4.65	0.141		0.316	0.31	0.03	0.15	0.08
Kisii site									
Height (m)	3.88	2.76-5.04	0.319		0.191	0.21	0.03	0.28	0.13
RCD (cm)	4.39	2.63-6.54	0.803		3.343	0.19	0.03	0.42	0.18
Crown width (m)	3.42	2.61-4.79	0.205		1.093	0.16	0.02	0.31	0.12
Machakos site									
Height (m)	3.50	2.51-4.21	0.121		0.286	0.30	0.03	0.15	0.08
RCD (cm)	4.37	3.19-5.78	0.317		1.216	0.21	0.02	0.25	0.11
Crown width (m)	3.41	3.22-3.95	0.132		0.330	0.28	0.03	0.17	0.09

RCD = Root collar diameter at 0.15m.

Estimates of broad-sense heritability (on individual tree basis) and their standard errors, coefficients of phenotypic and genetic variation for combined sites and single site are presented in Table 4.5. The H^2 values estimated following analyses for combined sites was 0.18 for height, 0.24 for root collar diameter and 0.17 for crown diameter after 8 months. At the individual site level, H^2 values for height were 0.36, 0.21 and 0.30 for Maseno, Kisii and Machakos respectively. The H^2 values for root collar diameter were 0.39, 0.19 and 0.21 and for crown diameter was 0.31, 0.16 and 0.28 for Maseno, Kisii and Machakos respectively. The broad-sense heritabilities were relatively higher at the individual sites than for the combined sites. The coefficient of phenotypic and genotypic variation for combined sites and individual sites were higher for root collar diameter than for height and crown diameter.

4.11. CROWN CHARACTERISTICS.

4.11.1. Branch morphology.

The GLM results of means, standard error, variance ratios and coefficient of variation for crown characteristics for S. sesban at 4 and 8 months growth for the three sites (Maseno, Kisii and Machakos) are presented in Tables A4.3 and A4.4. S. sesban clones varied in branch (primary) characteristics, resulting in differences in branch pattern and crown form. After four and eight months of growth there was no significant difference in the assessed branch characteristics between tree zones (Table A4.3 and A4.4).

After four months growth significant differences in branch length were observed between sites and clones at $P \leq 0.05$, while there was no clone by site interaction (Table A4.3). Branch basal diameter was significantly different between sites ($P \leq 0.01$) and clones ($P \leq 0.05$) but no significant differences were observed between zones and clone by site interaction (Table A4.3). Branch angles of origin and termination were significant different between sites ($P \leq 0.001$), clones ($P \leq 0.01$)

and clone by site interaction (P≤0.001), (Table A4.3). Leaf number per branch was significantly different between sites and clones (P≤0.05) while clone by site interaction was not significant (Table A4.3). Leaf area per branch was only significantly different between clones (P≤0.05, Table A4.3). Crown diameter (the crown diameter here is the mean of diameters taken at the lower, middle and upper zones of the tree) was only significantly different between clones P≤0.05 (Table A4.3).

After eight months growth in the field, significant differences in length of primary branch were observed only between sites (P≤0.001, Table A4.4). While there was no significant differences in basal diameter of primary branches (Table A4.4). Branch angles of origin and termination were significantly different between sites, clone and clone by site interaction at P≤0.001 (Table A4.4). Leaf number per branch was only significantly different between clones (P≤0.05) and leaf area per branch was significantly different between sites and clone (P≤0.05, Table A4.4). Crown diameter was significantly different between sites, clones at P≤0.001 and clone by site interaction (P≤0.05, Table A4.4).

Figures 4.5 to 4.9 show variation in crown characteristics at four and eight months for S. sesban clones grown at Maseno, Kisii and Machakos.

4.11.2. Branch length.

The variation in primary branch length for the three sites (Maseno, Kisii and Machakos) is shown in Figure 4.5. Mean branch length increase between four and eight months was 0.30 m month^{-1} at Maseno, 0.25 and 0.12 m month^{-1} for Kisii and Machakos respectively. At Maseno clones P4, L6 and L5 at four months and P4, P9 and F3 at eight months ranked higher in branch length, while L9 ranked lowest at both four and eight months (Fig. 4.5). At Kisii clones F3, F10 and P4 ranked high in branch lengths at 4 and 8 months while L5 ranked lowest for the same period (Fig. 4.5). Clones P4, P2 and P7 at four months and F10, P2 and P4 at eight months ranked higher in branch lengths while P8 ranked lowest for the same

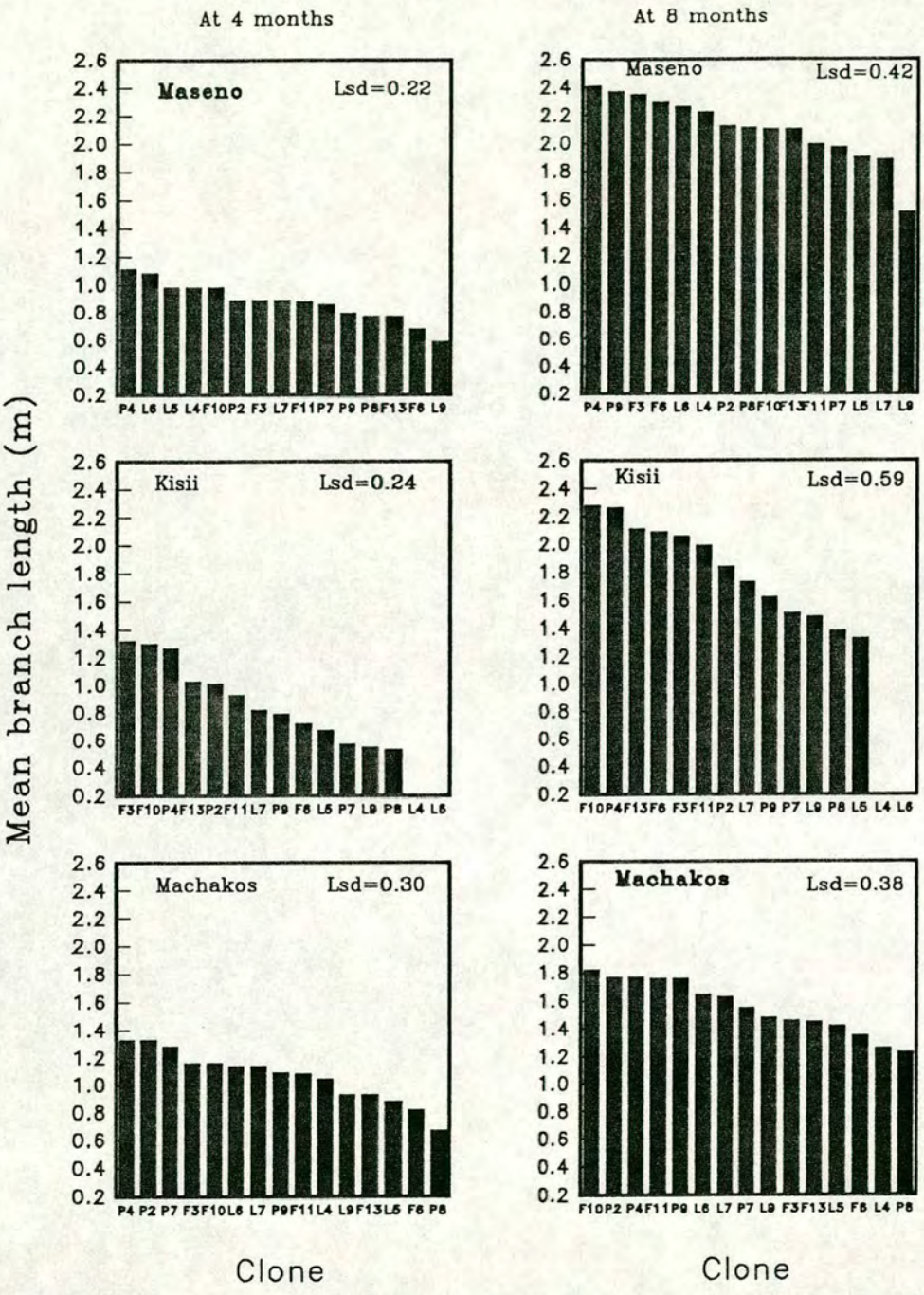

Fig. 4.5. Mean branch length in metres (n=12) of Sesbania sesban clones after 4 and 8 months growth in Maseno, Kisii and Machakos, Kenya.

period at Machakos (Fig. 4.5).

4.11.3. Branch diameter.

The development of branch diameter generally matched the evolution of branch length for all clones at the three sites (Fig. 4.6). The greatest increase in branch diameter between four and eight months was 0.18 cm month^{-1} at Maseno and Kisii, while at Machakos was 0.09 cm month^{-1}. Clones P4, L6 and F3 at four and eight months had greater branch diameters while clones P9 and L9 had the least branch diameter at Maseno (Fig. 4.6). Clones F3, P4 and P2 at four months and P4, F6 and F3 at eight months had greater branch diameters at Kisii while the least branch diameters were recorded in L5 and P7 at four months and P8 and L5 at eight months (Fig. 4.6). At Machakos clones P2 and P4 had greater branch diameters at four and eight months while P8 had the least branch diameters (Fig. 4.6).

4.11.4. Crown diameter.

The variation in crown diameter for the clones is shown in Figure 4.7. The mean crown diameter increase between four and eight months was 0.38 m month^{-1} at Maseno, while for Kisii and Machakos crown diameter increase was 0.03 and 0.04 m month^{-1} respectively. Clones P4 and F10 at four months and P4, P2 and F10 at eight months had the widest crowns while L9 and L4 had smaller crowns at four and eight months respectively at Maseno (Fig. 4.7). At Kisii clones F3 and F10 at four months and P4, P2 at eight months had the widest crowns at Kisii while for the same period P9 had the smallest crown (Fig. 4.7). Machakos site had wider crowns in clone P7 and smaller crowns in P8 at four and eight months respectively (Figs. 4.7).

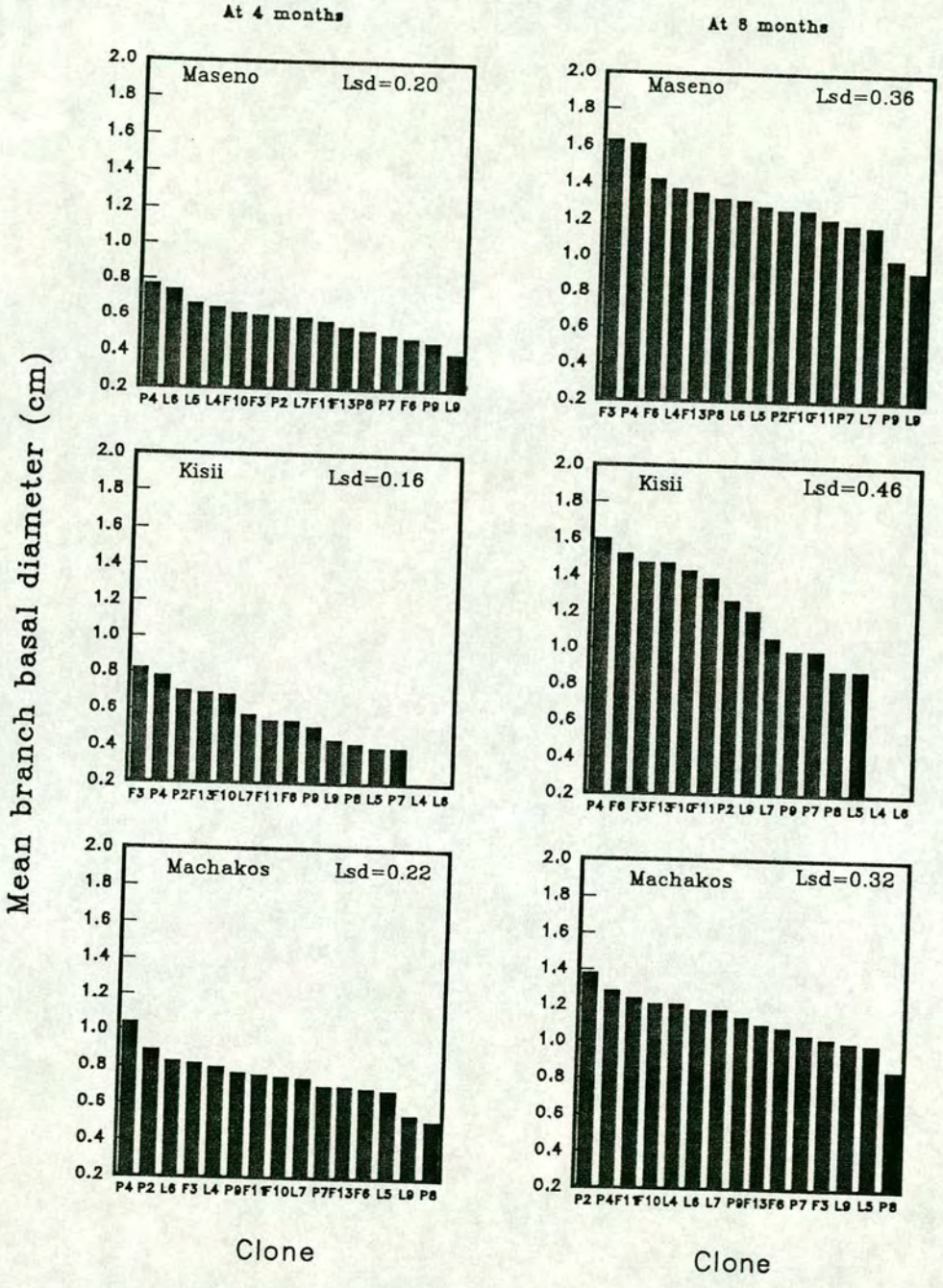

Fig.4.6. Mean branch basal diameter (cm) for Sesbania sesban clones after 4 and 8 months growth in Maseno, Kisii and Machakos, Kenya. (n=12).

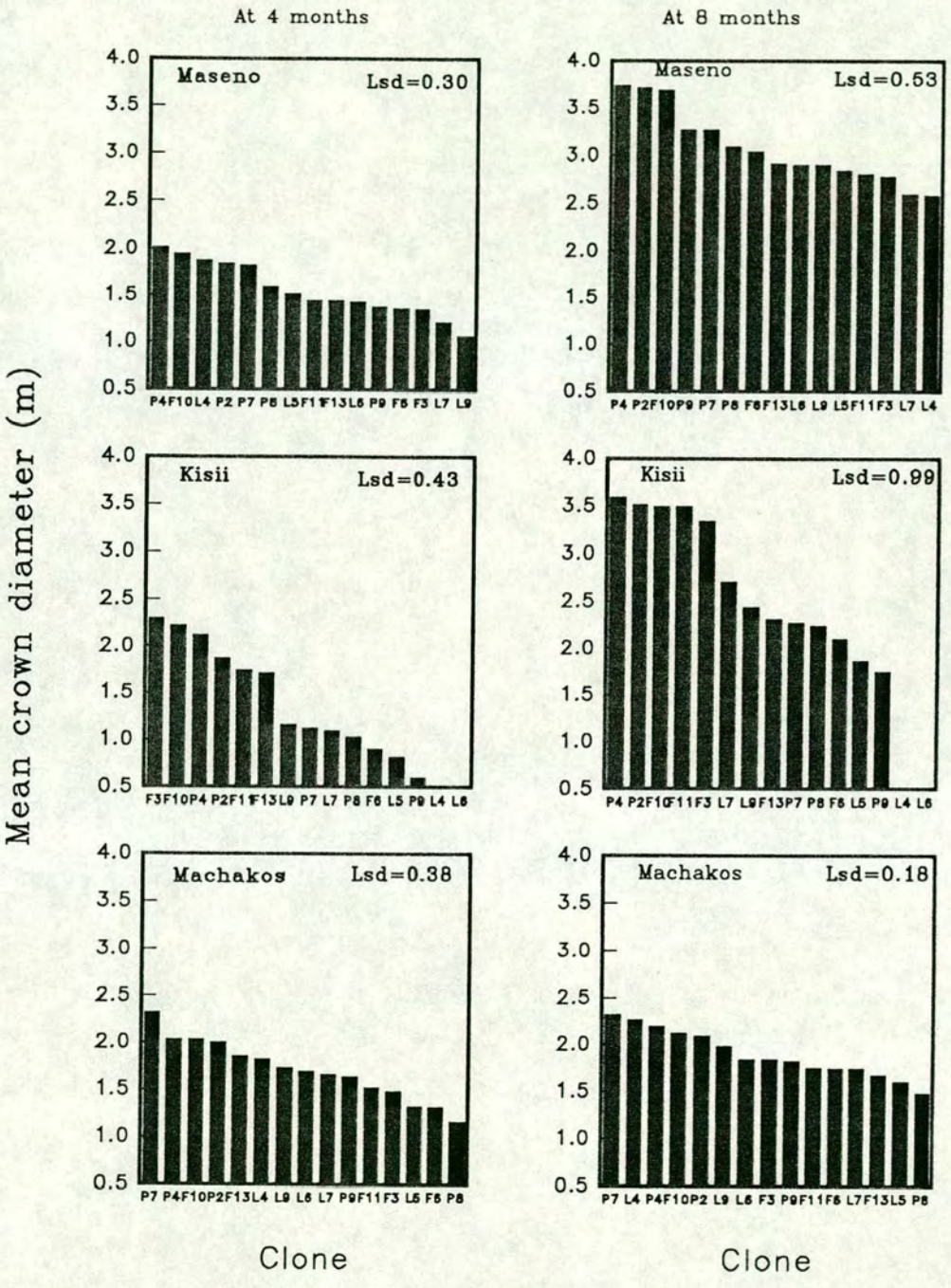

Fig. 4.7. Mean crown diameter in metres of Sesbania sesban clones after 4 and 8 months growth in Maseno, Kisii and Machakos, Kenya.

4.11.5. Branch orientation.

Branch inclination (angle of origin and inclination) for Sesbania sesban clones for the three sites is presented in Table 4.6 and 4.7. Significant variation in angles of origin and termination for primary branches were observed at four and eight months. At four months branch angles of origin ranged from 57° to 82° at Maseno from 59° to 82° at Kisii and 55° to 74° at Machakos while the branch angles of termination ranged from 55° to 71° at Maseno, 53° to 73° at Kisii and at Machakos from 42° to 60° (Table 4.6).

At eight months the branch angles of origin ranged from 66° to 80° at Maseno, 63° to 81° at Kisii and 64° to 77° at Machakos while the branch angles of termination ranged from 49° to 74° at Maseno, from 45° to 75° at Kisii and 41° to 55° at Machakos (Table 4.7). At both four and eight months Machakos site tended to have the smallest angles of origin and termination for the clones (Tables 4.6, 4.7). It is also interesting to note that the clonal ranking for angles of origin and termination are not similar (Tables 4.6, 4.7) and the branches were curved towards the stem. Some clones which had smaller angles of origin tended to have also small angles of termination. For example at Maseno clone F3 had smaller angle of origin and termination, while P9 had the biggest angle of origin and termination. At Kisii L5 had the smallest angle of origin and termination while F6 had the biggest angle of origin and termination. At Machakos L4 had smaller angle of origin and termination while F11 had the biggest angle of origin and termination. Figures 4.8a, 4.8b and 4.8c show the typical clonal phenograms at eight months for S. sesban clones at Maseno, Kisii and Machakos, drawn to scale for clonal means of height, number of branches (for clarity the number of branches is represented by a few branches), mean branch length and angles of origin and termination. Branch curvature was drawn for the correct angles of origin and termination for each particular branch lengths.

Table. 4.6. Average branch angles (°) of origin and termination for Sesbania sesban clones grown at Maseno, Kisii and Machakos after four months growth.

Clone	Angle of origin, degrees			Clone	Angle of termination, degrees		
	Maseno	Kisii	Machakos		Maseno	Kisii	Machakos
F3	57	68	64	F3	55	60	59
F6	68	82	56	F6	59	72	45
F10	78	71	64	F10	68	57	50
F11	77	71	74	F11	64	64	61
F13	75	71	61	F13	64	60	51
P2	73	71	70	P2	68	60	59
P4	78	70	63	P4	65	60	49
P7	68	67	69	P7	61	61	60
P8	78	74	67	P8	68	68	51
P9	82	71	71	P9	71	70	56
L4	70	-	55	L4	60	-	50
L5	67	59	64	L5	57	55	53
L6	69	-	58	L6	58	-	46
L7	68	66	59	L7	55	53	42
L9	71	79	56	L9	62	73	53
Mean	72	71	64	Mean	62	62	52
Se	5	3	6	Se	5	3	6

Table 4.7. Average branch angles (°) of origin and termination for Sesbania sesban clones grown at Maseno, Kisii and Machakos after eight months growth.

Clone	Angle of origin, degrees			Clone	Angle of termination, degrees		
	Maseno	Kisii	Machakos		Maseno	Kisii	Machakos
F3	72	69	65	F3	59	61	49
F6	78	78	74	F6	58	53	53
F10	76	72	64	F10	68	56	41
F11	74	77	77	F11	63	75	54
F13	73	69	66	F13	60	56	52
P2	77	70	71	P2	74	66	60
P4	78	71	62	P4	65	58	45
P7	68	63	70	P7	59	52	53
P8	74	73	71	P8	56	58	50
P9	80	81	72	P9	68	69	55
L4	74	-	63	L4	65	-	46
L5	70	63	71	L5	58	56	50
L6	75	-	62	L6	63	-	42
L7	66	64	65	L7	49	45	41
L9	72	81	64	L9	66	81	53
Mean	74	72	68	Mean	62	60	50
Se	3	3	3	Se	3	4	5

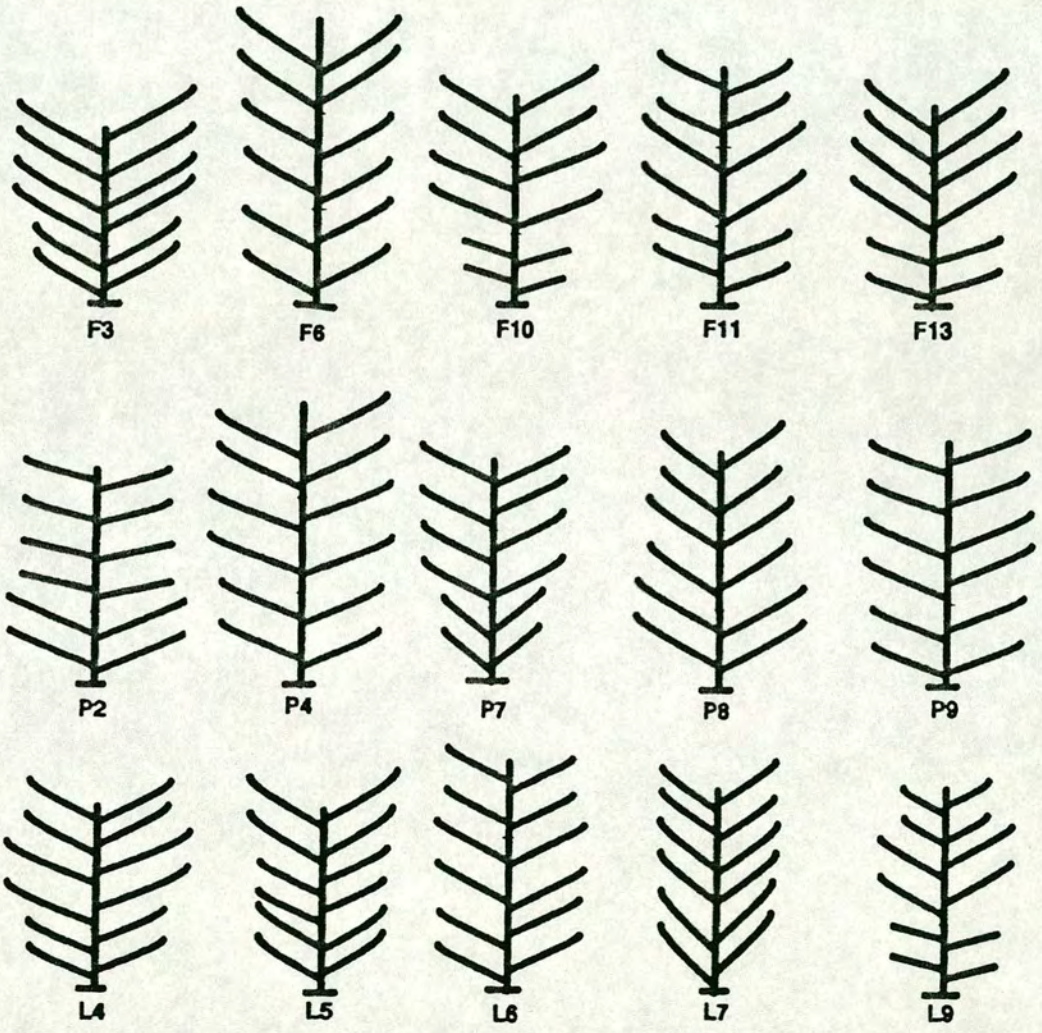

Fig. 4.8a. Phenograms for Sesbania sesban clones after 8 months growth at Maseno.

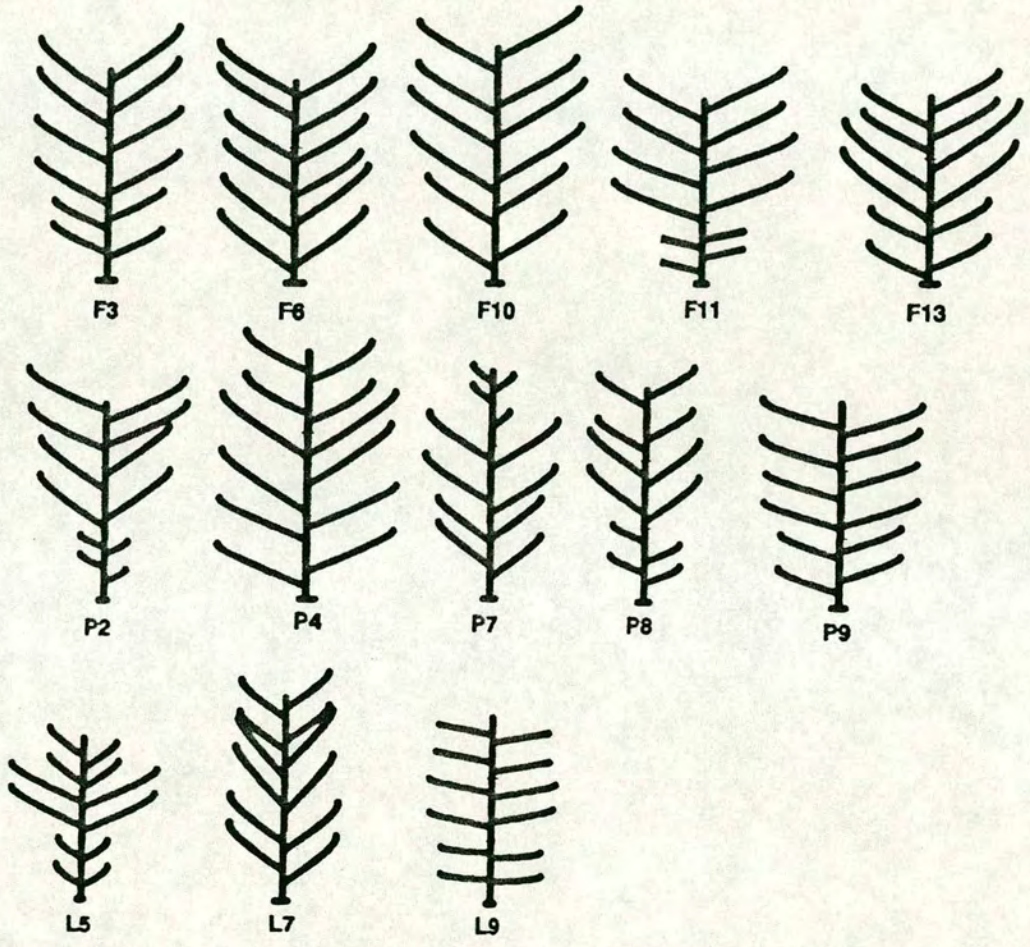

Fig. 4.8b. Phenograms for Sesbania sesban clones after 8 months growth at Kisii.

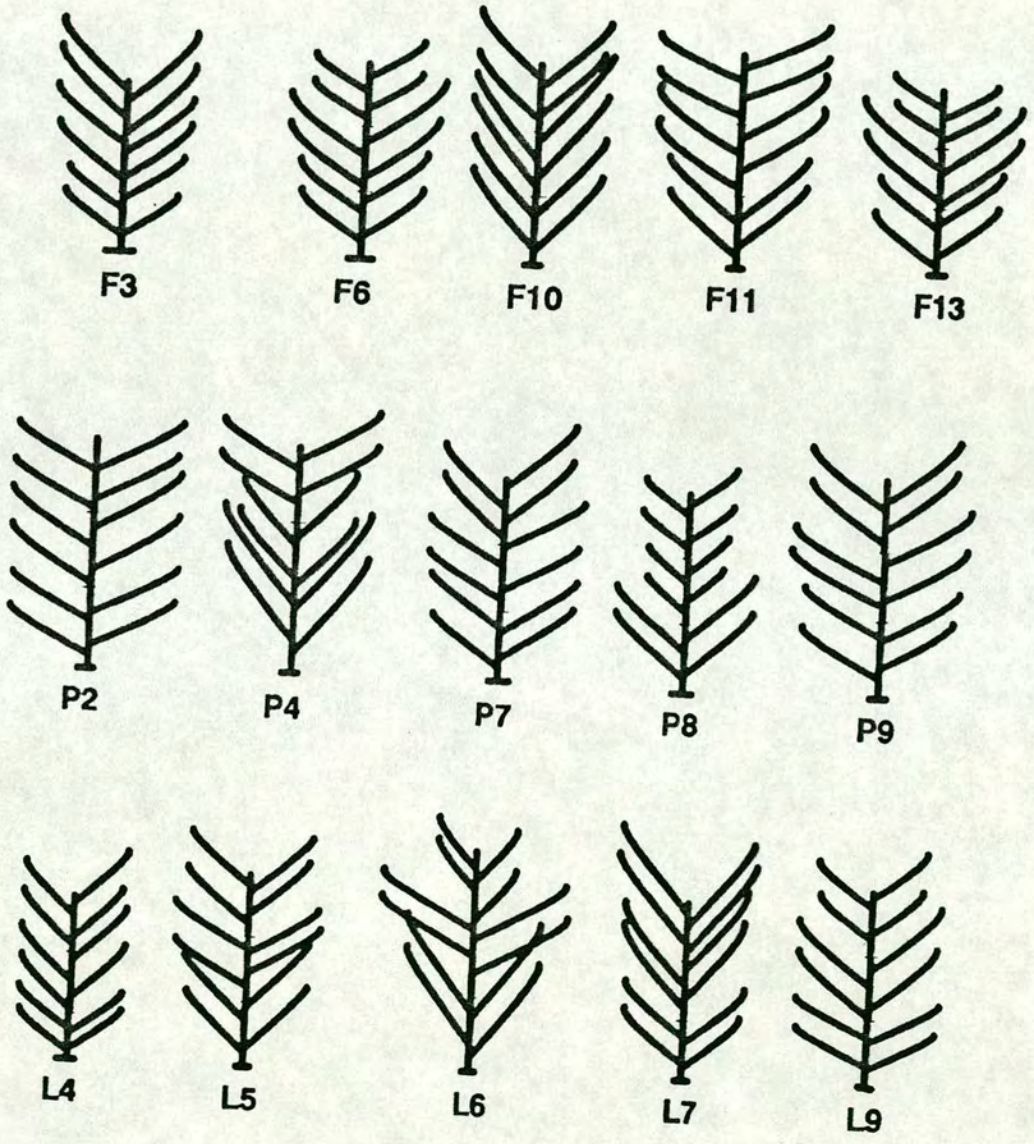

Fig. 4.8c. Phenograms for Sesbania sesban clones after 8 months growth at Machakos.

4.11.6. Leaf area.

The mean leaf areas per branch for S. sesban clones grown at Maseno, Kisii and Machakos are presented in Figure 4.9. There was a general increase in mean leaf area per branch in clones between four and eight months at all sites (Fig. 4.9). Clones P4 and F3 at Maseno and Kisii had greater mean leaf areas per branch at four and eight months while P9 had smaller mean leaf areas per branch at both sites (Figs. 4.9). At Machakos the leaf area per branch was greater in clone P4 at four and eight months while clone P8 and F3 had smaller leaf areas per branch at four and eight months respectively (Fig. 4.9).

4.11.7. Correlations among crown characteristics.

The phenotypic correlations among crown characteristics of S. sesban clones at eight months for the three sites are listed it Table 4.11. Correlations were used to show how crown traits vary with each other. Strong correlations were observed between branch characteristics. Branch diameter was observed to be significantly correlated with branch length at eight months ($P \leq 0.001$, $r^2=0.93$), an example of this linear relationship is depicted in Figure 4.10. Other correlations between branch length were leaf number (r=0.82), leaf area (r=0.77) and crown width (r=0.69). Branch diameter was also strongly correlated with leaf number (r=0.87), leaf area (r=0.84) and crown width (r=0.63). Low significant correlations were observed between branch angle of origin with length of primary branch (r=0.38) and branch diameter (r=0.35). Low correlations existed between branch number and most of the crown characteristics.

4.11.8. Variance components and broad-sense heritabilities (H^2)

Clone variance, error variance and broad-sense heritabilities with their standard errors, coefficients of phenotypic and genetic variation on individual tree basis for

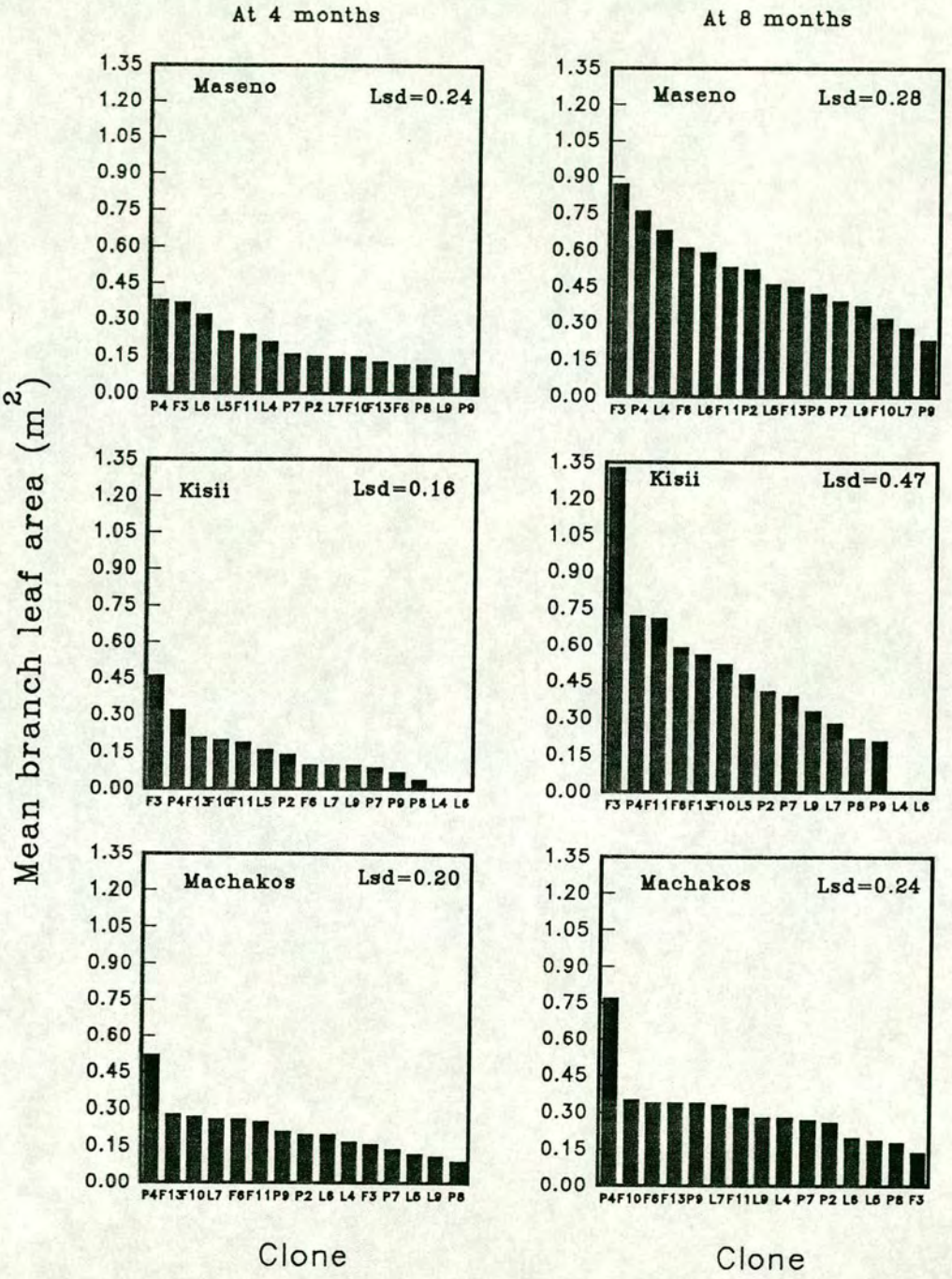

Fig. 4.9. Mean branch leaf area (m^2) for Sesbania sesban clones after 4 and 8 months growth in Maseno, Kisii and Machakos, Kenya.

Table 4.8. Phenotypic correlations for crown characteristics of Sesbania sesban clones at eight months grown for three sites (at Maseno, Kisii and Machakos) in Kenya.

Trait	1	2	3	4	5	6	7	8
1. Branch length* (m)		0.93a	0.38a	-0.02ns	0.82a	0.77a	0.69a	0.12c
2. Branch diameter (cm)			0.35a	-0.07ns	0.87a	0.84a	0.63a	0.11c
3. Angle of origin (°)				0.56a	0.26a	0.29a	0.42a	0.06ns
4. Angle of termination (°)					-0.07ns	-0.02ns	0.27a	0.04ns
5. Leaf number (count)						0.93a	0.56a	0.13a
6. Leaf area (m^2)							0.57a	0.08ns
7. Crown diameter (m)								0.21a
8. Number of branches								

* Branch refers to primary branches
a = Significant at P<0.001
b = Significant at P<0.01
c = Significant at P<0.05
ns = Not significant
Degrees of freedom for all combinations = 384.

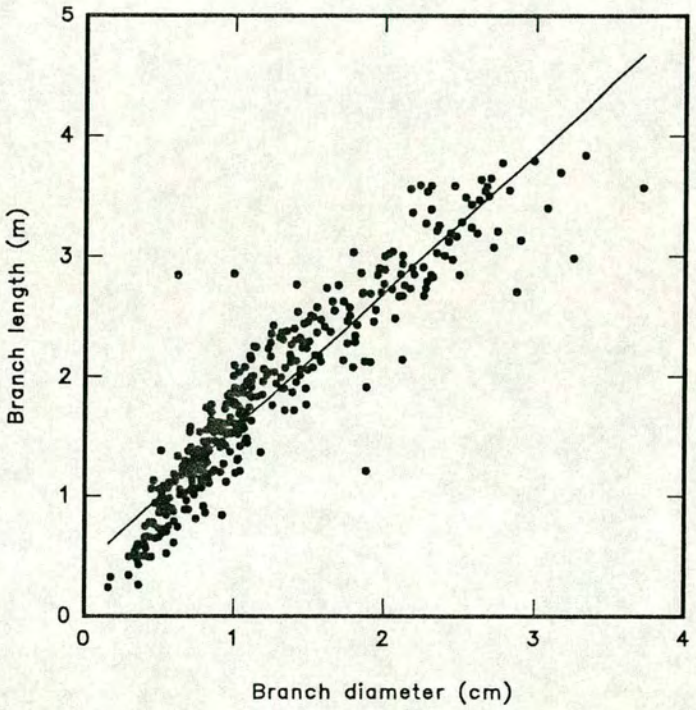

Fig. 4.10. Relationship between branch length and branch diameter for Sesbania sesban clones grown at three sites (Maseno, Kisii and Machakos), Kenya, at 8 months. Y = 0.42 + 1.14(x) r^2 =0.93, n=378.

Table 4.9. Means, range of clone means, variance components, broad-sense heritabilities, standard error, coefficients of phenotypic and genetic variation for crown traits in Sesbania sesban clones after eight months growth at Maseno, Kenya.

Traits	Test mean	Range of means	Clone variance σ^2c	Error variance σ^2e	H^2 $\frac{\sigma^2c}{\sigma^2c+\sigma^2e}$	Standard error for H^2	Coefficient of phenotypic variation	Coefficient of genetic variation
Branch length (m)	2.05	1.51-2.30	0.0203	0.1724	0.10	0.03	0.20	0.15
Branch diameter (cm)	1.29	0.91-1.63	0.0224	0.1235	0.15	0.05	0.27	0.30
Angle of origin (°)	74	67-80	12.4210	27.1444	0.31	0.08	0.07	0.01
Angle of termination (°)	62	48-74	30.2580	50.5124	0.37	0.09	0.11	0.01
Leaf area (m^2)	0.50	0.23-0.87	0.0234	0.0836	0.22	0.07	0.57	0.94
Crown diameter (m)	3.08	2.58-3.74	0.1185	0.2773	0.19	0.06	0.17	0.14

Table 4.10. Means, range of clone means, variance components, broad sense heritabilities, standard errors, coefficients of phenotypic and genetic variation for crown traits in Sesbania sesban clones after eight months growth at Kisii, Kenya.

Traits	Test mean	Range of means	Clone variance σ^2c	Error variance σ^2e	H^2 $\frac{\sigma^2c}{\sigma^2c+\sigma^2e}$	Standard error of H^2	Coefficient of phenotypic variation	Coefficient of genetic variation
Branch length (m)	1.83	1.28-2.28	0.0749	0.3809	0.16	0.06	0.32	0.22
Branch diameter (cm)	1.25	0.88-1.60	0.0435	0.2339	0.16	0.06	0.37	0.32
Angle of origin (°)	72	62-81	34.7213	34.2482	0.50	0.11	0.08	0.01
Angle of termination (°)	60	44-81	93.2192	72.2314	0.56	0.11	0.14	0.01
Leaf area (m^2)	0.52	0.28-0.71	0.0652	0.2302	0.22	0.07	0.91	0.42
Crown diameter (m)	2.68	1.56-3.59	0.3949	1.0159	0.28	0.09	0.37	0.19

Table 4.11. Means, range of clone means, variance components, broad-sense heritabilities, standard errors, coefficient of phenotypic and genetic variations for crown traits in Sesbania sesban clones after eight months growth at Machakos, Kenya.

Traits	Test mean	Range of means	Clone variance σ^2c	Error variance σ^2e	H^2 $\frac{\sigma^2c}{\sigma^2c+\sigma^2e}$	Standard error of H^2	Coefficient of phenotypic variation	Coefficient of genetic variation
Branch length (m)	1.56	1.23-1.82	0.0229	0.1436	0.14	0.05	0.24	0.24
Branch diameter (cm)	1.13	0.85-1.38	0.0065	0.1023	0.06	0.02	0.28	0.22
Angle of origin (°)	68	62-77	19.3857	43.0099	0.31	0.08	0.09	0.01
Angle of termination (°)	50	41-60	22.1733	90.4509	0.20	0.06	0.19	0.01
Leaf area (m^2)	0.31	0.14-0.36	0.0142	0.0611	0.19	0.06	0.79	1.41
Crown diameter (m)	1.89	1.48-2.26	0.0528	0.0374	0.58	0.10	0.10	0.40

most of the S. sesban clone crown traits at eight months grown at Maseno, Kisii and Machakos are presented in Tables 4.9 to 4.11. The broad-sense heritabilities for branch length was 0.10 for Maseno (Table 4.9), 0.16 for Kisii (Table 4.10) and 0.14 for Machakos (Table 4.11) while H^2 values for branch diameter were 0.15, 0.16 and 0.06 for Maseno, Kisii and Machakos respectively (Tables 4.9, 4.10, 4.11). Crown diameter, a complex character which reflects branch length and branch angle had relatively higher H^2 values of 0.19, 0.28 and 0.58 at Maseno, Kisii and Machakos respectively. Branch angles of origin and termination are the most highly heritable of the branch characters assessed as they had high H^2 values of 0.31, 0.50 and 0.31 for angle of origin and 0.37, 0.56 and 0.20 for angle of termination at Maseno, Kisii and Machakos respectively (Table 4.9, 4.10, 4.11). Clone variances for branch angles of origin and termination were relatively higher at the three sites than for other branch traits. Branch origin and termination also had low coefficients of phenotypic and genetic variation. Leaf area per branch had H^2 of 0.22 at Maseno and Kisii and 0.19 at Machakos, with high coefficients of phenotypic and genotypic variation.

4.12. BIOMASS PRODUCTION.

General linear model analysis results for the assessed variables on trees destructively sampled for biomass for combined sites (Maseno, Kisii and Machakos) and for single sites after nine months of growth are presented in appendices Tables A4.5 - A4.16. The results indicate significant differences between sites and clones in the assessed variables.

4.12.1. Growth attributes.

4.12.1.1. Height.

Total heights in destructively sampled S. sesban clones varied significantly

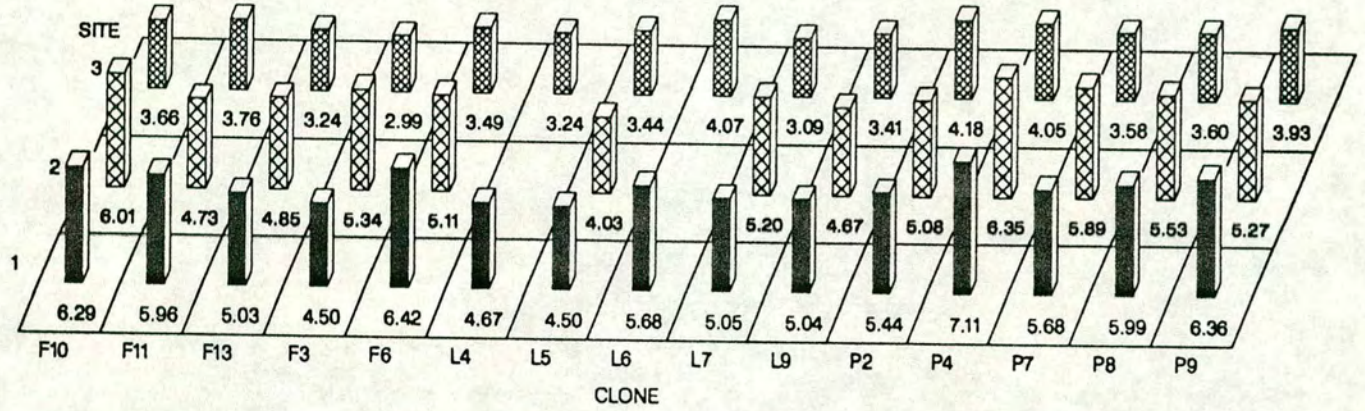

Fig. 4.11 Variation in height (m) among Sesbania sesban clones after 9 months growth at (1) Maseno (2) Kisii and (3) Machakos, sites in Kenya.

between sites, clone groups and clones ($P \leq 0.001$, Table A4.5). Mean heights for S. sesban clone groups was 4.75±1.30, 5.20±1.36 and 4.28±0.89 m for clones selected for fuelwood, poles and leaves respectively for clones combined sites. While mean heights for clones was 4.77±0.22 m (Table A4.5). Clone heights at Maseno ranged from 4.50 to 7.11 m, at Kisii from 4.03 to 6.35 m and at Machakos from 2.99 to 4.18 m (Fig. 4.11). For single sites significant differences in clone group heights were observed at Maseno ($P \leq 0.001$) and Machakos ($P \leq 0.05$). Clonal group means for heights were 5.64±0.84, 6.11±0.86 and 4.95±0.58 m for clones selected for fuelwood, poles and leaf respectively. At Machakos clonal group means for height were 3.42±0.45, 3.86±0.45 and 3.45±0.47 m for clones selected for fuelwood, poles and leaves respectively. Mean height for clones at Maseno was 5.58±0.30 m (Table A4.6) and 3.58±0.20 m at Machakos (Table A4.8). S. sesban clone heights were relatively higher at Maseno and Kisii than at Machakos.

4.12.1.2. Stem diameters.

Stem diameters at 0.15 and 0.30 m of S. sesban also varied significantly between sites and clones at $P \leq 0.001$ (Table A4.5). Stem diameter at 0.30 m for clone groups showed significant differences at Maseno ($P \leq 0.05$, Table A4.6). Mean stem diameters at 0.15 and 0.30 m for the combined sites were 5.88±0.47 and 4.98±0.36 cm respectively (Table A4.5), while for single sites significant differences in clones were observed at Maseno and Machakos (Tables A4.6 and A4.8). Clone P4, F3 and L6 ranked high in stem diameters at 0.15 at Maseno, Kisii and Machakos respectively (Fig. 4.12) and for stem diameter at 0.30 m clone P4 was ranked first Maseno and Kisii while L6 retained its superior position at Machakos (Fig. 4.13)

Stem diameters at 0.15 and 0.30 m like height were relatively higher at Maseno and Kisii than Machakos site (Figs. 4.12 and 4.13).

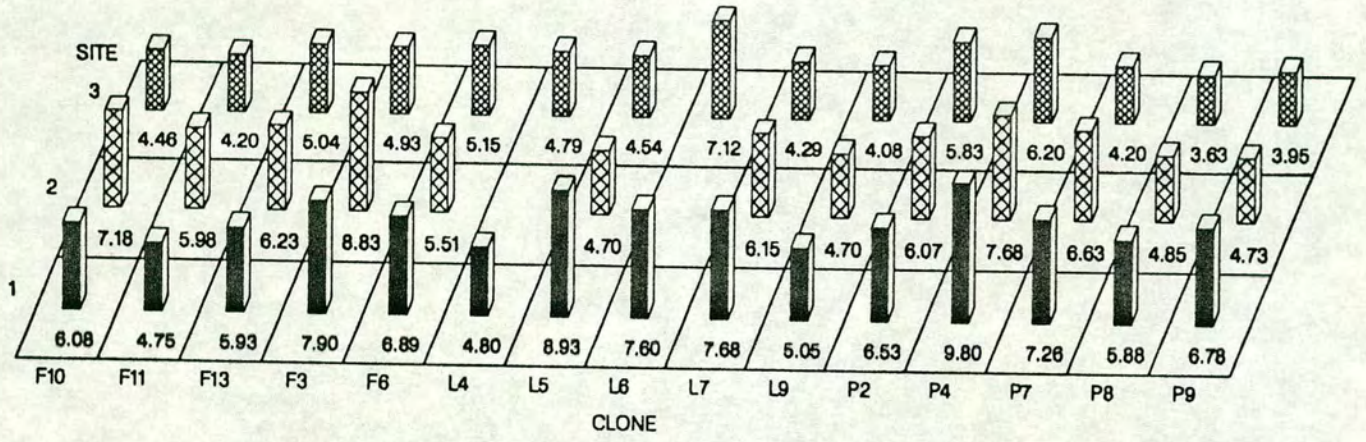

Fig. 4.12 Variation in root collar diameter at 0.15m (cm) among Sesbania sesban clones after 9 months growth at (1) Maseno (2) Kisii and (3) Machakos, sites in Kenya.

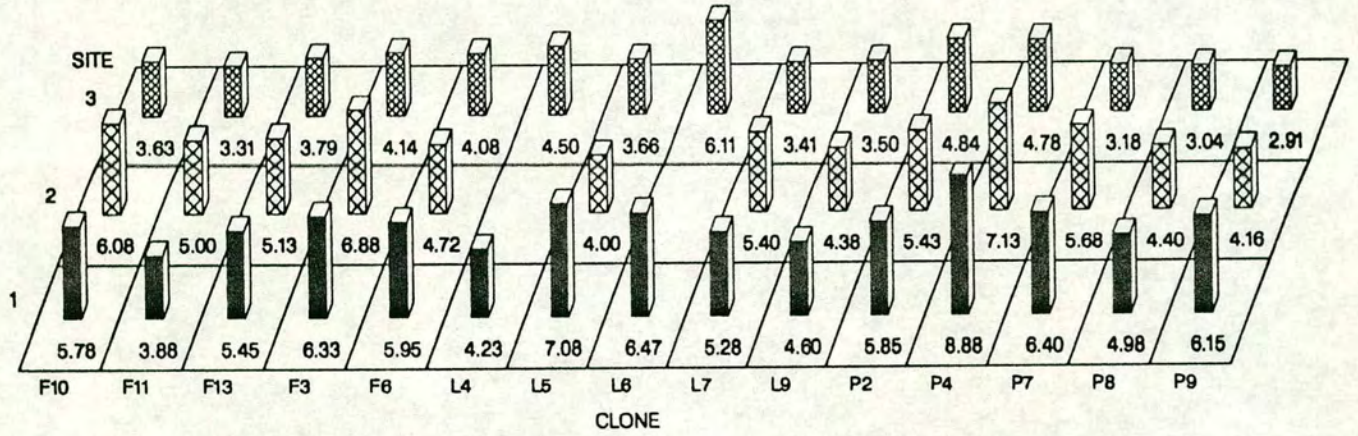

Fig. 4.13 Variation in root collar diameter at 0.30m (cm) among Sesbania sesban clones after 9 months growth at (1) Maseno (2) Kisii and (3) Machakos, sites in Kenya.

4.12.1.3. Number of branches.

Considerable genetic differences existed in number of primary branches per tree for S. sesban clones between sites, clonal group and clones (Table A4.5). For single sites, the number of branches per tree were significantly different between clones (Tables A4.6, A4.7, and A4.8), while clonal groups showed significant differences at Maseno and Machakos only. The mean number for branches for the combined sites was 59.16±3.17 (Table A4.5). Figure 4.14 shows the variability in the number of branches for the three sites. The range for the number of primary branches per tree for Maseno was from 55 to 97, at Kisii from 50 to 76 while at Machakos the number of branches per tree ranged from 29 to 58.

Branch frequency per metre (the total number of primary branches divided by tree height) was significantly different different between sites and clones ($P \leq 0.001$, Table A4.5). The mean branch frequency tree^{-1} for the three sites was 12.49±0.51 branches m^{-1} (Table A4.5). Significant differences in branch density were also observed at Maseno, Kisii and Machakos (Tables A4.6, A4.7 and A4.8) respectively. Figure 4.15 shows branch frequency m^{-1} for S. sesban clones at the three sites.

4.12.1.4. Crown diameter.

S. sesban clones showed significant differences in crown diameter between sites and clone ($P \leq 0.001$, Table A4.5). The mean crown diameter for the three sites was 3.17±0.23 m (Table A4.5). Crown diameter showed significant differences at single sites, of Maseno, Kisii and Machakos (Table A4.6, A4.7 and A4.8). Crown diameter ranged from 2.98 to 5.09 m at Maseno, at Kisii from 3.35 to 5.59 m and Machakos had the lowest crown diameters ranging from 1.21 to 2.68 m (Fig. 4.16).

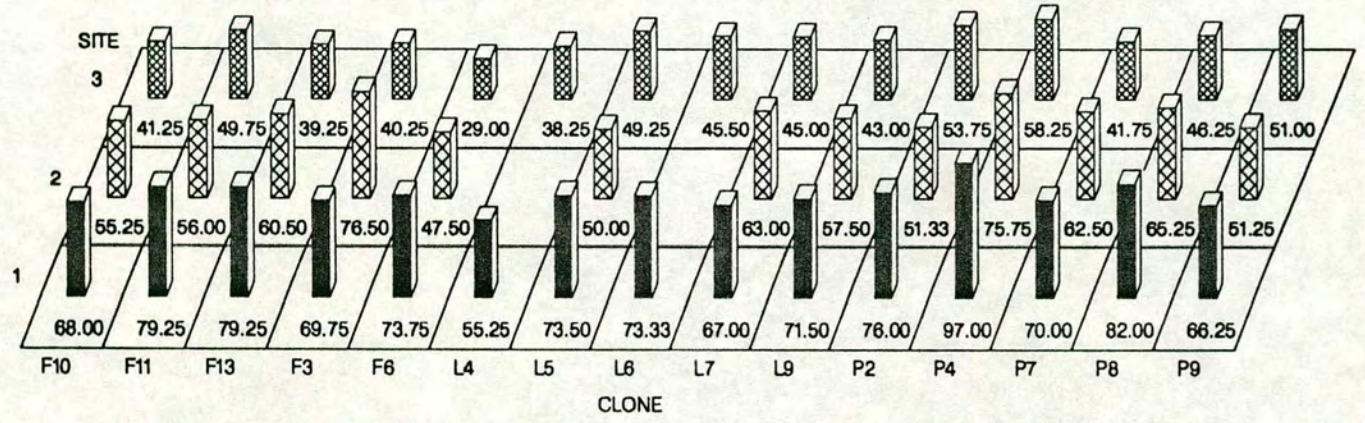

Fig. 4.14 Variation in number of primary branches among Sesbania sesban clones after 9 months growth at (1) Maseno (2) Kisii and (3) Machakos, sites in Kenya.

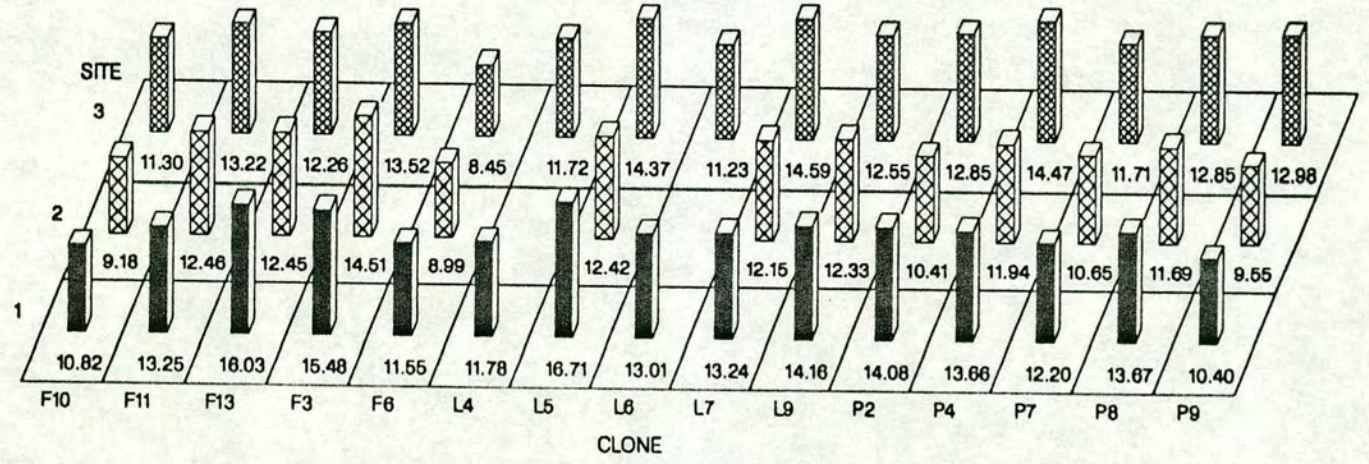

Fig 4.15 Variation in branch frequency per metre among Sesbania sesban clones after 9 months growth at (1) Maseno (2) Kisii and (3) Machakos, sites in Kenya.

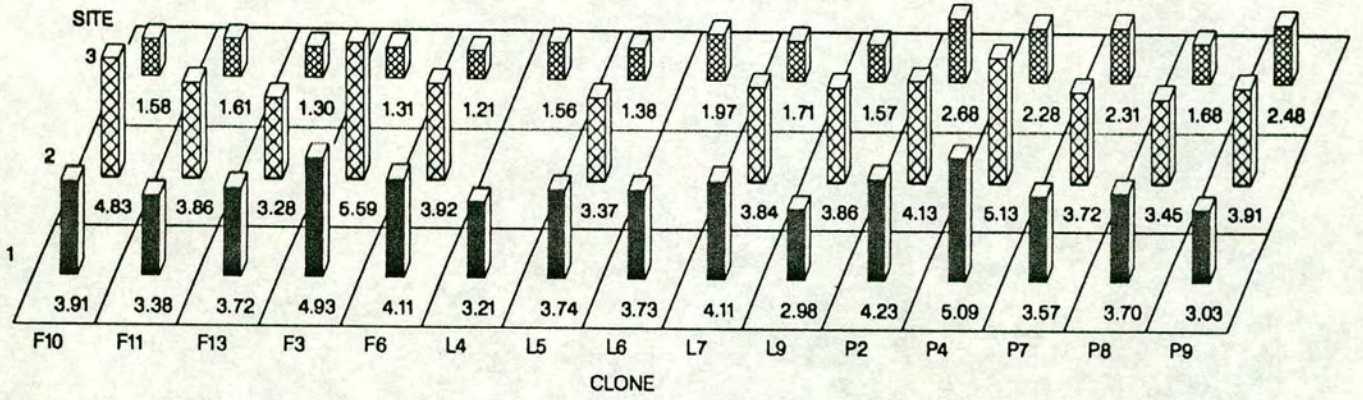

Fig 4.16 Variation in crown diameter (m) among Sesbania sesban clones after 9 months growth at (1) Maseno (2) Kisii and (3) Machakos, sites in Kenya.

4.12.2. Dry mass production and partitioning.

Dry mass production of S. sesban clones after nine months of growth differed significantly between sites, clone and clone by site interaction ($P \leq 0.05$) but there was no clone by site interaction for stem dry mass (Table A4.9). Clonal group dry mass was only significantly different in stem and root dry mass at $P \leq 0.05$ and $P \leq 0.001$ respectively (Table A4.9). Stem dry mass for clone groups was 1.27±0.90, 1.53±1.16 and 1.10±0.74 kg^{-1} $tree^{-1}$ for clones selected for fuelwood, poles and leaves respectively. While clone group means for root dry mass was 3.21±2.77, 2.32±1.83 and 1.94±1.74 kg^{-1} $tree^{-1}$ for clones selected for fuelwood, poles and leaves respectively. Tree dry mass (above and below-ground) was partitioned into stem, branches, leaves and roots. The mean for stem, branch, leaf, above and below-ground and total tree dry mass yield for the three sites were 1.31±0.21, 3.67±0.60, 1.23±0.26, 6.21±0.96, 2.50±0.41 and 8.67±1.29 kg^{-1} $tree^{-1}$ respectively (Table A4.9). At the single sites (Maseno, Kisii and Machakos), significant differences were observed in S. sesban clone dry mass yield (Tables A4.10, A4.11 and A4.12).

At Maseno, mean dry mass yield for S. sesban clones for stem, branch, leaf, above-ground, root and total tree were 1.75±0.39, 4.82±1.19, 1.67±0.40, 8.24±1.83, 3.59±0.76 and 11.82±2.40 kg^{-1} $tree^{-1}$ respectively (Table A4.10). Figures 4.17a and 4.17b show the variation in percentage contribution and dry mass partitioning of root, stem, branch and leaf in S. sesban clones at nine months in Maseno. Total tree dry mass at this site varied from as low as 4.92 (7.9 t ha^{-1}) to 23.19 kg^{-1} $tree^{-1}$ (37.1 t ha^{-1}) (Fig. 4.17b).

Yield of S. sesban clones at Kisii for stem, branch, leaf, above-ground, root and total tree dry mass for S. sesban clones were 1.68±0.49, 3.57±1.30, 2.02±0.72, 7.27±2.30, 2.72±0.94 and 9.99±3.01 kg^{-1} $tree^{-1}$ respectively (Table A4.11). Variation in percentage contribution and dry mass partitioning of root, stem, branch and leaf in S. sesban clones after nine months at Kisii are shown in Figures 4.18a and 4.18b. Total tree dry mass at this site ranged from 3.55 (5.68 t ha^{-1}) to 19.96 kg^{-1}

tree^{-1} (31.9 t ha^{-1}) (Fig. 4.18b).

Means for S. sesban clones at Machakos for stem, branch, leaf, above-ground, root and total tree dry mass were 0.57±0.11, 2.62±0.55, 0.12±0.05, 3.30±0.66, 1.22±0.26 and 4.52±0.87 kg^{-1} tree^{-1} respectively (Table A4.12). Clonal variation in percentage contribution and dry mass partitioning of root, stem, branch and leaf at nine months in Machakos are shown in Figs. 4.19a, 4.19b. Total tree dry mass among S. sesban clones at this site ranged from 2.14 (3.4 t ha^{-1}) to 8.74 kg^{-1} tree^{-1} (14.0 t ha^{-1}) (Fig. 4.19b).

The partioning of dry mass into components was variable, at the three sites (Maseno, Kisii and Machakos) as shown in Table 4.12.

4.12.3. Correlations.

Strong phenotypic correlations were found between assessed growth and morphology characteristics in S. sesban clones for the three sites after nine months of growth (Table 4.13). Tree heights were strongly correlated with stem diameters and crown diameters. Low significant correlations were found between heights and most root characters. A non significant negative correlation was found between tree height and branch frequency (r=-0.14ns). Strong correlations were found between stem diameters and most biomass traits. Branch frequency correlations with other characteristics were not significant except with number of branches (r=0.47, P≤0.001).

4.12.4. Regression.

Regressions were used to determine relationships between independent variables (height, stem diameters at 0.15 m and 0.30 m, number of branches and crown diameters) and dependent variables (stem, branch, leaf, root and above ground

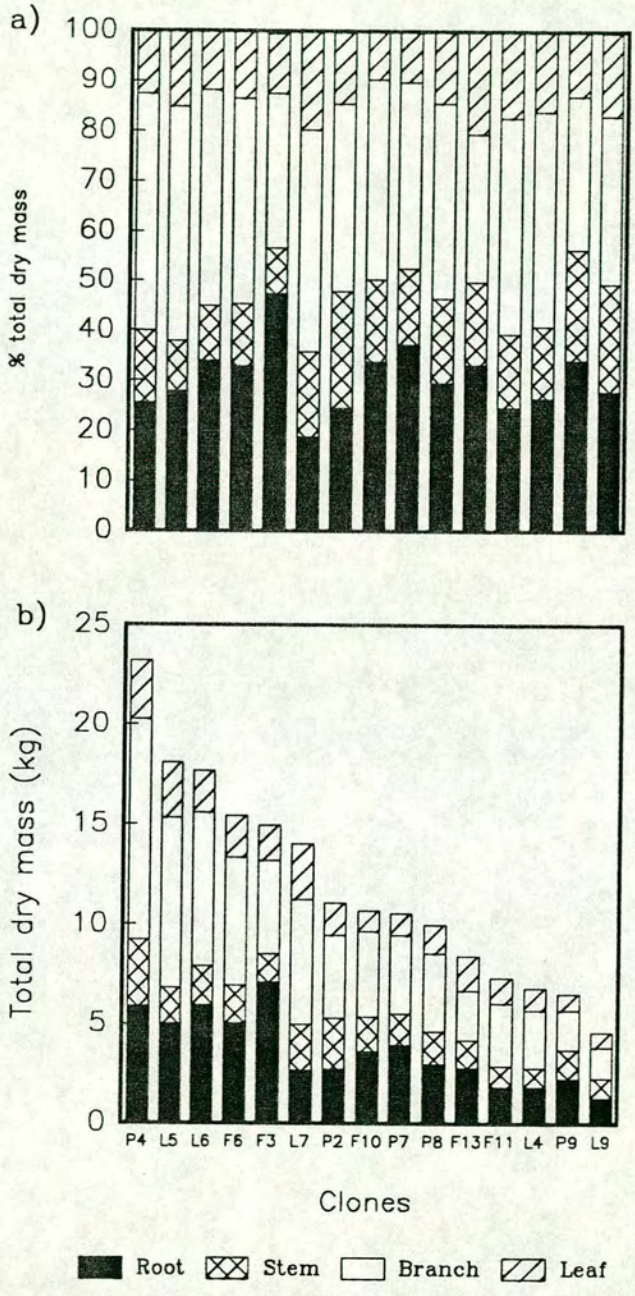

Fig. 4.17. Variation in (a) the percentage distribution and (b) dry mass partitioning of components of root, stem, branch, and leaf of Sesbania sesban clones at Maseno, Kenya.

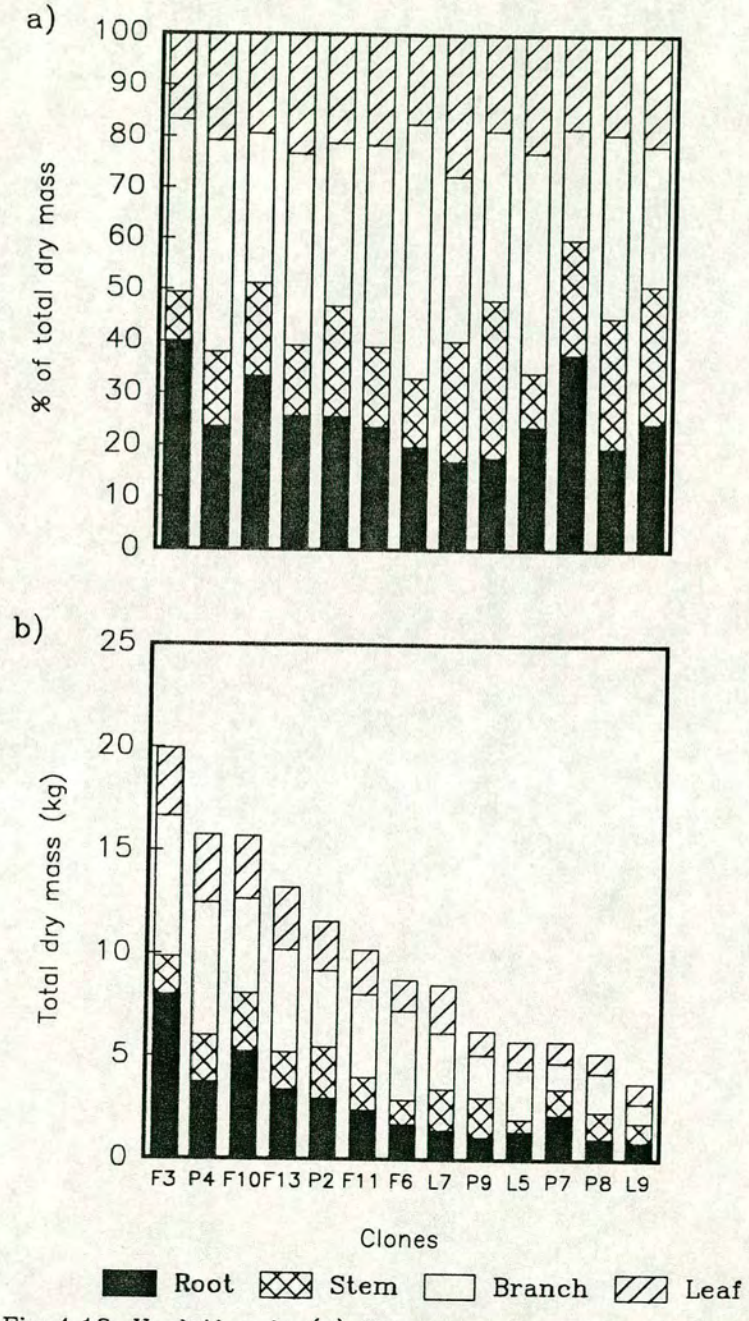

Fig 4.18. Variation in (a) the percentage distribution and (b) dry mass partitioning of components of root, stem, branch and leaf of Sesbania sesban clones at Kisii, Kenya.

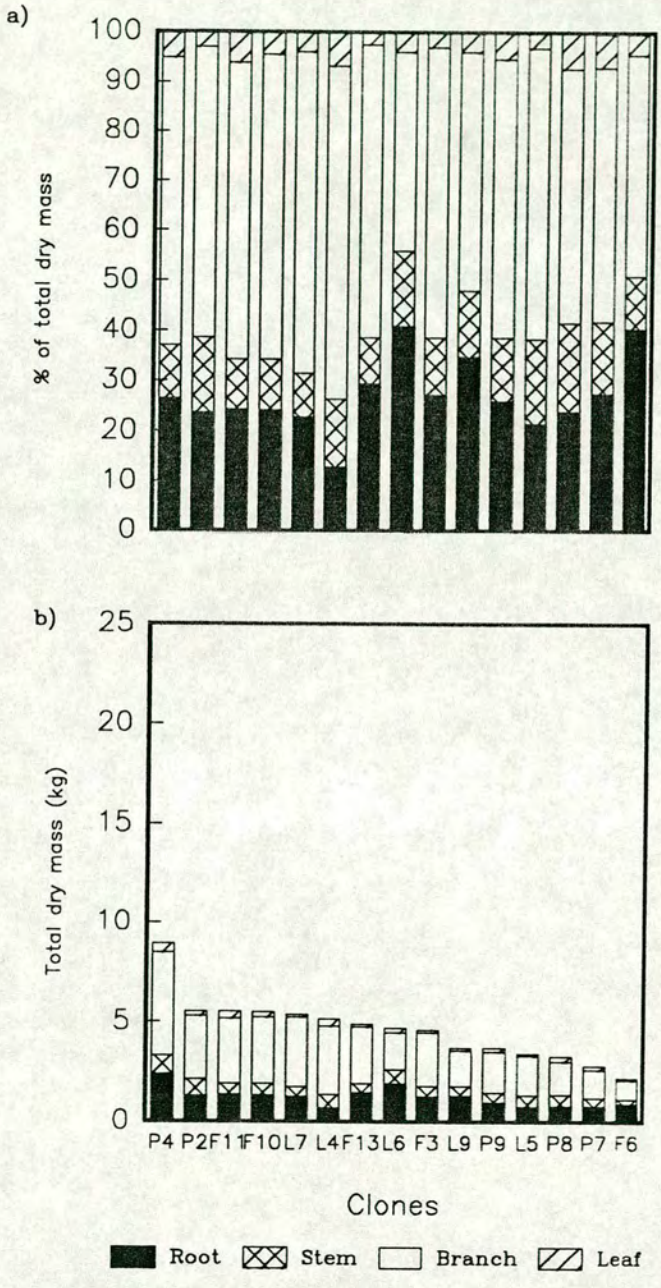

Fig. 4.19. Variation (a) percentage distibution and (b) dry mass partitioning of components of root, stem, branch, and leaf of Sesbania sesban clones at Machakos, Kenya.

Table 4.12. Dry matter partitioning (%) among S. sesban clones after 9 months growth at Maseno, Kisii and Machakos, Kenya.

Site	Product	Root %	Stem %	Branch %	Leaf %
Maseno	All clones	30	15	41	14
	Fuelwood clones	36	13	37	14
	Pole clones	29	17	41	13
	Leaf clones	27	13	44	15
Kisii	All clones	27	17	36	20
	Fuelwood clones	31	14	36	19
	Pole clones	25	21	34	20
	Leaf clones	21	19	35	25
Machakos	All clones	27	12	58	3
	Fuelwood clones	28	10	59	3
	Pole clones	26	13	57	3
	Leaf clones	27	13	57	3

Table 4.13. Phenotypic correlations based on individual trees for Sesbania sesban clones growth traits at nine months on at three sites, Maseno, Kisii and Machakos, Kenya.

Trait	2	3	4	5	6	7	8	9	10	11	12	13	14
1. Tree height (m)	0.78a	0.59a	0.67a	0.71a	0.72a	0.43a	0.59a	0.58a	0.50a	0.39a	0.27b	0.59a	-0.14ns
2. Number of branches		0.57a	0.63a	0.63a	0.63a	0.47a	0.54a	0.57a	0.52a	0.44a	0.25c	0.59a	0.47a
3. Stem diameter at 0.15m			0.92a	0.61a	0.69a	0.67a	0.65a	0.74a	0.74a	0.71a	0.36a	0.78a	0.08ns
4. Stem diameter at 0.30m				0.63a	0.71a	0.65a	0.66a	0.73a	0.70a	0.64a	0.37b	0.76a	0.06ns
5. Crown diameter at 1.3m					0.71a	0.49a	0.71a	0.65a	0.62a	0.51a	0.32a	0.68a	0.02ns
6. Stem dry mass						0.64a	0.73a	0.80a	0.64a	0.54a	0.35a	0.79a	0.01ns
7. Branch dry mass							0.75a	0.95a	0.71a	0.64a	0.47a	0.92a	0.13ns
8. Leaf dry mass								0.89a	0.66a	0.53a	0.41a	0.86a	0.02ns
9. Above ground dry mass									0.75a	0.65a	0.48a	0.97a	0.09ns
10. Root dry mass										0.91a	0.68a	0.88a	0.13ns
11. Lateral root dry mass											0.47a	0.78a	0.14ns
12. Vertical root dry mass												0.57a	0.03ns
13. Total tree dry mass													0.11ns
14. Branch density/meter													

a = Significant at P≤0.001.
b = Significant at P≤0.01.
c = Significant at P≤0.05.
ns = Not significant.
Degrees of freedom for all combinations 170

tree biomass) for the three sites. The best logical regressions are presented in Table 4.14. Stem diameter at 0.15 m was found to be the best in predicting stem, branch, leaf, root and above ground biomass. This is very useful as it is a parameter which can be measured quickly and accurately.

Table 4.14. Regression of stem diameter at 0.15 m and stem, branch, leaf, root and above ground biomass in Sesbania sesban clones after 9 months growth at 3 sites (Maseno, Kisii and Machakos), Kenya.

Dependent variable	Regression equation	R^2
Stem dry mass	Y = -0.65 + 0.33x	0.70
Branch dry mass	Y = -1.74 + 0.92x	0.67
Leaf dry mass	Y = -1.27 + 0.42x	0.65
Root dry mass	Y = -2.29 + 0.82x	0.74
Above ground dry mass	Y = -3.66 + 1.67x	0.74

4.12.5. Variance components and broad-sense heritabilities (H^2)

The variance components due to clones were relatively moderate to high at all sites. The broad-sense heritabilities at the single tree level for combined sites are presented in Table 4.15. The H^2 for height (0.23), stem diameter at 0.30 m (0.20) and root dry mass (0.22) were moderately high while the rest of the traits had H^2 less than 0.20 with leaf dry mass having the lowest H^2 of 0.08 (Table 4.15). Broad-sense heritabilities at Maseno were relatively high for the assessed traits (greater than 0.30), except for crown diameter which had H^2 of 0.19 (Table 4.16), while at Kisii site H^2 were relatively low with the highest being for root biomass with 0.46, the rest of the traits had H^2 less than 0.40. Height at Kisii had the lowest H^2 of 0.06 (Table 4.17). Machakos site had moderate broad-sense heritabilities between 0.20 to 0.45 with leaf dry mass having the lowest H^2 of 0.01 (Table 4.18).

Table 4.15. Sesbania sesban clone, means, range of clone means, variance components, broad-sense heritabilities and their standard errors (±), coeffients of phenotypic and genotypic variation for assessed traits after nine months of growth at Maseno, Kisii and Machakos,

Trait	Test mean	Range of Means	Clone variance (σ^2c)	Clone x Site interaction (σ^2cs)	Error variance (σ^2e)	H^2 $\frac{\sigma 2c}{\sigma^2c+\sigma^2cs+\sigma^2e}$	Standard error for H^2	coefficient of phenotypic variation	coefficient of genotypic variation
Height (m)	4.77	3.98-5.83	0.1914	0.0319	0.6099	0.23	0.02	0.16	0.08
Number of branches (count)	59.16	50.0-77.0	28.9805	14.0215	120.5047	0.17	0.02	0.18	0.08
Stem diameter at 0.15m (cm)	5.88	4.61-7.89	0.6228	0.2689	2.6437	0.17	0.02	0.28	0.11
Stem diameter at 0.30m (cm)	4.99	4.14-6.92	0.4530	0.2307	1.6005	0.20	0.02	0.25	0.11
Crown diameter at 1.3m (m)	3.17	2.79-4.16	0.1034	0.0887	0.6341	0.12	0.01	0.25	0.09
Stem dry mass (kg)	1.31	0.81-2.18	0.0867	0.0474	0.5201	0.13	0.02	0.55	0.20
Branch dry mass (kg)	3.67	1.44-7.56	1.2843	1.4597	4.2749	0.18	0.02	0.56	0.24
Leaf dry mass (kg)	1.23	0.53-2.15	0.0865	0.1531	0.8329	0.08	0.01	0.74	0.21
Above ground dry mass (kg)	6.21	2.78-11.89	2.8061	2.8750	11.1774	0.16	0.02	0.54	0.21
Root dry mass (kg)	2.50	1.15-5.46	0.8993	0.9873	2.0788	0.22	0.02	0.58	0.27
Above and below ground dry mass (kg)	8.67	3.93-15.89	5.7151	6.7917	19.8419	0.17	0.02	0.51	0.21

Table 4.16. Means, range of clone means, clone variance (σ^2c), error variance (σ^2e) and broad-sense heritabilities (H^2) and standard errors (±), coefficients of phenotypic and genotypic variation for assessed traits in Sesbania sesban clones after 9 months growth in the field at Maseno, Kenya.

Trait	Test range	Range of means	Clone variance	Error variance	H^2 $\frac{\sigma^2c}{\sigma^2c + \sigma^2e}$	Standard error	Coefficient of phenotypic variation	Coefficient of genotypic variation
Height (m)	5.58	4.50-7.11	0.5263	0.3049	0.63	0.05	0.09	0.08
Number of branches (count)	73.46	55.0-97.0	58.7724	102.4069	0.36	0.05	0.16	0.09
Stem diameter at 0.15m (cm)	6.77	4.75-9.8	1.5552	3.0278	0.34	0.05	0.26	0.15
Stem diameter at 0.30m (cm)	5.81	3.87-7.07	1.2231	1.3150	0.48	0.05	0.21	0.15
Crown diameter 1.3m (m)	3.83	2.98-5.08	0.1711	0.7029	0.19	0.03	0.21	0.09
Stem dry mass (kg)	1.75	0.98-3.31	0.2984	0.6368	0.32	0.05	0.45	0.26
Branch dry mass (kg)	4.82	1.56-11.01	6.2784	5.4219	0.53	0.05	0.49	0.36
Leaf dry mass (kg)	1.67	0.77-2.93	0.4625	0.5645	0.45	0.05	0.48	0.32
Above ground dry mass (kg)	8.24	3.32-17.25	12.7729	12.5987	0.50	0.05	0.44	0.31
Root dry mass (kg)	3.62	1.29-7.13	2.8346	2.1952	0.56	0.05	0.42	0.31
Above and below ground mass (kg)	11.82	4.62-23.19	24.5187	21.5050	0.53	0.05	0.40	0.29

Table 4.17. Means, range of clone means, clone variance (σ^2c), error variance (σ^2e), and broad-sense heritabilities (H^2) and standard errors (±), coefficients of phenotypic and genotypic variation for assessed traits in Sesbania sesban clones after 9 months growth in the field at Kisii, Kenya.

Trait	Test mean	Range of means	Clone variance	Error variance	$H^2 = \frac{\sigma^2c}{\sigma^2c + \sigma^2e}$	Standard error	Coefficient of phenotypic variation	Coefficient of genotypic variation
Height (m)	5.24	4.02-6.35	0.0833	1.2188	0.06	0.01	0.21	0.05
Number of branches (count)	59.57	47.0-76.0	56.5979	141.5884	0.28	0.05	0.21	0.11
Stem diameter at 0.15m (cm)	6.09	4.70-8.82	0.9568	3.5408	0.21	0.04	0.32	0.15
Stem diameter at 0.30m (cm)	5.25	4.0-7.12	0.5491	2.3179	0.19	0.03	0.31	0.13
Crown diameter at 1.3m (m)	4.06	3.27-5.59	0.2748	0.8416	0.24	0.04	0.23	0.11
Stem dry mass (kg)	1.68	0.60-2.81	0.1539	0.9514	0.14	0.03	0.58	0.22
Branch dry mass (kg)	3.56	0.98-6.77	2.1682	6.2545	0.26	0.04	0.73	0.37
Leaf dry mass (kg)	2.02	0.75-3.32	0.5183	1.7534	0.23	0.04	0.71	0.34
Above ground dry mass (kg)	7.27	2.68-12.03	6.0684	19.0436	0.24	0.04	0.63	0.31
Root dry mass (kg)	2.72	0.87-7.99	3.2386	3.7236	0.46	0.06	0.69	0.47
Above and below ground mass (kg)	9.99	3.55-19.96	17.3276	34.3605	0.33	0.05	0.60	0.34

Table 4.18. Means, range of clone means, clone variance (σ^2_c), error variance (σ^2_e) and broad-sense heritability (H^2) and their standard errors, coefficients of phenotypic and genotypic variations for asseessed traits in Sesbania sesban clones after 9 months grown in the field at Machakos, Kenya.

Trait	Test mean	Range of means	Clone variance	Error variance	$H^2 \frac{\sigma^2 c}{\sigma^2 c + \sigma^2 e}$	Standard error	Coefficient of phenotypic variation	Coefficient of genotypic variation
Height (m)	3.58	3.09-4.18	0.0999	0.1514	0.40	0.05	0.11	0.07
Number of branches (count)	44.76	29.0-58.0	39.0439	48.6545	0.44	0.05	0.16	0.10
Stem diameter at 0.15m (cm)	4.82	3.62-7.12	0.5346	1.0426	0.34	0.04	0.20	0.12
Stem diameter at 0.30m (cm)	3.92	2.91-6.11	0.4231	0.8126	0.34	0.04	0.22	0.13
Crown diameter at 1.3m (m)	1.77	1.20-2.67	0.1444	0.3243	0.31	0.04	0.34	0.19
Stem dry mass (kg)	0.56	0.23-0.96	0.0111	0.0448	0.20	0.03	0.39	0.17
Branch dry mass (kg)	2.62	0.99-5.16	0.8587	1.0447	0.45	0.05	0.42	0.28
Leaf dry mass (kg)	0.12	0.04-0.26	0.0001	0.0101	0.01	0.002	0.96	0.09
Above ground dry mass (kg)	3.30	1.26-6.38	1.1073	1.4489	0.43	0.05	0.40	0.26
Root dry mass (kg)	1.22	0.73-2.36	0.1716	0.2180	0.44	0.05	0.42	0.28
Above and below ground mass (kg)	4.52	2.14-8.74	1.7628	2.5022	0.41	0.05	0.38	0.25

Maseno site had relatively higher H^2 than Machakos and Kisii. Branch biomass tended to have a high H^2 (≥0.20) at most of the sites.

4.13. ROOT PARAMETERS.

4.13.1. General morphology.

The S. sesban clone root systems showed marked differences in both size and complexity. Significant differences were found between sites, clone and clone by site interactions in most of the root traits assessed (Table A4.13) and between clones on single sites of Maseno, Kisii and Machakos (Tables A4.14, A4.15 and A4.16). Most of the roots were concentrated in the 0 to 40 cm of the soil profile (Figs. 4.26 to 4.28).

All clones developed variable number of large roots, some of these were the main primary lateral roots, originating from the main root stock and secondary lateral roots originating from primary lateral roots. The lateral roots were large structural elements, whose main primary function was anchorage of the tree in the soil. Lateral roots further branched into secondary lateral roots, these were long and thin roots whose main function were absorbing roots due to the presence of numerous root hairs (personal observation in the field). The presence of sinker roots was observed, these are vertical in nature but were not frequent. In some trees, the roots extended equidistant around the root stock forming a symmetrical root system (Fig. 4.20) while others the root spread was irregular forming asymmetrical pattern with roots predominantly in one or two directions (Fig. 4.21).

4.13.2. Horizontal root spread.

Significant clone by site interaction existed for S. sesban clones in the horizontal spread of roots at $P \leq 0.05$ (Table A4.13). The mean horizontal spread

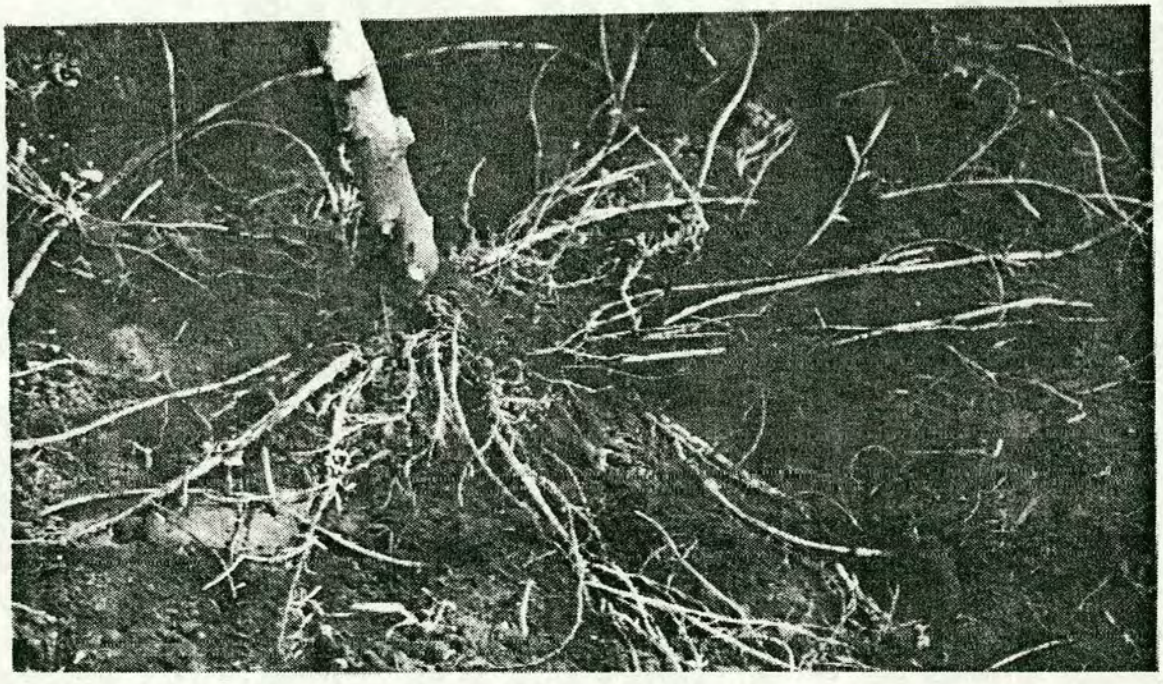

Fig. 4.20. Symmetrical root system of Sesbania sesban clones.

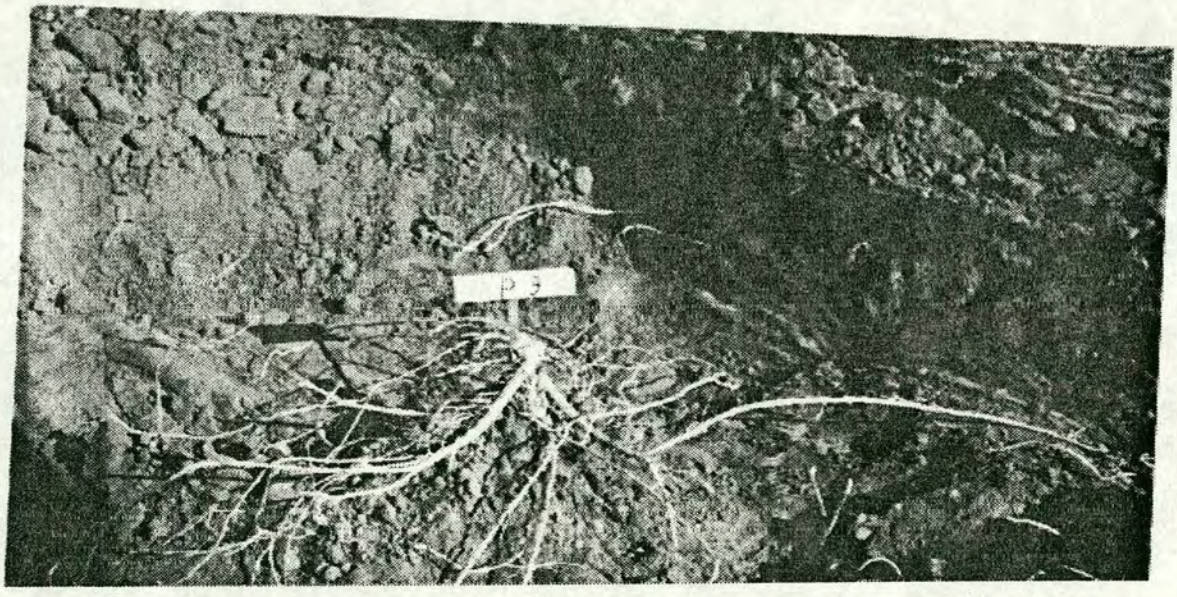

Fig. 4.21. Asymmetrical root system of Sesbania sesban clones.

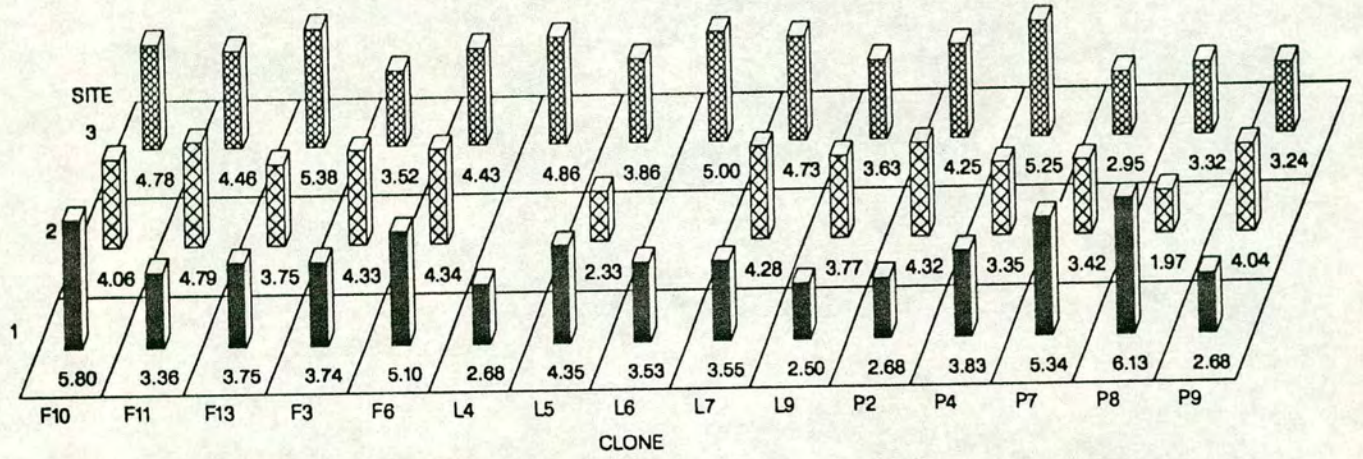

Fig.[4.22] Variation in horizontal spread of roots (m) among Sesbania sesban clones after 9 months growth at (1) Maseno (2) Kisii and (3) Machakos, sites in Kenya.

of roots for the combined sites was 3.99±0.42 m (Table A4.13). For single sites mean horizontal spread of roots was 3.94±0.6, 3.74±0.76 and 4.24±0.56 m at Maseno, Kisii and Machakos respectively (Table A4.14, A4.15 and A4.16). Horizontal spread of roots at Maseno ranged from 2.68 to 5.80 m, at Kisii the range for horizontal spread was from 2.33 to 4.79 m while at Machakos horizontal spread ranged from 2.95 to 5.38 m (Fig. 4.22). Most of these horizontal roots were in the top horizons immediately below the soil surface (Figs. 4.26, 4.27, 4.28). The root spread to crown spread ratio (horizontal root spread / crown diameter) in S. sesban clones was significantly different between sites ($P \leq 0.001$), clone and clone by site interaction $P \leq 0.05$ (Table A4.13). The mean root spread:crown spread ratio was 1.65±0.25 m for the combined sites (Table A4.13). About 47% and 46% of the clones at Maseno and Kisii had root spread:crown spread ratios of more than one respectively. while at Machakos all the clones (100%) had root spread:crown spread ratios of more than one (Fig. 4.23). This indicates that all clones at Machakos had their horizontal root spread exceeding crown spread.

4.13.3. Root depth.

Large variations in rooting depth were observed between sites ($P \leq 0.001$) and clone by site interaction ($P \leq 0.05$),(Table A4.13). The mean rooting depth for the combined sites was 1±0.08 m (Table A4.13) and for single sites rooting depth between clones was only significantly different at Maseno (Table A4.14). At Maseno the rooting depth for clones ranged from 0.32 to 1.48 m and at Kisii the rooting depth ranged from 0.43 to 0.82 m, while at Machakos rooting depth ranged from 0.50 to 1.87 m. The roots of S. sesban clones at Machakos penetrated deeper than Maseno and Kisii (Fig. 4.24).

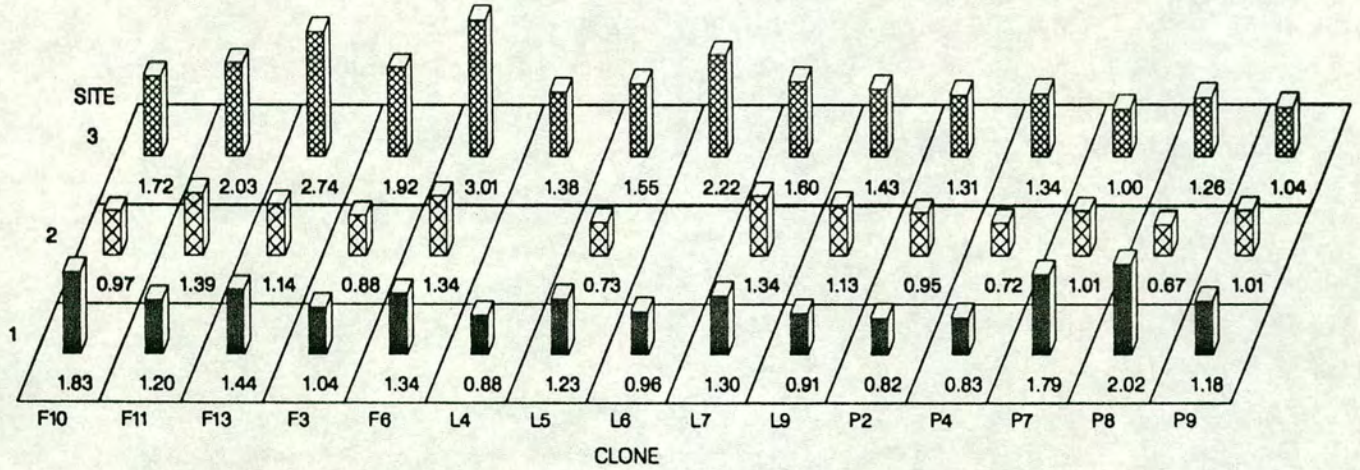

Fig.[4.23] Variation in horizontal spread of roots/crown spread ratio among Sesbania sesban clones after 9 months growth at (1) Maseno (2) Kisii and (3) Machakos, sites in Kenya.

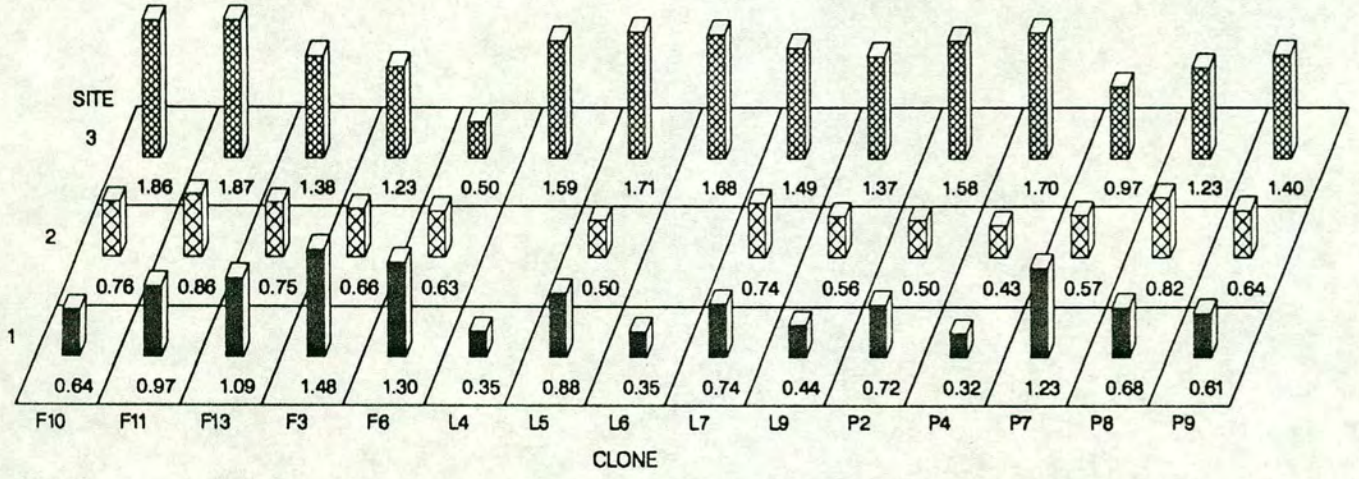

Fig. 4.24. Variation in root depth (m) among Sesbania sesban clones after 9 months growth at (1) Maseno (2) Kisii and (3) Machakos, sites in Kenya.

4.13.4. Number of roots.

The number of primary roots was significantly different between sites ($P \leq 0.001$) and clones ($P \leq 0.05$) and clone by site interaction was not significant for the combined sites (Table A4.13). The mean number of primary roots for the combined sites was 7.73±0.81 (Table A4.13). At Kisii significant differences were observed between clones (Table A4.15). The number of primary roots in S. sesban clones for the three sites are shown in Figure 4.25.

The depth-wise distribution of number of primary roots indicated that the top 30 cm of soil contained about 89% of the roots at Maseno (Fig. 4.26), 100% at Kisii (Fig. 4.27) and Machakos 78% (Fig. 4.28). The pattern of root allocation along the depth gradient varied between sites and the distribution of primary roots in the 0-10 cm ranged from 0 to 47% at Maseno (Fig. 4.26), 24 to 65% at Kisii (Fig. 4.27) and Machakos from 21 to 57% (Fig. 4.28). Machakos site also had primary roots distributed along the entire depth from 0-40 cm and showed a deeper rooting pattern than Maseno and Kisii. Generally the number of primary roots tended to decrease as depth increased at all sites.

The number of secondary roots were variable and significantly different between sites and clones ($P \leq 0.05$). The mean number of secondary roots for the combined sites was 116±41 (Table A4.13). Number of secondary roots for single sites of Maseno and Machakos are presented in Tables A4.14, A4.15 and A4.16. The number of secondary roots at Maseno varied from 83 to 464, while at Kisii ranged from 23 to 127 and at Machakos ranged from 15 to 331 (Fig. 4.29)

4.13.5. Root length and diameter

The length of primary roots varied between sites at $P \leq 0.001$, clones at $P \leq 0.05$ and clone by site interaction at $P \leq 0.001$ (Table A4.13). The mean length of primary roots for the combined sites was 1.39±0.24 m (Table A4.13), while for single sites at Maseno mean length of primary roots was 1.33±0.88 m ranging from 0.97 to

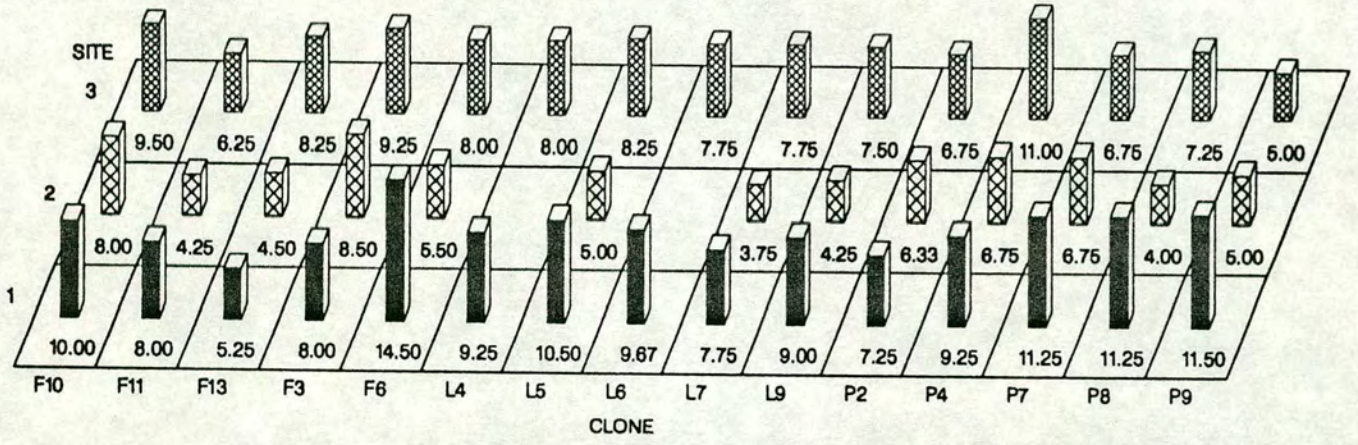

Fig. 4.25 Variation in number of primary roots among Sesbania sesban clones after 9 months growth at (1) Maseno (2) Kisii and (3) Machakos, sites in Kenya.

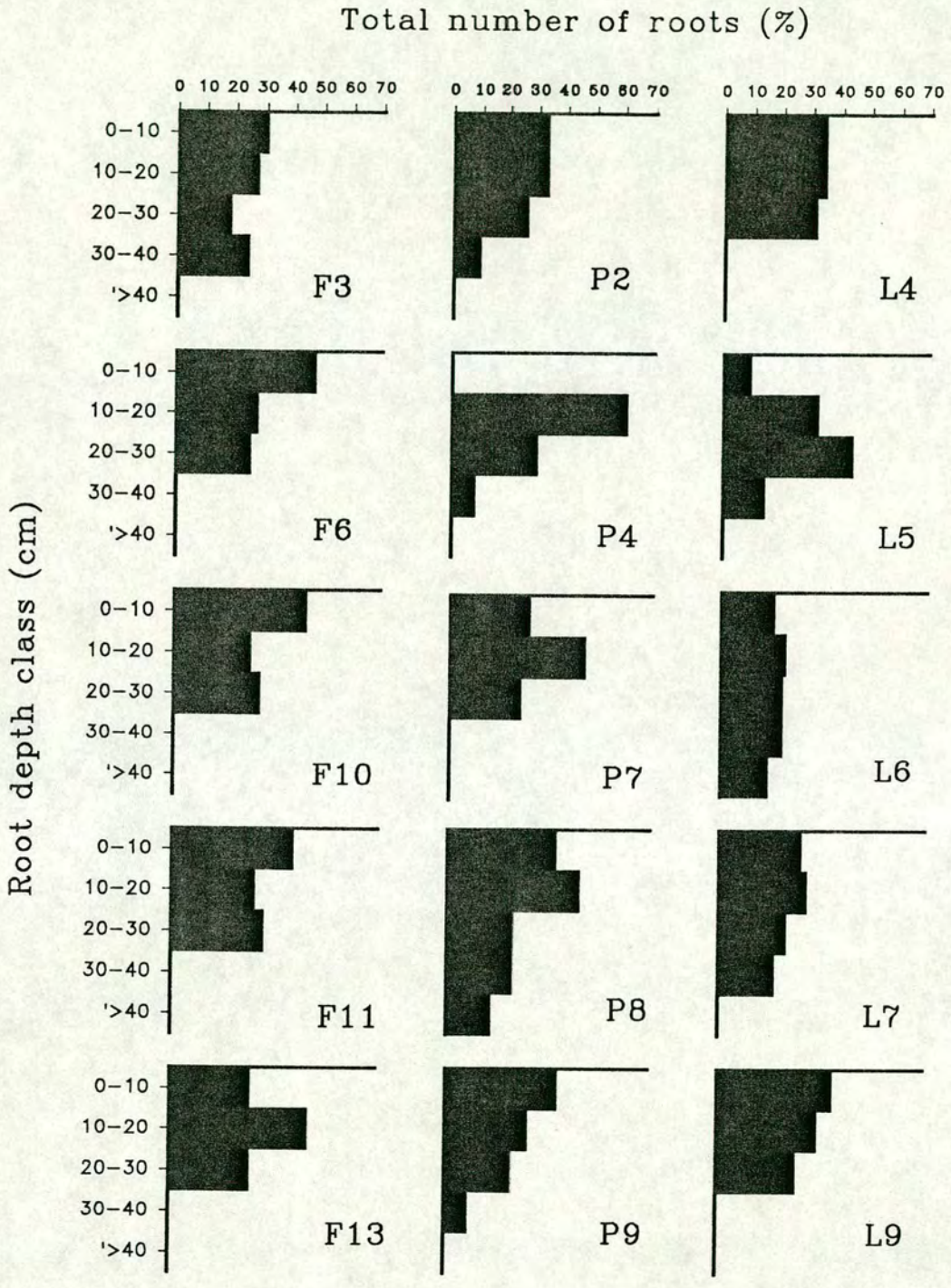

Fig. 4.26. Percentage distribution of primary roots in different soil depths 0–10, 10–20, 20–30, 30–40 and >40 cm for Sesbania sesban clones after nine months growth at Maseno, Kenya (F3...L9 are clone numbers).

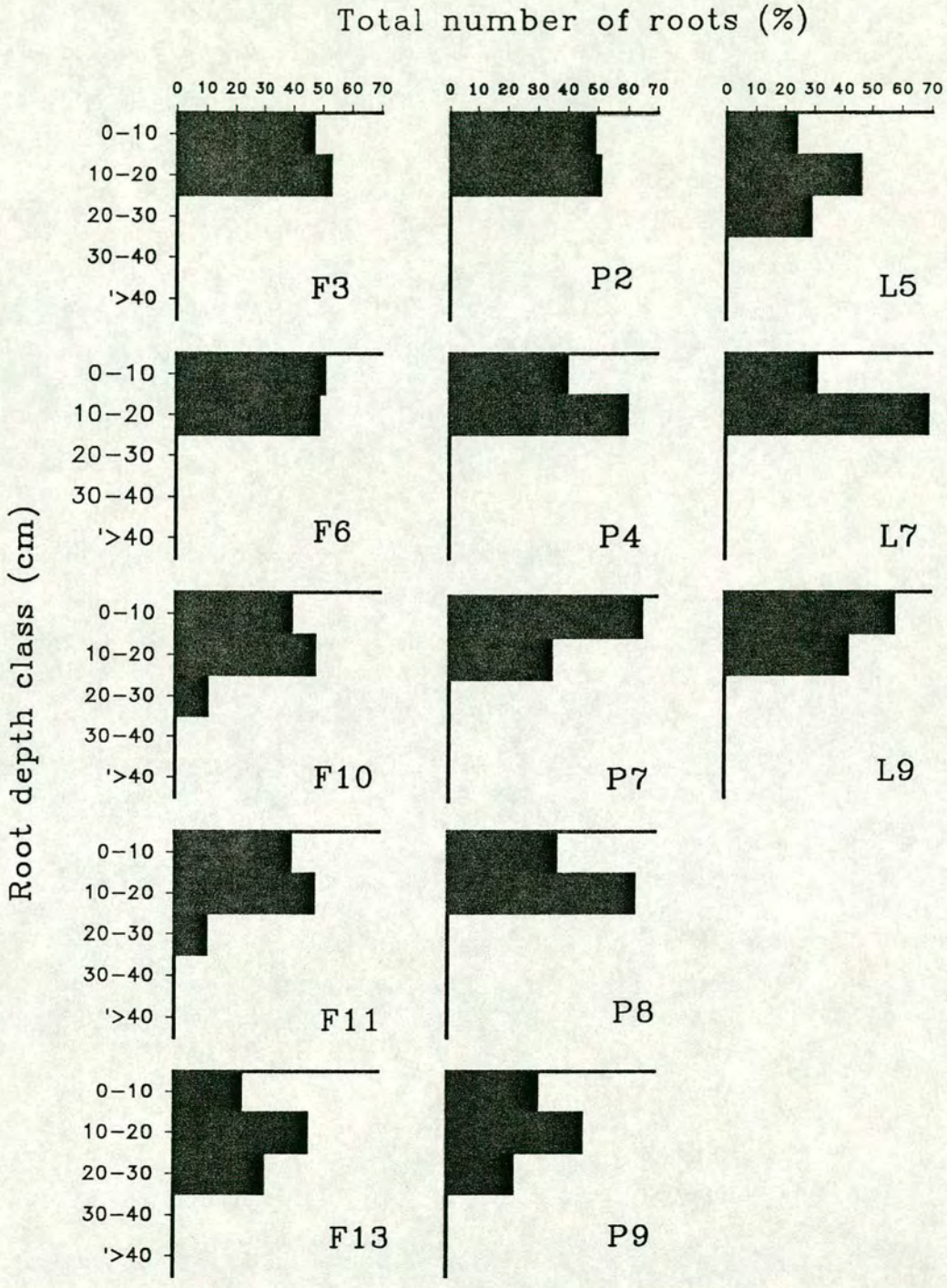

Fig. 4.27. Percentage distribution of primary roots in different soil depths 0–10, 10–20, 20–30, 30–40 and >40 cm for Sesbania sesban clones after nine months growth at Kisii Kenya. (F3, P2...L9 are clone numbers).

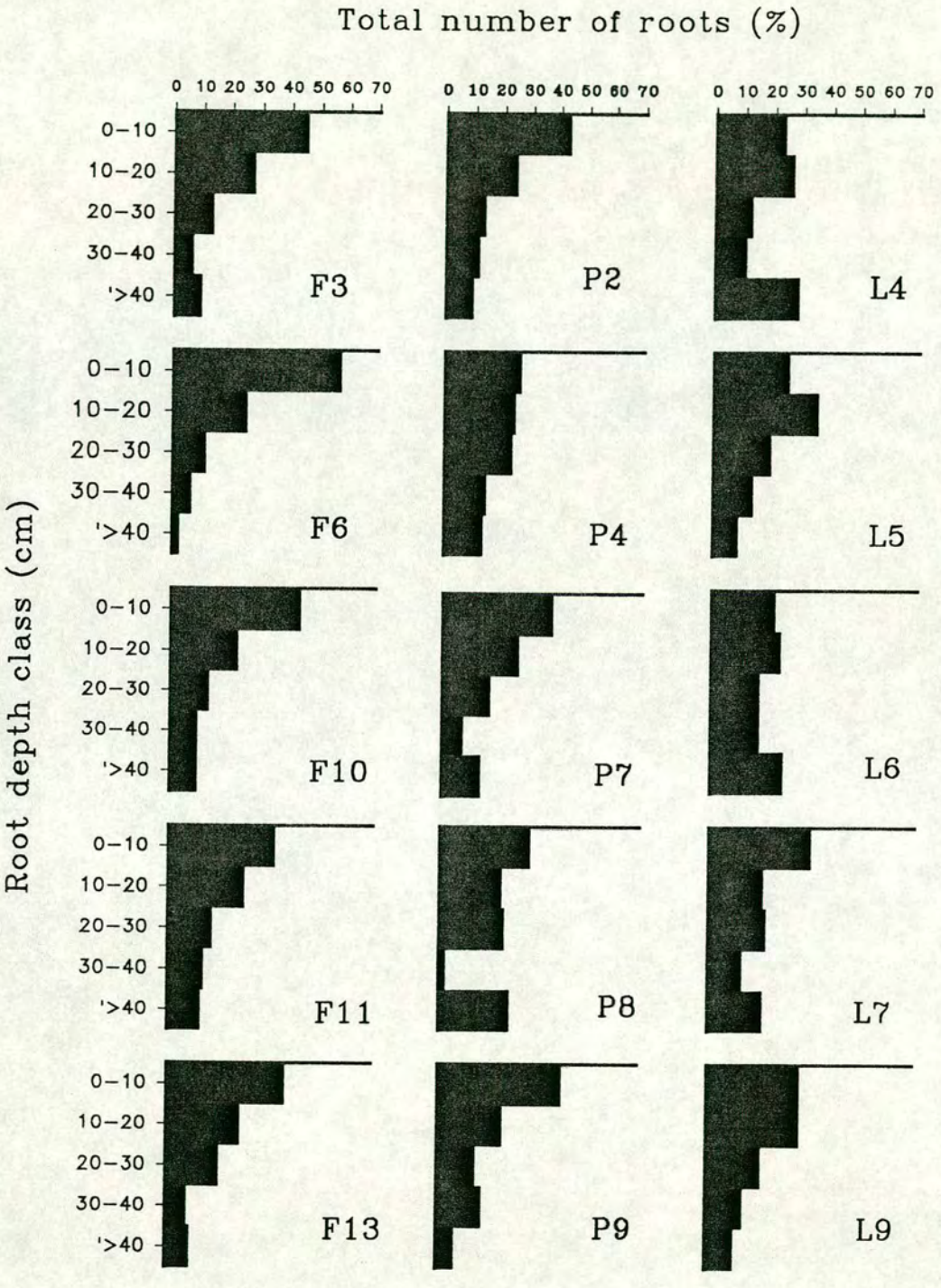

Fig. 4.28. Percentage distribution of primary roots in different soil depths 0–10, 10–20, 20–30, 30–40 and >40cm for Sesbania sesban clones after nine months growth at Machakos, Kenya. (F3...L9 are clone numbers).

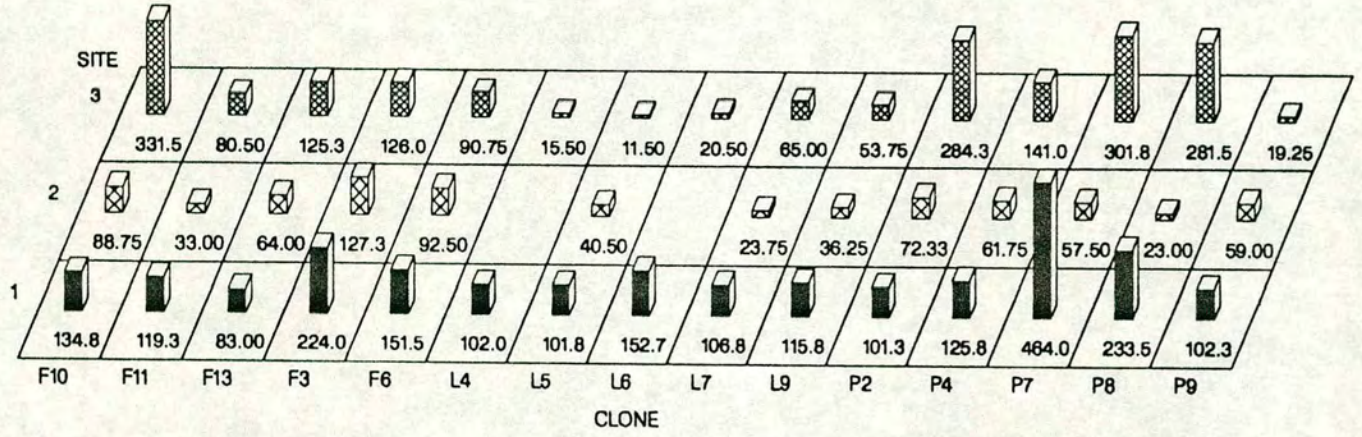

Fig. 4.29. Variation in number of secondary branches among Sesbania sesban clones after 9 months growth at (1) Maseno (2) Kisii and (3) Machakos, sites in Kenya.

1.64 m (Table 4.19), at Kisii the mean length of primary roots was 1.23±0.44 m ranging from 0.86 to 1.79 m (Table 4.20) and at Machakos the mean length for primary roots was 1.56±0.34 m with a range from 1.27 to 1.93 m (Table 4.21).
The length of secondary roots also varied between sites and was significantly different between sites, clone and clone by site interaction at P≤0.001 with a mean length for the combined sites of 0.77±0.15 m (Table A4.13). Significant differences between clones were observed in length of secondary roots for single sites (Tables A4.14, A4.15 and A4.16). At Maseno the mean length for secondary roots was 0.83±0.32 m with a range from 0.51 to 1.35 m (Table 4.19) while at Kisii the mean length for secondary roots was 0.55±0.20 m ranging from 0.39 to 0.89 m (Table 4.20) and at Machakos the mean secondary root length was 0.91±0.27 m with a range from 0.56 to 1.19 m (Table 4.21).
Significant differences existed in basal diameters of primary and secondary roots at the combined sites (Table A4.13) and for single sites of Maseno (Table A4.14), Kisii (Table A4.15) and Machakos (Table A4.16). The mean basal diameter for primary roots and secondary roots for the combined sites was 2.57±0.60 cm and 0.85±0.18 cm respectively (Table A4.13). For single sites, the mean basal diameter for primary branches and secondary branches at Maseno was 2.33±0.88 cm and 0.99±0.30 cm respectively (Table 4.19), for Kisii the basal diameter for primary roots was 3.32±1.76 cm and 0.74±0.31 cm for secondary roots (Table 4.20) while at Machakos the basal diameter for primary and secondary roots was 2.39±0.53 and 0.81±0.29 cm respectively (Table 4.21). The diameters for primary roots were comparatively thicker at Kisii than other sites (Table 4.20).

4.13.6. Root angles.

The angles of primary and secondary roots varied considerably between clones. The mean angle for primary and secondary roots across the three sites were 108±11° and 94±9° respectively (Table A4.13). At Maseno the mean angles for primary and secondary roots was 108±16° and 72±14° respectively, with a range

from 94° to 117° for primary roots and for secondary roots from 59° to 101° (Table 4.19). For Kisii site the mean angles for primary and secondary roots were 108±23° and 93±18° respectively, with a range from 81° to 123° for primary roots and for secondary roots from 84° to 105° (Table 4.20) and at Machakos the mean angles for primary and secondary roots were 108±20° and 115±12° respectively, with a range from 56° to 127° for primary roots and for secondary roots from 90° to 126° (Table 4.21). The angles for primary roots were generally higher than secondary roots (Tables 4.19, 4.20 and 4.21), thus the primary roots were more horizontal than the secondary roots.

4.13.7. Root dry mass.

Root dry mass varied between sites, clone and clone by site interaction ($P \leq 0.001$, Table A4.9). The mean root dry mass for the combined sites was 2.50±0.41 kg^{-1} tree (Table A4.9). Single sites analysis are presented in Tables A4.10, A4.11 and A4.12. At Maseno mean root dry mass among clones varied from as low as 1.81 to 7.83 kg^{-1} tree (Fig. 4.30), while at Kisii mean root dry mass for clones ranged from 0.88 kg^{-1} tree to 8 kg^{-1} tree, and at Machakos mean root dry mass among clones ranged from 0.66 to 2.36 kg^{-1} tree (Fig. 4.30). Root dry mass was relatively higher at Maseno where it was about three times that of Machakos (Fig. 4.30). Root dry mass was categorised into (i) lateral root dry mass which was composed mainly of primary and secondary roots and (ii) vertical root dry mass consisting of the main root system. Lateral root dry mass was significantly different between sites, clones at $P \leq 0.001$ and clone by site interaction at $P \leq 0.05$ (Table A4.9). The mean lateral dry mass for clones across the three sites was 1.38±0.63 kg^{-1} tree (Table A4.9). Vertical root dry mass was significantly different between sites, clones and clone by site interaction at $P \leq 0.05$ with a mean of 0.46±0.12 kg^{-1} tree for the three sites (Table A4.9). At Maseno mean lateral root dry mass was 1.87±0.51 kg^{-1} tree (Table 4.22) ranging from 0.54 to 4.61 kg^{-1}, while mean vertical root dry mass was 0.52±0.23 kg^{-1} tree with a range from 0.25 to 1.90 kg^{-1} tree

Table 4.19. Showing number, length, diameter, angles of primary and secondary roots, root depth, horizontal spread of roots and root spread/crown spread ratio of Sesbania sesban clones at 9 months in Maseno, Kenya.

Clone	Length of primary roots (m)	Diameter of primary root (cm)	Root angle primary root (o)	Length of secondary root (m)	Diameter of secondary root (cm)	Root angle of secondary root (o)
F6	1.34	2.18	113	1.00	1.19	85
P9	1.05	1.66	108	0.51	0.91	66
P7	1.51	2.12	105	0.62	0.79	101
P8	1.62	1.90	110	1.35	1.13	79
L5	1.61	2.68	120	0.93	0.91	66
F10	1.64	2.68	116	1.03	1.14	63
L6	1.27	2.39	113	0.96	1.08	82
L4	1.07	1.62	94	0.52	0.47	65
P4	1.38	4.09	97	1.03	1.18	80
F3	1.41	2.63	117	0.82	1.17	76
L9	1.18	1.70	111	0.69	0.74	82
F11	0.97	1.82	117	0.69	0.82	59
L7	1.12	2.19	101	0.99	1.05	54
P2	1.16	2.98	103	0.52	0.98	75
F13	1.52	2.96	94	0.67	1.07	69
Mean	1.33	3.32	108	0.83	0.74	93
Se	0.88	1.72	23	0.32	0.31	18

Table 4.20. Showing number, length, diameter, angles of primary and secondary roots, root depth, horizontal spread of roots and root spread/crown spread ratio for Sesbania sesban clones at nine months at Kisii, Kenya.

Clone	Length of primary roots (m)	Diameter of primary root (cm)	Root angle primary root (o)	Length of secondary root (m)	Diameter of secondary root (cm)	Root angle of secondary root (o)
F3	1.24	2.86	108	0.89	1.21	101
F10	1.38	3.33	104	0.48	0.78	97
P7	1.02	2.01	119	0.72	0.78	96
P4	0.89	4.05	99	0.49	0.64	107
P2	1.21	3.34	121	0.44	0.60	95
F6	1.47	3.80	110	0.63	1.25	88
P9	1.21	2.75	118	0.43	0.46	89
L5	0.86	2.77	81	0.47	0.80	84
F13	1.79	3.26	101	0.49	0.48	77
L9	1.24	6.05	100	0.45	0.61	82
F11	1.43	2.88	123	0.76	0.85	105
P8	1.11	3.00	122	0.39	0.51	98
L7	1.36	3.95	114	0.55	0.57	97
Mean	1.23	2.33	108	0.55	0.99	72
Se	0.44	0.88	16	0.20	0.30	14

Table 4.21. Showing number, length, diameter, angles of primary and secondary roots, root depth, horizontal spread of roots and root spread/crown ratio of Sesbania sesban at nine months at Machakos, Kenya.

Clone	Length of primary roots (m)	Diameter of primary root (cm)	Root angle primary root (°)	Length of secondary root (m)	Diamater of secondary root (cm)	Root angle of secondary root (°)
P4	1.70	2.82	100	1.14	0.80	128
F10	1.64	2.32	111	0.99	0.78	90
F3	1.29	2.11	105	0.60	0.77	120
L5	1.46	1.88	110	0.93	0.72	126
F13	1.72	2.58	126	1.00	0.96	108
L4	1.56	1.98	111	0.56	0.44	95
F6	1.58	2.09	124	0.78	0.81	111
L6	1.93	2.95	117	1.11	1.01	114
L7	1.61	2.38	99	0.90	0.75	121
L9	1.55	2.27	109	0.87	0.80	117
P8	1.41	2.42	98	0.89	0.96	120
P2	1.27	2.80	56	0.99	1.05	119
P7	1.21	2.08	100	0.64	0.59	118
F11	1.81	2.90	125	1.19	0.84	120
P9	1.53	2.65	127	1.01	0.94	119
Mean	1.56	2.39	108	0.91	0.81	115
Se	0.34	0.53	20	0.27	0.29	12

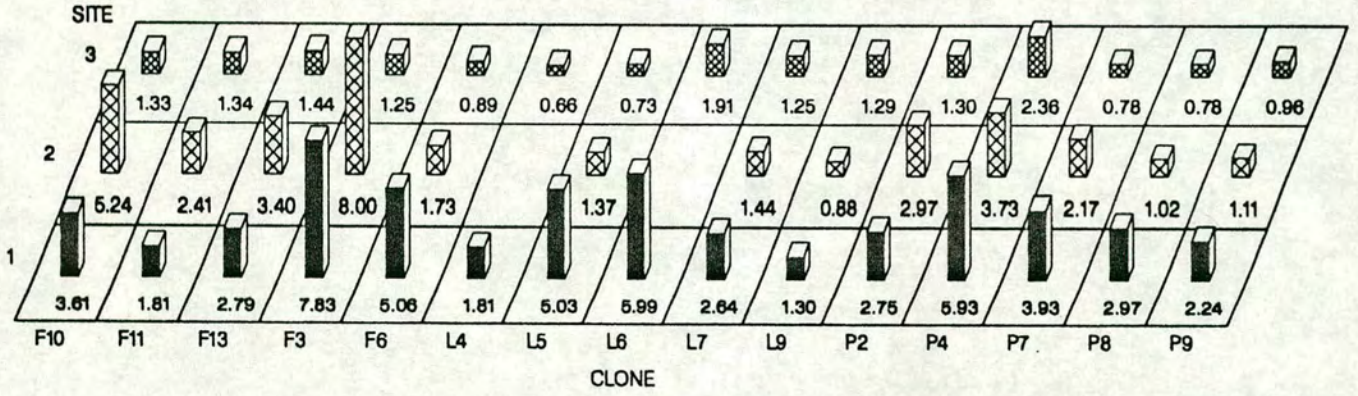

Fig. 4.30 Variation in roots dry mass (kg) among Sesbania sesban clones after 9 months growth at (1) Maseno (2) Kisii and (3) Machakos, sites in Kenya.

(Table 4.22). The lateral and vertical mean root dry mass at Kisii was 1.39±0.63 and 0.57±0.36 kg^{-1} tree (Table 4.22) respectively. The range for lateral roots at Kisii was from 0.24 kg^{-1} to 4.09 kg^{-1} tree and for vertical roots was from 0.14 to 1.52 kg^{-1} tree (Table 4.22). At Machakos, mean lateral root dry mass was 0.89±0.24 kg^{-1} tree which varied from 0.35 to 1.79 kg^{-1} tree (Table 4.22) while, mean vertical root dry mass was 0.32±0.10 kg^{-1} tree with a range from 0.07 to 0.57 kg^{-1} tree (Table 4.22).

4.13.8. Root/Shoot ratio.

Root to shoot ratios were significantly different between sites ($P \leq 0.05$), clones ($P \leq 0.001$) and clone by site interaction ($P \leq 0.01$) with a mean of 0.42±0.05 for combined sites (Table A4.9). Root:shoot ratios were significantly different between clones at single sites, of Maseno, Kisii and Machakos (Tables A4.10, A4.11 and A4.12). The root:shoot ratios ranged from 0.24 to 0.93 at Maseno, and from 0.21 to 0.69 at Kisii while at Machakos root:shoot ratio ranged from 0.29 to 0.78 (Fig. 4.31). Some clones had higher root:shoot ratios across all sites, for example F3, P7 and F10 (Fig. 4.31). Root dry mass accounted for about 19 to 47% of total tree dry mass at Maseno, 12 to 40% at Kisii and 13 to 41% at Machakos. The comparison of root:shoot dry mass in different clones showed variable allocation of root dry mass among clones and between sites.

4.14. Soil and foliar nutrient concentration.

4.14.1. Seasonal variation in soil chemical characteristics.

The results of the soil chemical characteristics before and 9 month after S. sesban plantings are shown in Table A4.17. An analysis of variance revealed significant differences between sites for Organic matter, pH, K, Ca, Mg and $N\text{-}NO_3$ at $P \leq 0.001$, and P at $P \leq 0.05$ while $N\text{-}NH_4$ was not significant (Table A4.17). Soil chemical for

Table 4.22. Showing lateral and vertical root dry of Sesbania sesban clones after nine months growth at Maseno, Kisii and Machakos, Kenya.

Clone	Maseno		Clone	Kisii		Clone	Machakos	
	Lateral root dry mass (kg)	Vertical root dry mass (kg)		Lateral root dry mass (kg)	Vertical root dry mass (kg)		Lateral root dry mass (kg)	Vertical root dry mass (kg)
F3	4.61	0.52	F3	4.09	1.52	P4	1.79	0.57
P4	3.65	0.57	F13	2.50	0.47	L6	1.78	0.13
F6	2.72	0.61	F10	2.27	0.93	F10	1.08	0.24
L6	2.38	1.90	P4	1.45	0.63	F13	1.03	0.40
L5	2.33	0.62	F6	1.30	0.14	P2	1.00	0.29
F10	2.33	0.67	P2	1.24	1.03	F11	0.97	0.37
P7	1.69	0.59	F11	1.22	0.59	L9	0.92	0.36
P2	1.66	0.25	P7	1.03	0.29	F3	0.87	0.38
P8	1.52	0.22	L5	1.01	0.35	F6	0.81	0.07
F11	1.36	0.63	L7	0.52	0.41	L7	0.79	0.45
L7	1.16	0.36	P8	0.38	0.32	L5	0.61	0.12
P9	0.94	0.35	P9	0.33	0.24	P9	0.58	0.38
F11	0.82	0.41	L9	0.24	0.32	P8	0.39	0.39
L4	0.69	0.19				P7	0.37	0.40
L9	0.54	0.25				L4	0.35	0.31
Mean	1.87	0.52	Mean	1.39	0.57	Mean	0.89	0.32
Se	0.51	0.23	Se	0.63	0.36	Se	0.24	0.10

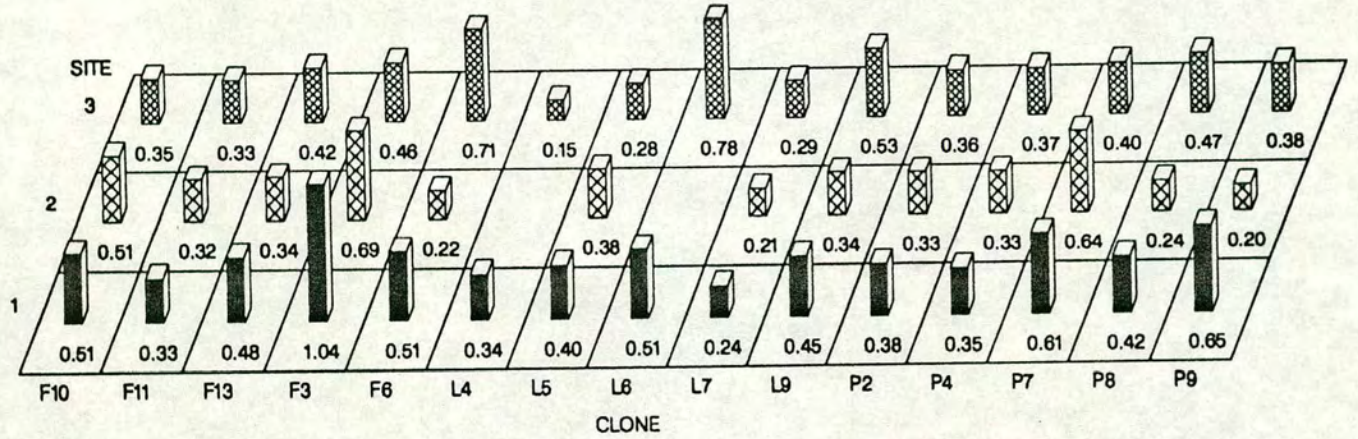

Fig. 4.31 Variation in roots:shoot ratio among Sesbania sesban clones after 9 months growth at (1) Maseno (2) Kisii and (3) Machakos, sites in Kenya.

$N\text{-}NH_4$ at $P \leq 0.001$. There were no differences in soil chemical characteristicsbetween depths at all sites.

The soil pH was less variable at each site. For example, the Maseno plots had pH range from 5.21 to 5.27 with a standard deviation of 0.1, while Kisii site had the lowest pH which varied from 4.88 to 4.94 with standard deviation of 0.1 and Machakos had the highest pH ranging from 6.24 to 6.37 with a standard deviation of 0.04 (Table 4.23).

Soil organic matter at Maseno varied from 9.19 to 10.90%, there were no changes at both soil depths for the two sampling times. At Kisii, soil organic matter at the 0-30 cm depth was 10.63% and 10.83% at 0 and 9 months while the 30-60 cm depth had 13.70% and 11.56% for the same period. Machakos had the lowest organic matter which varied from 5.26 to 5.76 with no significant changes between sampling periods (Table 4.23).

There were no soil K concentrations changes at Maseno. At Kisii there was an increase of 67% in soil K in the 0-30 cm depth and a decrease of 17% in the 30-60 cm depth between 0 and 9 months while soil K concentrations at Machakos in the 0-30 cm increased by 21% and decreased by 11% in the 30-60 cm depth for the same period.

Soil Ca levels increased at Maseno from 49.55 to 53.39 mg 100 g^{-1} for the 0-30 cm depth and from 57.37 to 61.50 mg 100 g^{-1} for the 30-60 cm depth, representing an increase of 8%. At Kisii soil Ca decreased by 14% in the 0-30 cm depth and increased by 30% in the 30-60 cm depth between the two sampling dates. The reverse situation was observed at Machakos where there was an increase of 11% in soil Ca in the 0-30 cm depth and a decrease of 26% in Ca in the 30-60 cm depth.

Soil $N\text{-}NH_4$ also varied between dates. At Maseno for the 30-90 cm depth soil $N\text{-}NH_4$ decreased by 38%. At Kisii soil $N\text{-}NH_4$ decreased by 18% at the 0-30 cm depth and 13% at the 30-60 cm depth while at Machakos there was a decrease at the 30-90 cm depth (Table 4.23).

The available P values were consistent at all sites for the sampling periods,

Table 4.23 . Soil chemical characteristics under Sesbania sesban clone plantings at Maseno, Kisii and Machakos in Kenya at different times (results for K, Ca, Mg, $N\text{-}NO_3$, $N\text{-}NH_4$ and P expressed as mg/100 g^{-1}).

Site	Maseno				Kisii				Machakos			
Depth	0-30 cm		30-60 cm		0-30 cm		30-60 cm		0-30 cm		30-60 cm	
Time	0	9	0	9	0	9	0	9	0	9	0	9
LOI %	10.90±0.42	10.59±0.49	9.39±0.48	9.19±0.38	10.63±0.60	13.70±0.14	10.83±0.70	11.56±1.15	5.26±0.04	5.29±0.41	5.76±0.13	5.38±0.39
pH	5.27±0.10	5.21±0.09	5.21±0.10	5.22±0.02	4.94±0.12	4.92±0.02	4.88±0.12	4.90±0.05	6.26±0.04	6.24±0.05	6.37±0.04	6.32±0.03
K	15.35±1.80	11.47±1.68	16.10±1.55	11.47±1.01	12.25±1.93	31.24±2.83	20.48±4.08	26.06±3.00	35.33±2.96	39.48±1.56	42.76±3.58	35.03±4.56
Ca	49.55±6.61	57.37±6.15	53.39±4.68	61.50±3.93	51.14±7.47	26.84±5.75	44.08±7.87	34.28±4.83	70.21±1.80	66.65±2.33	78.30±2.50	49.51±5.05
Mg	10.25±1.05	6.52±0.73	10.67±0.57	10.23±0.53	8.72±0.69	7.31±0.84	9.28±1.01	8.60±0.52	16.46±0.56	18.21±0.86	17.47±1.03	16.66±1.61
$N\text{-}NO_3$	1.06±0.34	1.16±0.28	0.88±0.25	0.66±0.19	1.79±0.63	1.40±0.18	2.86±0.70	2.72±0.47	0.99±0.13	0.48±0.03	0.99±0.13	0.49±0.07
$N\text{-}NH_4$	2.75±0.32	2.30±0.27	2.68±0.62	1.41±0.37	2.06±0.42	1.51±0.17	1.69±0.18	1.31±0.14	3.42±0.38	0.4±0.08	4.28±0.25	0.32±0.11
P	0.5±0.20	0.5±0.20	0.2±0.00	0.2±0.00	0.2±0.00	0.2±0.00	0.2±0.00	0.2±0.00	0.4±0.00	0.4±0.00	0.4±0.00	0.3±0.00

Time 0 = start of experiment.
Time 9 = after nine months.
LOI (%) = Loss on ignition (%).
± = standard deviation.

generally the sites had low P values (Table 4.23).

4.14.2. Seasonal variation in foliar nutrients.

Analysis of variance (ANOVA) was conducted for the concentrations of five foliar nutrients for S. sesban clones for the three sites (Maseno, Kisii and Machakos) over two collection dates. The ANOVA is presented in Table A4.18. The results indicate that there were significant differences in S. sesban clones and sites in foliar P, K, Mg, Ca and N contents ($P \leq 0.001$, Table A4.18). Significant differences were also observed between date of sampling for K and N at $P \leq 0.001$, while Mg and Ca were significant at $P \leq 0.01$. Clone by site interaction existed for P and N at $P \leq 0.05$, K at $P \leq 0.01$, Mg at $P \leq 0.001$ while the interaction for Ca was not significant (Table A4.18).

The concentrations of foliar nutrients at 3 and 9 months for the three sites are presented in Tables 4.24 and 4.25 respectively. Phosphorus (P) content in S. sesban clones at 3 months at Maseno varied from 0.10% in F10 to 0.36% in P9 at Maseno, and at Kisii varied from 0.12% in F6 to 0.23% in P8 while at Machakos P varied from 0.17% in P4 to 0.32% in F3. At 9 months P content was less variable from 0.19% in L7 to 0.26% in L4 at Maseno and at Kisii from 0.15% in F3 to 0.25% in L7 while at Machakos P varied from 0.14% in F6 to 0.36% in L5. Phosphorus mean concentrations in the foliage were relatively higher at Maseno and Machakos for both periods of sampling than Kisii (Tables 4.24 and 4.25).

Potassium (K) concentrations in S. sesban clones at three months varied at Maseno from 0.99% in F10 to 1.87% in F11. At Kisii K contents varied from 1.50% in P2 to 3.72% in L9, while at Machakos K varied from 1.47% in P4 to 3.07% in L4. After 9 months K contents at Maseno varied from 0.98% in F10 to 1.87% in P7 and at Kisii K contents ranged from 1.50% in P2 to 2.26% in L9, while at Machakos K ranged from 1.10% in F13 to 1.92% in L6. There was a general decline in the mean P contents in the clones at the second sampling after 9 months for all sites (Tables 4.24 and 4.25).

Table 4.24 . Foliar P, K, Ca, Mg and N contents of 3 month old Sesbania sesban clones growing at Maseno, Kisii and Machakos, Kenya.

Site	MASENO					KISII					MACHAKOS				
Clone	P%	K%	Mg%	Ca%	N%	P%	K%	Mg%	Ca%	N%	P%	K%	Mg%	Ca%	N%
F3	0.25	1.76	0.24	2.22	4.07	0.13	1.88	0.32	2.72	4.03	0.32	2.08	0.21	2.99	4.04
F6	0.21	1.45	0.29	3.07	4.21	0.12	3.19	0.17	1.57	4.03	0.26	2.07	0.25	3.25	4.05
F10	0.19	0.99	0.30	3.60	3.75	0.16	2.30	0.23	1.39	4.38	0.19	1.68	0.30	2.88	3.99
F11	0.25	1.87	0.18	1.87	4.95	0.17	2.47	0.28	1.19	4.43	0.21	2.20	0.27	3.64	4.06
F13	0.20	1.18	0.37	3.68	4.38	0.18	2.37	0.22	1.50	4.06	0.21	1.50	0.39	4.01	3.83
P2	0.22	1.21	0.27	2.96	3.98	0.20	1.50	0.35	2.62	3.88	0.19	2.10	0.28	3.67	3.99
P4	0.26	1.19	0.23	2.91	4.28	0.13	1.67	0.22	1.21	4.58	0.17	1.47	0.44	3.70	3.57
P7	0.29	1.48	0.24	1.90	4.70	0.16	2.32	0.16	1.65	4.91	0.29	2.29	0.24	2.98	4.51
P8	0.23	1.52	0.28	3.18	3.66	0.23	1.76	0.32	3.24	5.17	0.26	1.92	0.39	3.75	4.47
P9	0.36	1.95	0.24	1.61	4.75	0.20	1.92	0.18	1.84	4.65	0.32	2.35	0.24	3.43	4.08
L4	0.25	1.59	0.37	2.34	4.14	-	-	-	-	-	0.26	3.07	0.35	2.49	4.49
L5	0.28	1.69	0.29	3.63	4.11	0.18	2.24	0.33	2.59	4.99	0.27	1.52	0.31	3.99	3.71
L6	0.21	1.69	0.19	2.43	4.42	-	-	-	-	-	0.27	1.86	0.23	3.79	4.24
L7	0.22	1.19	0.28	2.84	3.77	0.16	2.04	0.22	2.01	4.55	0.23	1.48	0.38	3.29	4.31
L9	0.30	1.63	0.20	2.62	4.92	0.12	3.72	0.22	1.11	4.23	0.30	2.21	0.23	3.49	4.74
Mean	0.25	1.49	0.26	2.72	4.27	0.16	2.26	0.25	1.89	4.49	0.25	1..98	0.30	3.42	4.14
Sd	0.04	0.27	0.05	0.64	0.39	0.03	0.59	0.06	0.66	0.48	0.05	0.41	0.07	0.42	0.31

Table 4.25 . Foliar P, K, Ca, Mg and N contents of nine month old Sesbania sesban clones growing at Maseno, Kisii and Machakos in Kenya.

Site	MASENO					KISII					MACHAKOS				
Clone	P%	K%	Mg%	Ca%	N%	P%	K%	Mg%	Ca%	N%	P%	K%	Mg%	Ca%	N%
F3	0.20	1.42	0.29	3.06	3.83	0.15	1.87	0.34	2.57	3.61	0.17	1.27	0.51	3.77	3.46
F6	0.21	1.03	0.42	2.95	3.51	0.18	2.16	0.24	1.35	4.72	0.14	1.09	0.38	3.69	2.92
F10	0.19	0.98	0.37	1.85	3.52	0.18	2.08	0.25	2.48	4.53	0.30	1.49	0.26	3.17	4.07
F11	0.20	1.55	0.26	3.87	3.47	0.19	2.21	0.26	2.15	5.00	0.24	1.27	0.27	2.28	2.93
F13	0.25	1.24	0.24	3.70	3.59	0.21	1.83	0.28	2.28	4.42	0.17	1.10	0.40	3.91	3.02
P2	0.24	1.25	0.30	2.84	3.87	0.20	1.50	0.35	2.62	3.88	0.29	1.46	0.27	2.72	4.36
P4	0.19	1.63	0.31	1.98	3.22	0.20	1.84	0.44	3.33	3.75	0.16	1.38	0.51	4.51	2.69
P7	0.20	1.87	0.21	2.16	3.95	0.17	1.83	0.30	1.70	4.62	0.27	1.05	0.32	3.68	2.85
P8	0.20	1.04	0.42	3.30	3.38	0.20	1.84	0.33	3.16	3.98	0.21	1.10	0.42	5.05	3.03
P9	0.23	1.23	0.31	3.45	4.26	0.21	2.13	0.23	2.24	4.37	0.31	1.39	0.33	3.66	4.25
L4	0.26	1.38	0.42	2.25	4.28	-	-	-	-	-	0.15	1.04	0.38	3.44	3.97
L5	0.24	1.65	0.31	3.63	4.09	0.18	2.13	0.29	3.06	4.43	0.36	1.64	0.33	4.13	3.52
L6	0.21	1.80	0.22	2.77	3.83	-	-	-	-	-	0.16	1.92	0.38	3.17	4.15
L7	0.19	1.45	0.30	3.59	3.94	0.25	2.04	0.42	2.64	4.81	0.19	1.19	0.31	4.40	2.96
L9	0.20	1.76	0.19	2.90	3.92	0.24	2.26	0.23	1.90	4.96	0.29	1.53	0.22	3.86	4.37
Mean	0.21	1.42	0.30	2.95	3.78	0.19	1.97	0.30	2.42	4.39	0.23	1.33	0.35	3.69	3.50
Sd	0.02	0.28	0.07	0.63	0.31	0.02	0.20	0.06	0.55	0.44	0.06	0.24	0.08	0.67	0.61

Magnesium (Mg) and Calcium (Ca) concentrations were relatively stable with slight increase between 3 and 9 month sampling. The foliage mean concentration for Mg increased from 0.26% to 0.30% at Maseno, 0.25% to 0.30% at Kisii and Machakos from 0.30% to 0.35% between 3 and 9 months. Calcium content increased from 2.72% to 2.95% between 3 and 9 months at Maseno and at Kisii from 1.89% to 2.42% while at Machakos Ca increased from 3.42% to 3.69%.

Nitrogen (N) foliar content at 3 months varied from 3.66% in P8 to 4.95% in F11 at Maseno and at Kisii from 4.03% in F6 to 5.17% in P8 while at Machakos N content ranged from 3.57% in P2 to 4.74% in L9. After 9 months N content at Maseno varied from 3.22% in P4 to 4.28% in L4. At Kisii for the same period N ranged from 3.61% in F3 to 4.96% in L9 while at Machakos N content varied from 2.69% in P4 to 4.37% in L9. Using a conversion factor of 6.25, the average protein content for the clones after 3 months at Maseno was 27% with F11 having the highest protein content of 31%, while at 9 months average rotein content was 24%, clone L4 had the highest protein content of 27%. At Kisii the mean protein content was 28% at 3 months with P8 having the highest protein content of 32% and while at 9 months the average protein content was 27% with L9 having the highest protein content of 29%. For Machakos average protein content was 26% at 3 months and 22% at 9 months with L9 having the highest protein content in its foliage of 29% and 27% at 3 and 9 months respectively.

4.15. DISCUSSION.

The clonal trials planted at Maseno, Kisii and Machakos, have shown variation in height, root collar diameter and crown diameter. Clone group analysis showed significant differences for height only, with clones selected for poles having greater heights while clones selected for leaf production had consistently lower heights at the three sites. Maseno and Kisii were generally better sites with high rainfall and better soil physical properties than Machakos which normally receives only 700 mm of rainfall and has a prolonged dry period. Similar observations were noted by

Owino et al. (1994) in the performance of S. sesban progeny tests at Maseno and Kisii. The growth rates for height, root collar diameter and crown diameter at Machakos were affected due to the drop in rainfall during the experimental period (Fig. 4.1). There were no distinctly superior clones, as clone by site interactions were was quite strong. This reflected the inability of some clones to perform satisfactorily at some sites.

Significant differences in field growth across the three sites did not emerge in the initial stages. This can be attributed to the fact that the clones were not yet adapted to the sites at this early age and may also be due to "carry over" effects from the nursery (Libby 1974).

Clonal ranking in height between site did not change among the best and worst clones up to time of harvest. Some clones, eg. P4 and P2, performed consistently well, as they were taller and had bigger root collar diameters (RCD) across the sites, while clones P8 and F13 were still relatively short after eight months.

After nine months the clones selected for biomass production varied by 57% in height at Maseno and Kisii and by 40% at Machakos. For root collar diameter (0.15 m) the equivalent values were 94%, 90% and 74%. These significant variations in height, root collar diameters, crown diameter, number of branches, branch frequency and rates of growth result from non-additivity of genetic and environmental effects. These interactions occurred due to changes in the middle ranks above and below the overall mean.

The high correlations over the early period of study relative to the total growth period, indicates the consistency in growth of clones growth from month to month. Height and diameter were strongly correlated. These two parameters have been found to be strongly correlated in many tree species (Wilcox and Farmer 1967 and Zobel and Talbert 1984). Since total height, root collar diameter and crown diameter are a summation of annual growth, these correlations are bound to increase with age.

Broad sense-heritabilities at individual sites were higher than those for combined sites. This is due to the environmentally induced variance of the clones being

tested. For the combined sites the environmental variance is large so heritability is lower, as would be expected (van Buijtenen 1993). The broad-sense heritabilities of these clones indicate that the genetic components of variance are large enough to permit effective selection for height and root collar diameter in these clones. During selection emphasis should be given to root collar diameter, since it has a great impact on volume in trees and it is easy to assess with great accuracy. Clonal variances for root collar diameter were consistently higher at the three sites, indicating that this trait is under genetic control and that the rankings of clones, with respect to root collar diameter, are stable over the sites.

The data confirms the potential value of short-term screening tests for MPTs, as the high correlations indicate that selection for one characteristic would give meaningful gains in the other. The positive correlations between measurements made over time support the conclusion that early selection can be profitable, particularly if it is performed on the data collected from S. sesban trees 6 months old.

This study showed that S. sesban clones at the three sites varied in crown form, due to differences in crown branch lengths, the total number of branches and the sum total of branch lengths per tree. This can be seen from the rate in radial expansion of the branches, which was 0.30, 0.25 and 0.12 m month^{-1} at Maseno, Kisii and Machakos respectively.

Variations in branch length are one of the major determinants of crown form in trees (Barker et al. 1973). In this study branch diameters followed the same trends as the branch lengths, these two variables being highly correlated (r^2=0.93, Fig. 4.10).

Leaf area per branch and per tree also differed between sites and clones. Leaf area per branch more than doubled at Maseno and Kisii over 4-8 months. These two sites had ideal conditions for growth with better soil physical properties than Machakos. Leaf area on primary branches accounted for a substantial proportion of the total functioning leaf area of the trees. Leaf area was strongly correlated with branch length (r=0.77, Table 4.8). Clones P4, P2 and F3 which had higher branch

leaf areas also had longer branches, bigger branch diameters and higher biomass production at the three sites.

The variability in tree crown diameters between sites and clones was as a net result of the differences in branch length, branch diameter and leaf areas hence in crown form.

Branch angle determines their orientation. In this study there were significant clonal differences in branch angle which changed with age (Tables 4.6 and 4.7). As branch length and branch weight increased, so did branch angles, regulated by the interacting factors of gravity, light and genetic mechanisms (Matziris 1989). Branch angle is therefore not a stable character in young trees. For example, clones P4 and F3 developed their crowns at an early age. This was an exploitative growth strategy to cover maximum available space, a characteristic of dominant species in forest ecosystems (Boormann and Likens 1979). Through rapid early expansion the trees adjust to the changing light environment and are able to use larger quantity of incoming energy for their growth. Thus taller clones in this study tended to have larger wider crowns.

The orientation of branches and leaves normally determines the geometry of the crown, as an adaptive strategy for light interception (Brunig 1976). The pattern of crown development in the early ontogeny of S. sesban clones was quite regular, as the branches extended nearly equal in all directions at four and eight months at all sites. This observed symmetry probably reflected the ample spacing of these trees and their position at the equator, where shading is primarily vertical (Gates 1980).

The high broad-sense heritabilities noted for crown diameter and branch angle combined with the non-significant relationships between crown diameter and branch angles suggest that these characters could be combined in a breeding programme for S. sesban to develop narrow-crowned ideotypes of S. sesban, with wide branch angles. This would enhance the individual tree productivity, as well as less shading on adjacent crops.

Leaf area also had moderately high heritability with large phenotypic and genotypic

variations at all sites. This indicates that response to selection for this trait would also be beneficial. Caution needs to taken however, in that leaf area changes with moisture regimes. In this case the leaf area was assessed when all the trees were at the same phenological age (phase) at all the sites. But if the clones were in different phenological phases then it would be difficult to compare heritabilities across sites.

Variation between clones in crown form offers the opportunity to chose the right ideotype for a site and form of land use. It can be affected by and modified for different spacings since the architectural model is usually phenotypically plastic (Tomlinson 1978). In this study, the form of S. sesban crowns seems to be fairly similar on each site. Thus it seems that S. sesban exhibits a high morphological plasticity relative to site. This is good in that an ideotype selected based on crown form would be stable on several sites.

After 9 months growth, dry mass production varied among S. sesban clones. There were no clear variation in biomass among clonal groups. No significant differences were observed in most of the biomass components of clonal groups. Total dry mass (above and below ground) production was higher at Maseno than at Kisii or Machakos. Between clones total dry mass production at Maseno varied by 371% between L9 and P4. At Kisii dry mass production between L9 and F3 varied by 462%, while at Machakos which had the lowest dry mass production (on average half that of other sites) differences between F6 and P4 were 308%. Machakos only receives 700 mm of rainfall per year with a prolonged dry period and nutrient deficient soils. Average biomass production among clones of 17.6, 15.5 and 7.0 t ha^{-1} yr^{-1} for Maseno and Kisii representing the humid zones and Machakos the semi-arid zone far exceeds the expected production of 8-10 and 2 t ha^{-1} yr^{-1} for humid and semi-arid zones (Young 1989).

The study has shown that it is possible to improve and increase wood production by use of clones. In trial at Machakos using S. sesban seedlings at a 2.0 x 2.0 spacing a 3 t ha^{-1} of dry mass was attained at the site after 7 months growth (Oduol and Akunda 1989). The current study using S. sesban clones at a 2.5 x 2.5

spacing the productivity has increased ranging from 3.4 t ha^{-1} to 14 t ha^{-1} in 9 months.

Dry matter partitioning among clones for root, stem, branch and leaf was relatively similar at each site (Table 4.12). The high partitioning of dry biomass to branches and low partitioning to leaf at Machakos represents variation in the phenological phases of the sites. Most of the clones at Machakos at the time of harvest had shed off their leaves, while at Maseno and Kisii the clones were still in active vegetative growth. Site variables rather than genetic variation may have been the major determinants of dry matter allocation. This perhaps was influenced by selection methods used by which the relative percent dry mass partitioning were not largely different in the original ortets selected in the field. In this study the allocation of about 30% of dry matter to roots is in direct agreement with Zobel (1975).

Significant strong correlations existed between stem diameters, height and crown diameters with dry mass components. These correlations indicate an opportunity to use growth traits for the genetic selection of clones for high yield.

Regressions has been used to predict tree performance in forestry (Whittaker and Marks 1975). The results from this study indicate that stem diameters at 0.15 m was the most useful trait in predicting dry mass components of S. sesban clones. This trait is the easiest and most reliable to assess in MPTs and can be measured with great accuracy.

The results show that the fifteen S. sesban clones have contrasting patterns of root distribution and that these are influenced by both genetic and site conditions. The root systems were basically characterised at the soil surface by a high concentration of root around the stem with a sharp decrease with depth. Shallow root systems are characteristic of tropical trees (Kotze and Geldenhuys 1992).

Though based on a study of only a few clones the root system of S. sesban had the following features, according to Kolesnikov's (1971) descrpitions of primary root systems:-

i) a bimorphic root system, consisting of a root plate with a tap root as a secondary

feature.

ii) A thick root stock formed by the fusion of buttressed main lateral roots close to the stem to form a solid plate.

iii) A few horizontal roots extending further away from the central root stock.

iv) Most of the fine roots were distributed in the top horizon though some fine roots could also be observed in lower horizons on tips of laterals.

Site characteristics may have been a major cause of different forms of root development among the clones. There were significant variations in rooting depth, lateral spread and concentration between sites. The differences at the sites could be in soil profile, nutrients and drainage.

The results show that the rooting patterns of S. sesban clones, especially the growth of structural roots, was systematic but variable. The length of roots varied among clones and competition seemed to have been a major factor in shaping the root systems. The length of the longest root is not a useful measure in root systems as roots tend not grow straight and are highly forked. During excavation it was found that roots overlapped, and all zones of the root system contained at least some intruding roots from other clones. This caused problems, preventing the determination of the effective soil volume being exploited by clones. It appears that the horizontal spread was influenced by soil moisture/nutrients, (Coutts and Phillipson 1977) as the penetrating roots had fine root hairs on their ends. The greater extension in horizontal and vertical roots at Machakos where there is moisture deficiency support this conclusion. The advantage of S. sesban in agroforestry context is that most of its roots are concentrated around the stem and with a sharp decrease in lateral roots away from the tree base and below the soil surface there is an even distribution of roots. This type of allocation reduces the competition for nutrients and water with food crops so that the area between trees can be used as alley farming.

Root:Shoot ratios reflect differences in relative growth rates of the roots and shoots in trees. The root:shoot dry mass ratio for the clones was relatively low, indicating that the clones allocate more to the shoot system in order to produce a canopy as

fast as possible.

Results for soil and foliar nutrient contents have shown that significant differences existed between sites and may indeed, together with moisture availability, explain the differences in productivity between sites. The low soil fertility at Machakos is characterised by the low organic matter (O.M) content and nutrient levels. Organic matter levels at Machakos were half those of Maseno and Kisii (Table 4.29). Organic matter content influences the storage, release and availability of soil nutrients such as P, N and Ca (Jha et al. 1991). Thus the high organic matter content at Maseno and Kisii, implies that S. sesban plants might have had more nutrients available to them for growth, than at Machakos. S. sesban clone productivity at Machakos may also have been detrimentally affected by the low pH and clay content of the soils. Low clay content reduces the water holding capacity of soils (Nicou 1986). In general it is clear that the soil physical environment at Machakos was less favourable than Maseno and Kisii.

Sesbania sesban is a good source of organic N, as it has a high nitrogen fixation capacity (Rao et al. 1989, Onim et al. 1987) and also contributes more phosphorus into the soil (Onim et al. 1990), although there is no evidence in the current data showing any change in phosphorus between the two sampling times. Improvement in soil fertility and physical properties by S. sesban mulch have been reported by Onim et al. (1990), where they found significant contributions of N, K and Ca. Long term experiments using S. sesban as a fallow have yielded significant changes in soil fertility and improved grain yields in maize (Onim et al. 1990). Nine months is a short time in which to effectively register any changes in soil nutrient status due to the growth of S. sesban clones. But the data given indicates the possible influence of S. sesban plantings on soil properties.

Foliar nutrient contents in S. sesban clones was variable at all sites. The foliar nutrients were generally similar for the two sampling periods, though the first sampling tended to have slightly higher levels. This may have been due to the juvenility of the plants as compared to nine month old plants. The levels of N in the leaves were more than sufficient to be used as useful for fodder, as the protein

levels were between 24 to 32%, these levels compare with those reported by Gohl (1981), Robertson (1988) and Onim et al. (1989) of 19.4 to 26%. It is clear therefore that these clones would be used as fodder for animals and mulch for soil improvement.

The study has helped to assemble data on the average performance of the S. sesban clones and their genetic parameters. In future this may allow some clones to be classified according to their suitability for some sites. For example P4, L5 and L6 are appropriate for Maseno site, F3, P4 and F10 for Kisii and P4 for Machakos. Some other clones like P2, F11, F10, L7 and L4 could be specifically developed for Machakos as they had similar performance on this marginal site. The results of this study suggest that it may be possible to select and develop highly productive single-purpose clones for some sites (Leakey 1991).

4.16. SUMMARY.

1. There was genotype by environment interaction among S. sesban clones for height growth. All clones managed to survive at all sites.
2. Selection of high yielding clones for different purposes was successful as reflected in the high heights for clones selected for poles and lower heights for clones selected for leaves.
3. Differences in crown form among S. sesban clones were due to differences in branch lengths and angles.
4. Site influenced different forms of root systems.
5. Biomass production was higher at Maseno and Kisii than Machakos.
6. Root collar diamater at 0.15 m was the best variable in predicting biomass.
7. Sesbania sesban invested most of their dry mass in branches than in stem, root and leaves.

CHAPTER 5

PLANT GROWTH ANALYSIS OF SESBANIA SESBAN CLONES

5.1. AIMS.

Individual trees have different growth patterns, development and productivity. Data on growth and dry matter production is generally lacking for most tree species. Little use if any has been made of within species growth analysis data in genetic investigations of trees. To fill this knowledge gap it is necessary to understand the relationship between early growth characteristics of fast growing tropical trees and productivity. The aim of this study is to test whether early growth characteristics of S. sesban clones could be used as early indicators of potential productivity for clones selected for fuelwood, poles and leaf.

The hypothesis tested in this study was that individual Sesbania sesban clones selected as superior producers of fuelwood, poles and leaf differ in growth patterns, development and productivity.

5.2. INTRODUCTION.

The planting of trees on small scale farms to diversify the wood production base and also reduce pressure on tropical forests is a very difficult task because data on growth and productivity of these species is lacking. Plant growth is defined as an irreversible change with time in plant dry mass and size (Hunt 1978). Plants can successfully grow and reproduce over a wide range of habitats due to their high physiological and morphological plasticity (Grime et al. 1986, Poorter and Lambers 1986) and generally differ in their growth rates and dry matter production (Grime and Hunt 1975, Poorter 1990). The differences in plant performance may be due to genetical, physiological, morphological, environmental and/or interaction of these factors.

Growth analysis has been used to investigate the physiological causes of variation in plant productivity (Gregory 1917, Evans 1972, Grime and Hunt 1975, Poorter 1990). There are three basic methods which have been used widely to study plant growth:-

(i) Yield component analysis has been used extensively in agricultural research to study crop yield, this method sub divides productivity (harvest index) into a set of morphological components whose product is yield (Fraser and Eaton 1983).

(ii) Demographic analysis, follows the presence or loss of morphological components in plants (Bazzaz and Harper 1977).

(iii) Classical and functional plant growth analysis, which includes the indices of both the presence and assimilating performance of morphological components (Causton and Venus 1981, Evans 1972 and Hunt 1982).

Classical growth analysis involves direct harvesting techniques at predetermined time intervals, to investigate photosynthetic productivity of plants, and is the first step in the analysis of primary production in plants (Blackman 1919, West et al. 1920).

Classical growth analysis involves the assessment of:-

(i) Primary growth characteristics that describe the morphological status of the plants at each sampling stage, such as total dry mass of the plants and the separate mass of various plant parts of stem, root, branches and the size of the assimilatory apparatus leaf area. (ii) Growth characteristics which describe the relationship between the assimilatory apparatus and dry matter production.

The established growth indexes explain the causes of differences in plant productivity. The following attributes and indexes describe the growth processes of the plant and are used to compare plant performance in classical growth analysis (Williams 1946, Coombe 1960 and Evans 1972):-

(i) Relative growth rate (RGR), is the increase in dry mass per unit of biomass per time and provides the overall index of plant growth.

(ii) net assimilation rate (NAR), is a physiological growth index which describes the increase in plant mass per unit leaf area per unit time. (iii) Leaf area ratio (LAR)

describes the relative size of the assimilatory apparatus, which is the ratio between leaf area and total plant dry mass.

(iv) Specific leaf area (SLA) is a measure of leaf expansion, a ratio between leaf area and leaf dry mass.

(v) Leaf mass ratio (LMR) measures the distribution of dry material between the leaves and the rest of the plant. A ratio between leaf dry mass and total plant dry mass.

(vi) Shoot mass ratio (SMR) is a ratio between the stem and branch dry mass to total plant dry mass.

(vii) Root mass ratio (RMR) is the ratio between the root dry mass and total plant dry mass.

Through classical growth analysis, it is possible to understand the dynamics of plant performance at various stages of growth and how their growth is affected by the environment. The indices derived are good indicators of the actual equilibrium between the plant and its habitat. Growth analysis also enables you to compare genotypic and phenotypic differences in productivity among and between species and varieties. This information can form a basis for predicting and planning the productivity of growth as well as the development of management strategies for multipurpose trees for the production of different products in agroforestry.

Most multipurpose tree species are still wild and have not been studied yet. In the domestication process of these plants we need to know the growth rates, productivity and physiological plasticity that will enable these trees to succeed in new agro-ecological niches.

Sesbania sesban in the tropical regions of Africa and Asia is one of the most important tree species in agroforestry. This species grows fast with single or multiple-stemmed plants, and has been used by farmers as a source of fuelwood, small sized poles and leaf fodder (Evans and Rotar 1987 and Owino et al. 1994). Its fast growth offers an opportunity to study its growth over a short time through harvests at various intervals. In this way information on the relationship between dry mass and leaf area (the two principal measurements of plant productivity) over

a large fraction of the life cycle of a plant can be obtained. Such information is only available for a few tree species. Normally this information is confined to the early life cycle of the plant, such as for seedlings in greenhouses or nurseries. The results derived from this study are more appropriate and can be used in planning its management in agroforestry.

The following authors, Ovington (1957), Coombe (1960), Coombe and Hadfield (1962), Jarvis and Jarvis (1964), Pollard and Wareing (1968), Loach (1970), Okali (1971), Mooney et al. (1978), Kwesiga and Grace (1986), Oberbauer & Donnelly (1986) and Kamaluddin (1991) report growth analysis data in woody plants. Dutt and Jamwal (1989), Evans and Rotar (1987), Kwesiga (1989), Oduol and Akunda (1989) and Yamoah and Getahun (1989) report general growth on S. sesban under field conditions. Information on growth analysis of tropical tree species grown under field conditions is very scarce.

The objective of this study was to determine the early growth characteristics of S. sesban clones selected for fuelwood, poles and leaf production that could be used as early indicators of their potential production when grown under field conditions.

5.3. MATERIALS AND METHODS.

5.3.1. Experimental site.

The plant growth analysis study was conducted at KEFRI/KARI/ICRAF field station at Maseno. Site details are described in Chapter 2. The total rainfall during the experimental period was 633.2 mm (Fig. 5.1). The trial was located on a former grass pasture with a slope of less than three percent.

5.3.2. Origins of Sesbania sesban clones.

The S. sesban clones used in this study were selected from the provenance variation study (Chapter 3) for their superior production of fuelwood (high stem and

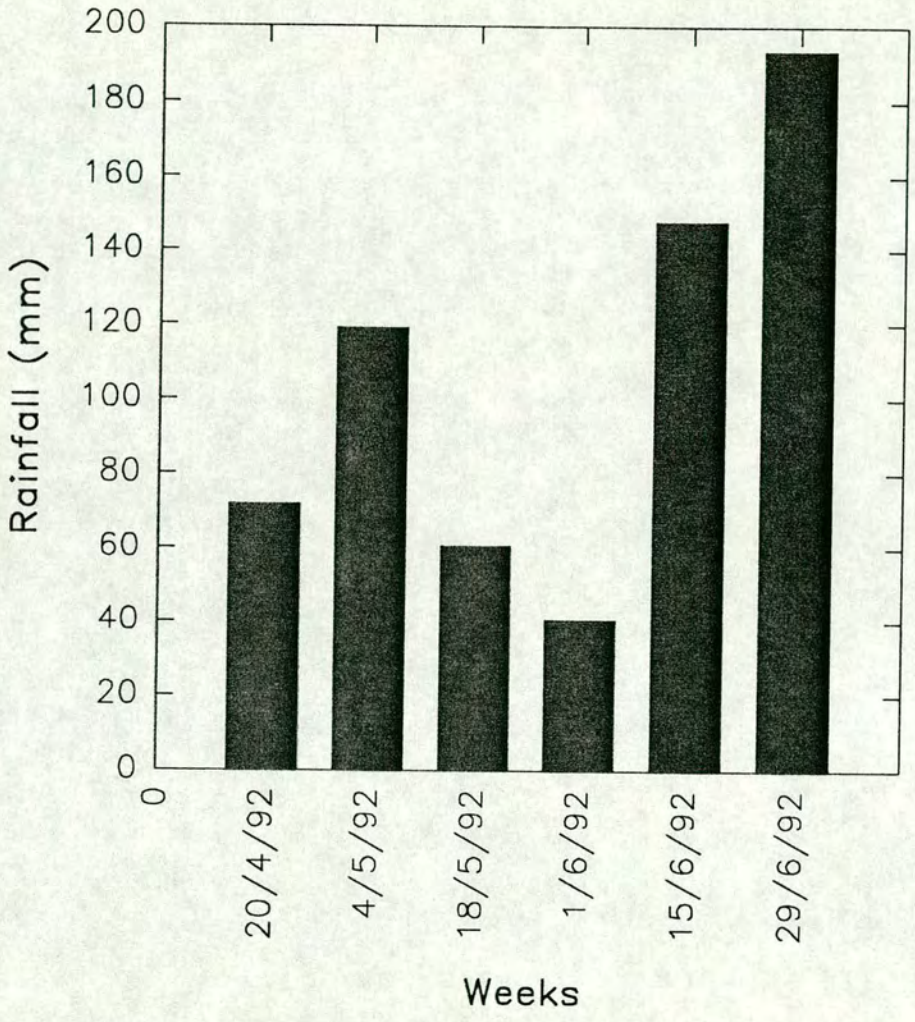

Fig. 5.1. Rainfall in mm at Maseno for the experimental period.

branch dry mass), poles (low branch frequency and high stem dry mass) and leaf (high leaf dry mass). Clone selection details are described in Chapter 4. Five clones were selected for each category and coded as follows; for fuelwood (F3, F6, F10, F11, F13) for poles (P2, P4, P7, P8, P9) and leaf (L4, L5, L6, L7, L9). Table 5.1 shows the clone codes, provenance sources, country of origin, product selected and some climatic conditions at the site of origin. The clones in the text will be referred to by their code numbers. Clone L4, L7 and L9 were not included in the trial as sufficient numbers could not be raised.

5.3.3. Experimental management and field design.

In growth analysis it is necessary to use material as uniform as possible in order to reduce variability (Evans 1972). The plants used in this trial were raised as rooted cuttings. Juvenile cuttings were taken from stockplants in the nursery (See propagation details in Chapter 2). At eight weeks after severence the rooted cuttings were planted on the 6th April 1992, at a field prepared by deep ploughing to minimize weeds. The plots were kept weed free (by manual weeding) throughout the experimental period.

The rooted cuttings were planted in a randomized block design composed of six replicates, each of five blocks. The spacing was 1 X 1 meter in a 5 X 3 array (15 trees randomized in each block as single tree plot represented each clone). The gaps for clones L4, L7 and L9 were planted with S. sesban clones of the same size in order to give a complete canopy. The experimental area was 576 square metres with 450 plants. A single guard row was planted around each replicate (Fig. 5.2).

5.3.4. Assessment of the experiment.

The following growth characteristics were obtained every two weeks for the three month period.

Table 5.1. Showing sources of the Sesbania sesban clones used in Plant growth analysis study at Maseno.

Clone code	Provenance Code	Country of origin	Product selected for	Altitude (m)	Rainfall (mm)
F3	TZ38	Tanzania	Fuelwood	400	1000
F6	TZ32	Tanzania	Fuelwood	940	1074
F10	TZ33	Tanzania	Fuelwood	920	1074
F11	TZ12	Tanzania	Fuelwood	1520	626.4
F13	TZ46	Tanzania	Fuelwood	350	610.8
L5	TZ28	Tanzania	Leaf	1100	2040
L6	HW63	Hawaii	Leaf	-	-
P2	TZ35	Tanzania	Poles	910	808.8
P4	HW63	Hawaii	Poles	-	-
P7	TZ39	Tanzania	Poles	400	1000
P8	TZ39	Tanzania	Poles	400	1000
P9	HW63	Hawaii	Poles	-	-

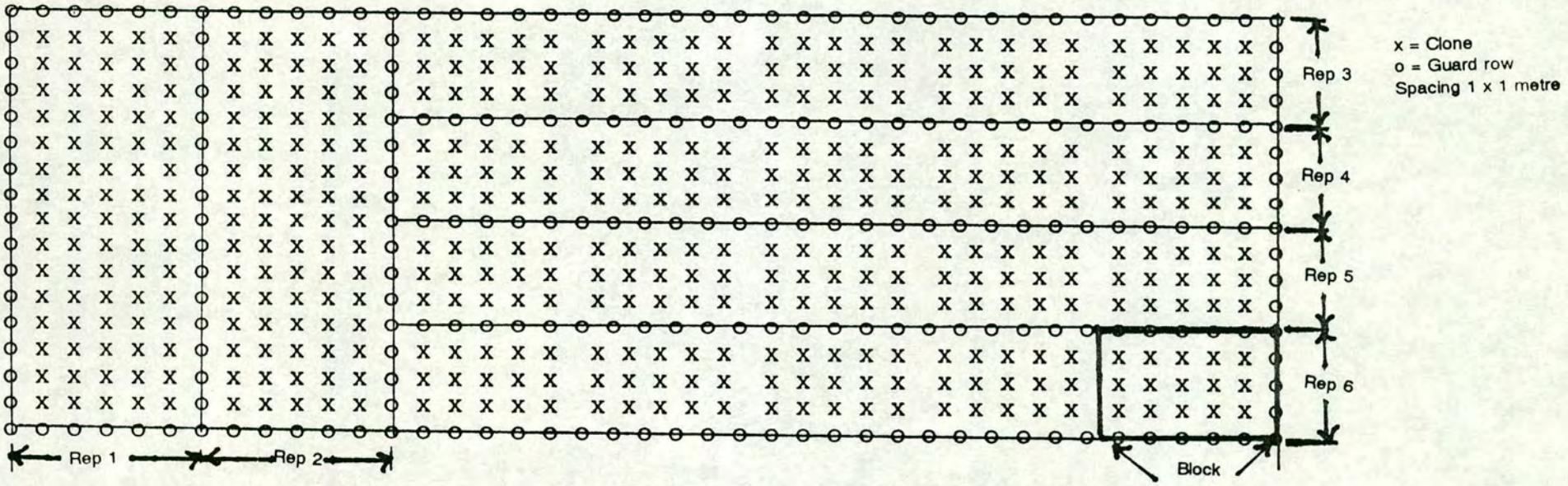

Fig. 5.2. Plot layout for Growth analysis study at Maseno.

(i) Height in metres was measured on the tallest shoot from the base to the tip of the terminal bud, (ii) root collar diameter (cm) was measured with calipers at a marked point 2.5 cm on the new vegetative shoot, (iii) number of primary branches directly originating from the main stem were counted, (iv) the number of leaves per tree were counted (v) leaf area was determined by using a leaf-length measurements as described in detail in Chapter 2. (vi) Crown diameter a measure of crown spread was assessed after six weeks in the field and is expressed in meters. (vii) Harvesting was done at two weeks intervals from 20/4/92 until 29/6/92. A complete replicate was harvested representing five plants of each clone. The plants at each harvest were separated into portions of root, stem, branch and leaves whose dry mass were determined after drying in the oven for 24 hours at 105°C. A large proportion of roots was concentrated around the main stem within the top soil horizon, thus it was possible to excavate the main root branches and to wash them before drying. All harvests were done on the exact date specified. Linear measurements precision were to the nearest centimetre.

5.3.5. Analysis of growth.

Using the data already collected the following variables were derived independently for each harvest in order to compare the increase in dry mass, assuming a linear relationship between mass and leaf area over the growth interval (Williams 1946, Watson 1947, Coombe 1960, Okali 1971).
These attributes describe the growth processes of a plant.

(i). Relative growth rate (RGR)

$$RGR = \frac{Log_e W_2 - Log_e W_1}{t_2 - t_1} \quad g^{-1}\ week^{-1}$$

(ii) Net assimilation rate (NAR) or Unit leaf rate (E)

$$NAR = \frac{(W_2 - W_1)}{(t_2 - t_1)} \frac{(\log_e W_2 - \log_e W_1)}{(L_2 - L_1)} \quad g\ m^{-2}\ week^{-1}$$

(iii) Leaf area ratio (LAR)

$$LAR = \frac{(L_2 - L_1)}{(\log_e L_2 - \log_e L_1)} \frac{(\log_e W_2 - \log_e W_1)}{(W_2 - W_1)} \quad m^2\ g^{-1}$$

Where: W_1 = total plant dry mass at time t_1

W_2 = total plant dry mass at time t_2

L_1 = leaf area at time t_1

L_2 = leaf area at time t_2

The attributes that describe the growth processes of the plant (RGR, NAR and LAR) and the following indexes which describe the morphogenetic condition of the plant were calculated as mean values of each plant part for each time interval (between two harvests) (Hunt 1978). These ratios are used to compare the distribution of dry-matter between the main organs of root, shoot (stem + branch) and leaves in the clones.

The time intervals are denoted as follows:

(i) first time interval (t_1-t_2) between harvests at two and four weeks.

(ii) second time interval (t_2-t_3) between harvests at four and six weeks.

(iii) third time interval (t_3-t_4) between harvests at six and eight weeks.

(iv) fourth time interval (t_4-t_5) between harvests at eight and ten weeks.

(v) fifth time interval (t_5-t_6) between harvests at ten and twelve weeks.

The other variables assuming linearity were calculated as follows.

i) Specific leaf area (SLA) = leaf area/leaf dry mass (m^2 g^{-1}).

Mean value over the interval t_1 to t_2 is given by:

$$SLA = [(L_1/LW_1)+(L_2/LW_2)]/2.$$

Where: L_1 = leaf area at time t_1

L_2 = leaf area at time t_2

LW_1 = leaf dry mass at time t_1

LW_2 = leaf dry mass at time t_2

ii) Leaf mass ratio (LMR) = leaf dry mass/total plant dry mass (g^{-1}).

Mean value over the interval t_1 to t_2 is given by:

$$LMR = [(LW_1/W_1)+(LW_2/W_2)]/2.$$

Where: LW_1 = leaf dry mass at time t_1

LW_2 = leaf dry mass at time t_2

W_1 = total plant dry mass at time t_1

W_2 = total plant dry mass at time t_2

iii) Shoot mass ratio (SMR) = stem + branch dry mass/total plant dry mass (g g^{-1}).

Mean value over the interval t_1 to t_2 is given by:

$$SMR = [(SW_1/W_1)+(SW_2/W_2)]/2.$$

Where: SW_1 = shoot dry mass at time t_1

SW_2 = shoot dry mass at time t_2

W_1 = total plant dry mass at time t_1

W_2 = total plant dry mass at time t_2

v) Root mass ratio (RMR) = root dry mass/total plant dry mass (g g^{-1}).

Mean value over the interval t_1 to t_2 is given by:

$$RMR = [(RW_1/W_1)+(RW_2/W_2)]/2.$$

Where: RW_1 = root dry mass at time t_1

RW_2 = root dry mass at time t_2

W_1 = total plant dry mass at time t_1

W_2 = total plant dry mass at time t_2

5.4. DATA ANALYSIS.

The data was analyzed using statistical analytical system (SAS) on the Microvax Computer System at Institute of Terrestrial Ecology, Bush Estate. The General Linear Model (GLM) for the analysis of variance for un-balanced experiments (Barr et al. 1979) was used to explore the variation in each parameter. Means were compared using standard errors. Significant levels are based on a probability of $P \leq 0.05$.

5.5. RESULTS.

The results of the assessment are given in the form of individual analysis using the GLM procedure in SAS. The GLM summaries of variance ratios, significance levels, clone means, standard errors and coefficient of variation for the assessed variables are presented for each harvest interval in appendix Tables A5.2 to A5.7 (height; root collar diameter; number of primary branches; crown diameter; leaf area; root; stem and leaf dry mass; total dry mass; leaf area ratio; specific leaf area; leaf mass ratio; shoot mass ratio and root mass ratio) while seasonal changes in clonal performance for the assessed variables are presented in figures 5.3 to 5.17. The figures are categorised for (a) clones selected for fuelwood, (b) clones selected for poles and (c) clones selected for leaves. Time is indicated as weeks after planting in the field.

5.5.1. Primary growth attributes.

No significant differences were observed at the six harvests from 20/4/92 to 29/6/92 between clones and blocks in primary growth variables of height, root collar diameter (rcd), branch number, crown diameter and leaf number (Figs. 5.3-

5.7 and Tables A5.2 - A5.7). At the start of the experiment the average height for the plants was 0.45±0.13 m and leaf area of 0.04±0.05 m^2. There was a general increase in height between harvests (Fig. 5.3). At the first harvest (20/4/92) the average height for clones was 0.71±0.13 m while at second harvest (4/5/92) there was a 40% increase in average height to 1±0.16 m. The biggest increase in height by 50% was at harvest four (1/6/92) when the clones had an average height of 2.05±0.25 m. Minimum height increment was between week 8 to 10. Root collar diameter (rcd) increased between harvests (Fig. 5.4). The biggest increase in root collar diameter was between harvest three and four with a 78% increase. The number of branches per tree also increased with time in clones doubling between week two and four (Fig. 5.5). Crown diameter assessment started after six weeks growth in the field and is represented in figure 5.6. Crown diameter increased by 115% between weeks six and eight. Leaf number also increased with time among clones (Fig. 5.7), more than doubling between week two and four. At the final harvest clone L5 had the highest number of leaves 2218.0±651.0 (Fig. 5.7c).

5.5.2. Morphogenetic growth attributes.

5.5.2.1 Plant dry mass.

Plant dry mass (g) is presented in figure 5.8. Significant differences were observed between clones at harvest one ($P \leq 0.001$, Table A5.2). The average total plant dry mass was 12.08±0.64 g. Clones selected for fuelwood had dry mass range from 9.54 g in F3 to 12.84 g in F13 (Fig. 5.8a) while those selected for poles had a range from 8 g in P8 to 13.08 g in P9 (Fig. 5.8b), and those clones selected for leaves had dry mass of 14.8 and 13.14 g in L5 and L6 respectively (Fig. 5.8c). Clone L5 had the highest mean plant dry mass of 14.8 g, while the lowest plant dry mass was recorded in clone P8 with 8 g. At harvests two, three, four, five and six there were no significant differences between clones in plant dry mass (Tables A5.3 - A5.7). At harvest two, the average plant dry mass of clones was

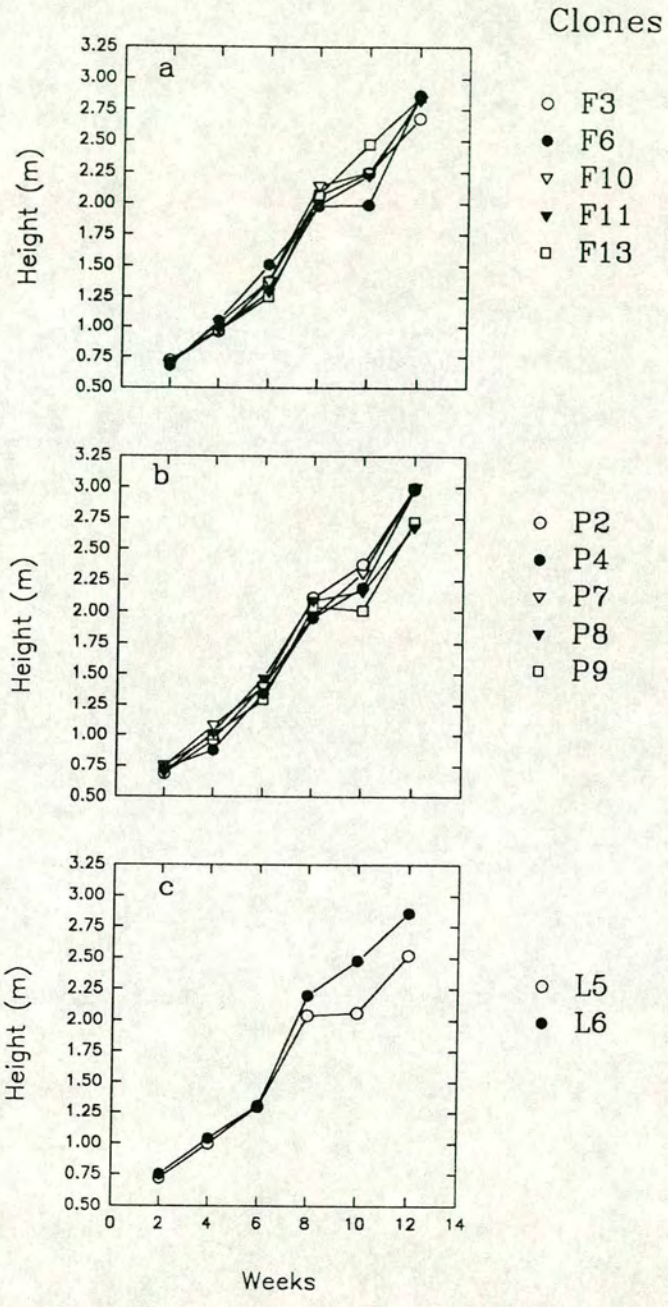

Fig. 5.3. Height growth (m) in Sesbania sesban clones at Maseno. (a) Clones selected for fuelwood
(b) Clones selected for poles
(c) Clones selected for leaves

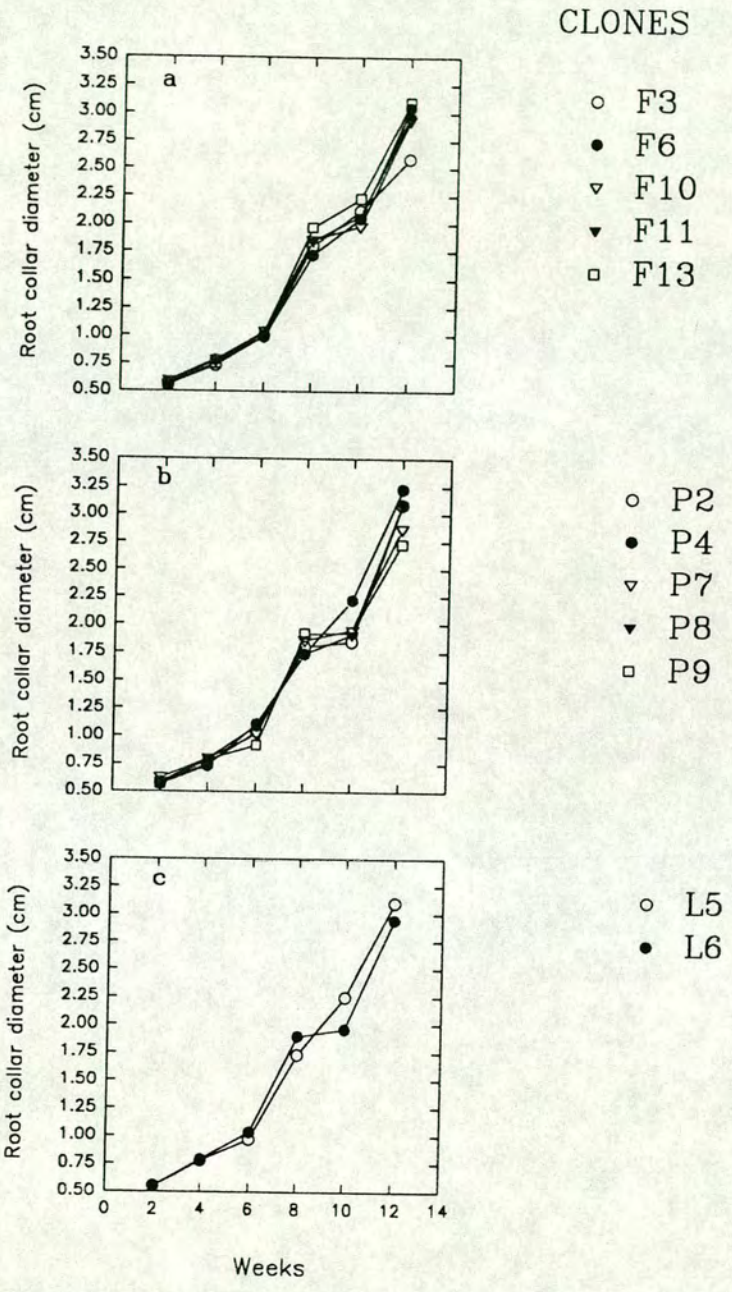

Fig. 5.4. Root collar diameter (cm) growth in Sesbania sesban clones at Maseno.
(a) Clones selected for fuelwood
(b) Clones selected for poles
(c) Clones selected for leaves.

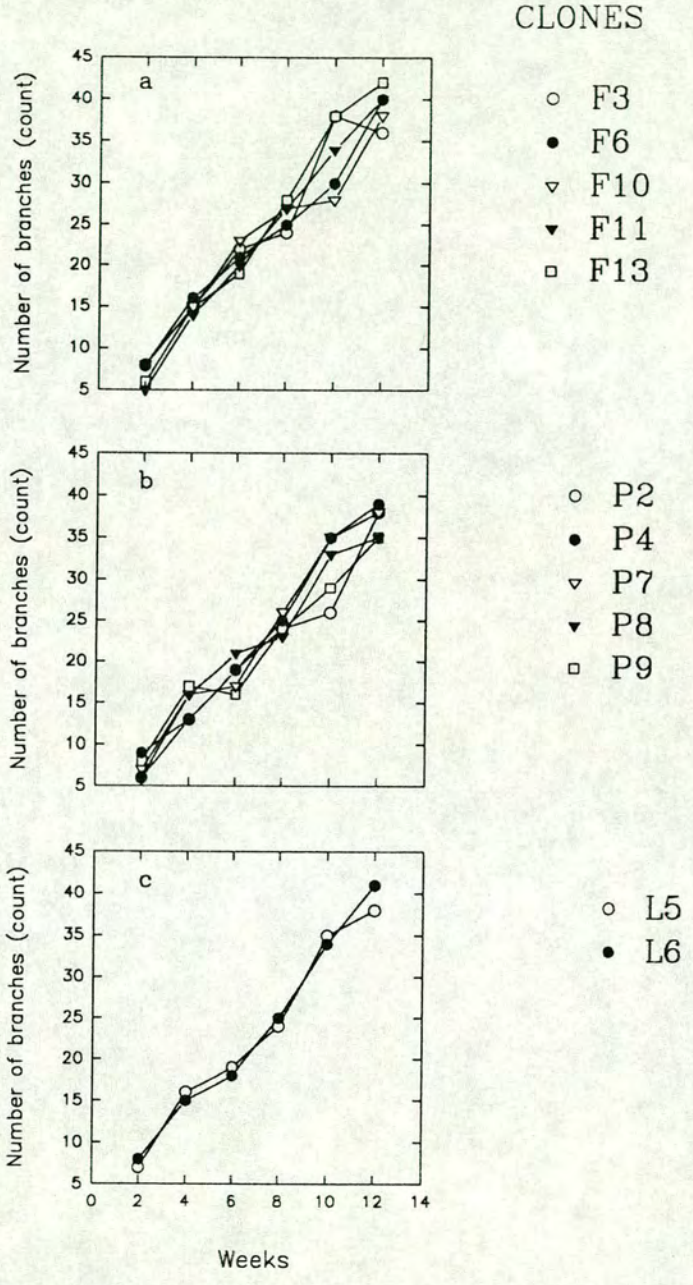

Fig. 5.5. Variation with time in number of branches per tree in Sesbania sesban clones at Maseno.
(a) Clones selected for fuelwood
(b) Clones selected for poles
(c) clones selected for leaves.

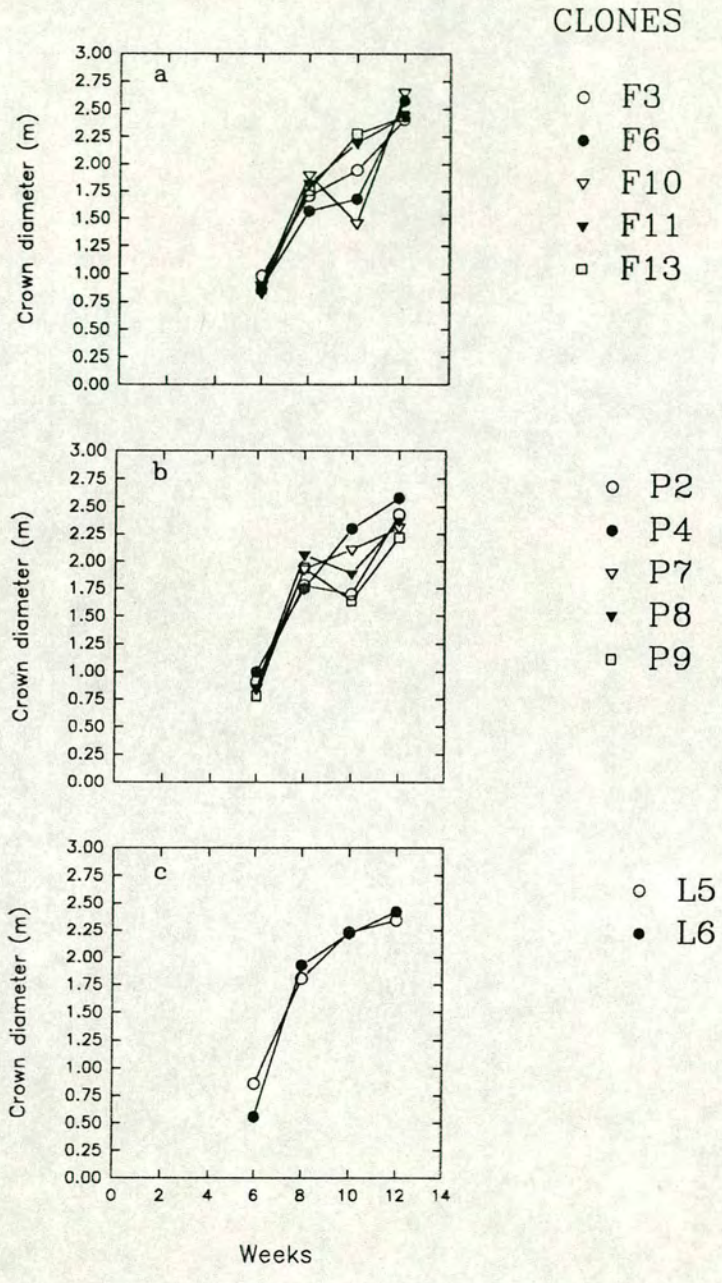

Fig. 5.6.. Variation with time in Crown diameter (m) in Sesbania sesban clones at Maseno.
(a) Clones selected for fuelwood.
(b) Clones selected for poles
(c) Clones selected for leaves.

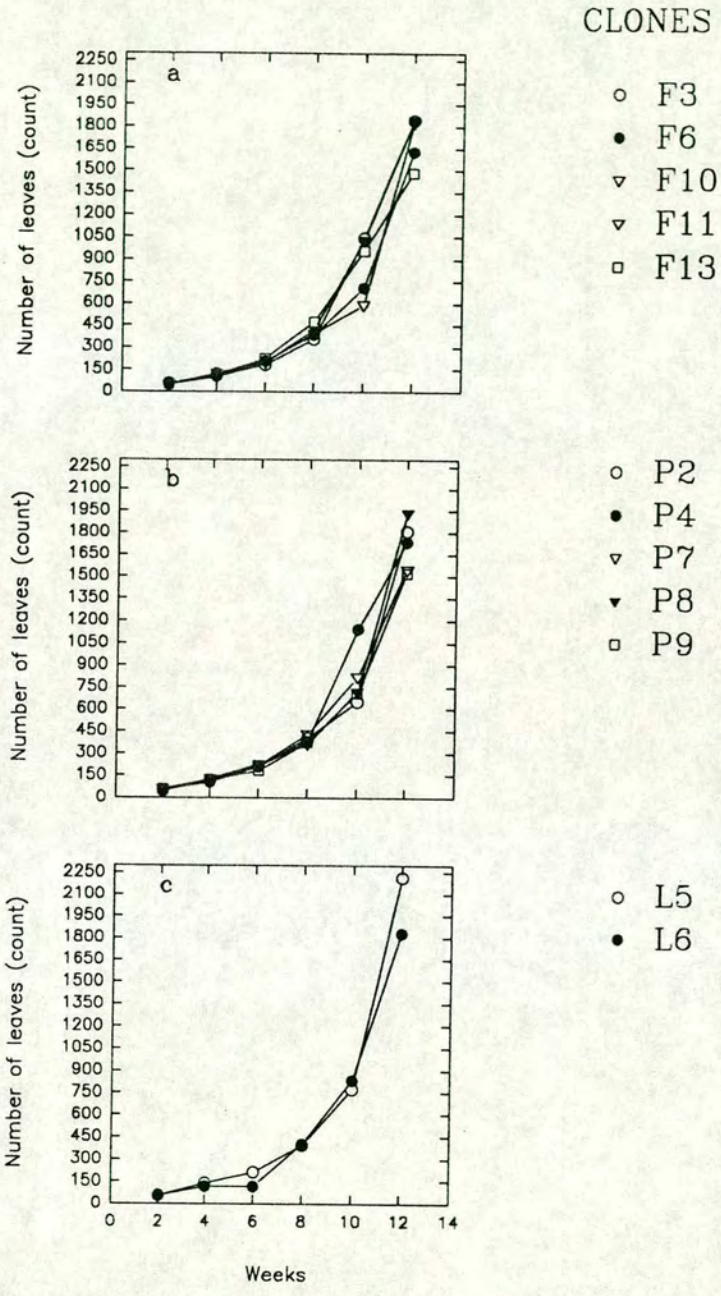

Fig. 5.7. Variation with time in Number of Leaves in Sesbania sesban clones at Maseno.
(a) Clones selected for fuelwood
(b) Clones selected for poles.
(c) Clones selected for leaves.

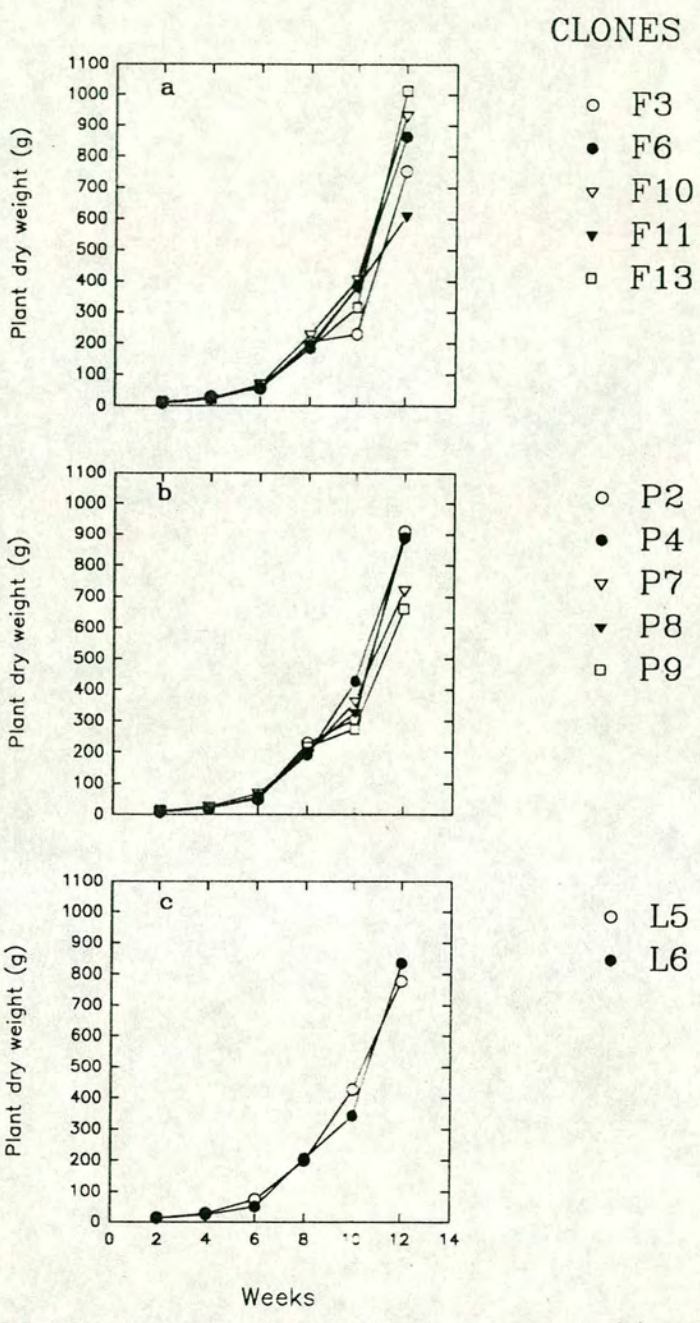

Fig. 5.8. Variation with time in Plant dry weight (g) in Sesbania sesban clones at Maseno.
(a) Clones selected for fuelwood.
(b) Clones selected for poles
(c) Clones selected for poles.

25.26±1.19 g, this was an increase of 109% over the first harvest. At harvest three and four, average plant dry mass were 59.5±1.81 and 204.01±3.55 g respectively. This represented the highest percentage increase of 242.8% during the experimental period. Harvests five and six had average plant dry mass of 348.95±5.42 and 814.03±6.95 g. Generally there was an exponential increase in plant dry mass with time among clones, except between week 8 and 10.

5.5.2.2. Dry-matter allocation.

Allocation of dry matter to roots, stem, branches and leaves was similar in the clones. The percent dry mass of root, stem, branches and leaves are presented in figure 5.9. At harvest one, the average for root dry mass was 28.9±2.5%, for stem 34.0±2.1 %, 2.57±0.7% for branches and 34.0±1.9% for leaves (Fig. 5.9a). At harvest two, there was a slight drop in percent dry mass of roots in all clones to 16.86±4.3% while proportion for stem dry mass remained almost the same as in harvest one with 34.0±2.0% and dry mass for branch increased to 11.3±2.1% and for leaves increased to 36.4±2.9% (Fig. 5.9b). At harvest three, the allocation of dry mass of roots increased to 20.4±1.8% while for stem dropped to 28.3±2.9% and branches increased to 17.2±2.4% and for leaves was 32.6±3.0% (Fig. 5.9c). At harvest four, five and six the dry mass allocation of roots, stem, branch and leaves stabilized with averages of 17.1±1.8%, 24.4±1.4%, 26.6±2.3% and 30.3±2.9% for roots, stem, branch and leaves respectively (Fig. 5.9d, 5.9e and 5.9f). For the whole experimental period from harvest one to harvest six the proportion allocation of dry mass for roots, stem and leaves dropped by 38%, 29% and 10% for root, stem and leaves respectively, while the proportion allocated to branches increased with age (Fig. 5.9).

5.5.2.3. Leaf area.

Seasonal changes in leaf areas are presented in figure 5.10. There were significant

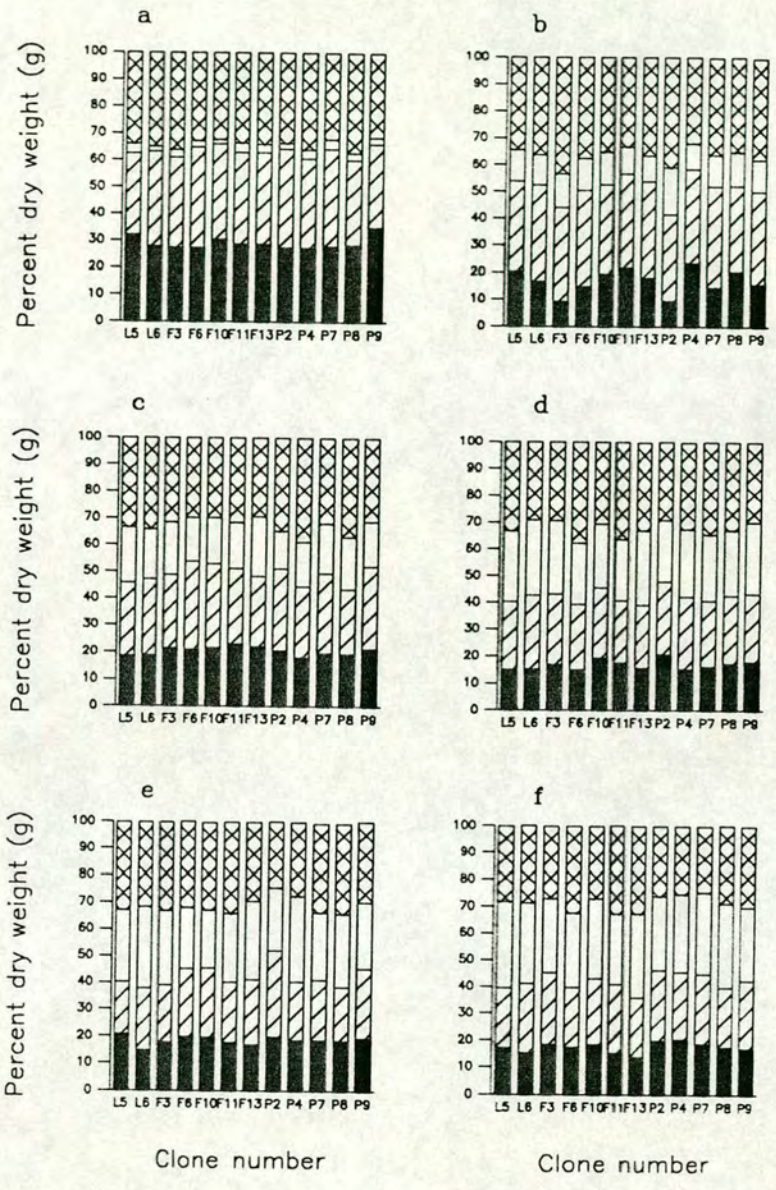

Fig. 5.9. Dry matter distribution between Root ■, Stem ▨, Branch □, and Leaf ⊠ in Sesbania sesban clones as percentages of total plant dry weight.

(a) Harvest after 2 weeks (b) Harvest after 4 weeks
(c) Harvest after 6 weeks (d) Harvest after 8 weeks
(e) Harvest after 10 weeks (f) Harvest after 12 weeks.

differences between clones in leaf area for harvest one ($P \leq 0.001$, Table A5.2). The average leaf area of clones was 0.06±0.05 m^2. Clones L5, L6, P7 and P8 were significantly different from the rest of the clones with leaf areas above the mean. Clones selected for fuelwood had average leaf area of 0.05 m^2 (Fig. 5.10a) while clones selected for poles had leaf area of 0.06 m^2 (Fig. 5.10b) and clones selected for leaves had average leaf area of 0.08 m^2 (Fig. 5.10c). Significant differences in leaf area for clones were also observed at second harvest ($P \leq 0.001$, Table A5.3) with an average leaf area of 0.22±0.1 m^2 which was an increase of 259% over the first harvest. Clones P7, P8, L5 and L6 were significantly different from the rest of the clones, with leaf areas above the mean. The average leaf area for clones selected for fuelwood was 0.05 m^2 (Fig. 5.3a), while clones selected for poles had average leaf area of 0.06 m^2 and clones selected for leaves had average leaf area of 0.08 m^2. (Fig. 5.3c). No significant differences were observed in leaf area between clones at harvest three (Table A5.4) with average leaf area between clones of 0.32±0.1 m^2. Significant differences in leaf area were observed at harvest four between clones ($P \leq 0.001$, Table A5.5). The average leaf area for clones was 0.6±0.16 m^2 which was an increase of 100% over harvest three. Clones F6, F11, F13, P4, P9 and L6 were significantly different from the rest of the clones with average leaf areas above the mean. Clones selected for fuelwood had average leaf area of 0.65 m^2 while clones selected for poles had average leaf of 0.60 m^2 and clones selected for leaves had average leaf area of 0.67 m^2. At harvest five significant differences were observed in leaf areas between clones ($P \leq 0.01$, Table A5.6). The average leaf area of clones was 1.47±0.36 m^2. Clones F3, F11, F13, P4, P7 and L5 were significantly different from the rest of the clones and their means were above the overall mean. Clones selected for fuelwood had average leaf area of 1.42 m^2 while clones selected for poles had average leaf area of 1.49 m^2 and clones selected for leaves had average leaf area of 1.54 m^2. Significant differences between clones were observed at harvest six ($P \leq 0.05$, Table A5.7). The average leaf area of clones was 3.65±0.46 m^2 an increase of 148% over harvest five. Clones F6, F10, F13 and L5 were significantly different from

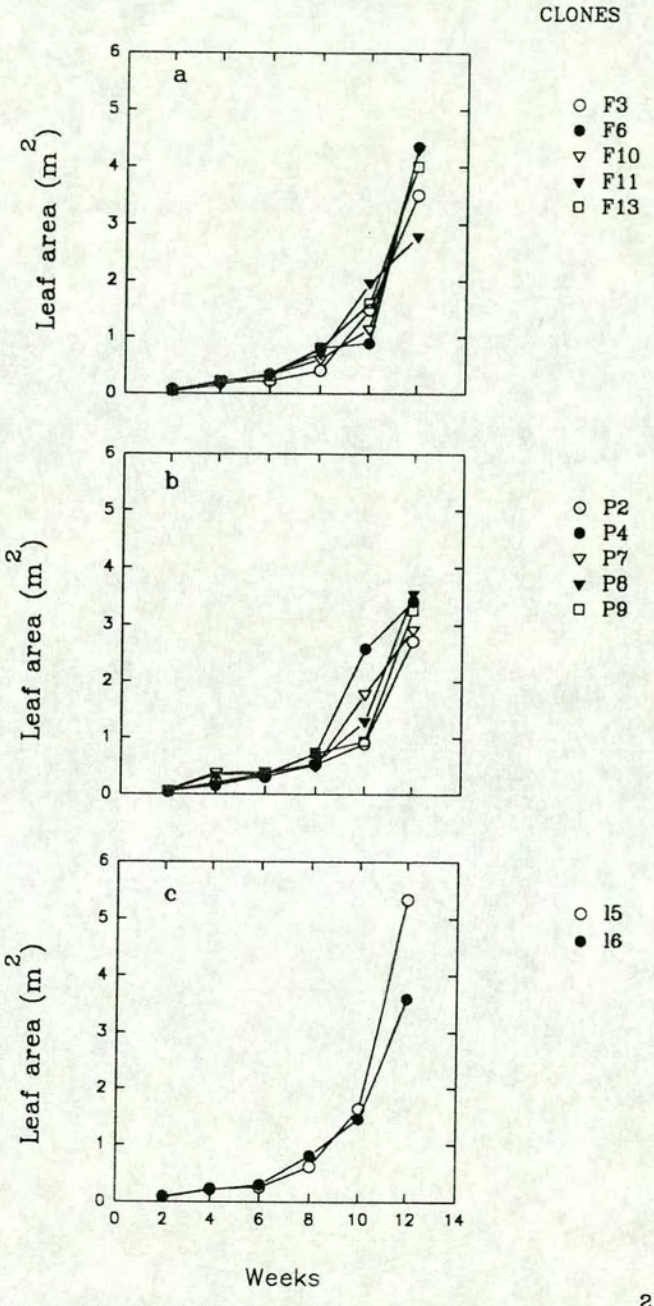

Fig 5.10. Variation with time in Leaf areas (m^2) in Sesbania sesban clones at Maseno

(a) Clones selected for fuelwood
(b) Clones selected for poles
(c) Clones selected for leaves.

other clones with leaf areas above the mean. Clones selected for fuelwood had average leaf area of 3.79 m^2 while clones selected for poles had mean leaf area of 3.17 m^2 and clones selected for leaves had average leaf area of 4.46 m^2 with clone L5 having the highest leaf area of 5.33 m^2. Generally leaf area increased with time (Figs. 5.10a, 5.10b and 5.10c).

5.5.2.4. Specific leaf area (SLA).

Specific leaf areas (SLA) for S. sesban clones are plotted in figure 5.11. The time interval used was the means between two harvests. There were significant differences at first time interval in SLA between blocks ($P \leq 0.05$) and clones ($P \leq 0.001$, Table A5.8). The average SLA for clones was 0.021 ± 0.03 $m^2 g^{-1}$. Clones P2, P7 and P8 were significantly different from the rest of the clones with SLA's above average. Clones selected for fuelwood had SLA averaging 0.018 $m^2 g^{-1}$ (Fig. 5.11a) while clones selected for poles had SLA average of 0.023 $m^2 g^{-1}$ (Fig. 5.11b) and clones selected for leaves had SLA average of 0.021 $m^2 g^{-1}$ (Fig. 5.11c). At the second time interval significant differences were observed in SLA for blocks and clones ($P \leq 0.05$, Table A5.8). The average SLA for clones was 0.021 ± 0.03 $m^2 g^{-1}$. The SLA's for clones P7, P8, P9 and L6 were significantly different from the rest of the clones. The clones selected for fuelwood had average SLA of 0.019 $m^2 g^{-1}$ (Fig. 5.11a) while clones selected for poles had average SLA of 0.024 $m^2 g^{-1}$ (Fig. 5.11b) and clones selected for leaves had SLA averaging 0.02 $m^2 g^{-1}$ (Fig. 5.11c). There were no significant differences in SLA between clones at the third time interval (Table A5.8). The average SLA for clones was 0.014 ± 0.03 $m^2 g^{-1}$. At fourth time interval significant differences were observed between blocks and clones in SLA ($P \leq 0.05$, Table 5.8). The average SLA for clones dropped to 0.013 ± 0.02 $m^2 g^{-1}$. Clones F10, P4, P9 and L6 had significantly different SLA's from rest of the clones. Clones selected for fuelwood had average SLA of 0.012 $m^2 g^{-1}$ (Fig. 5.11a) while clones selected for poles and leaves had average SLA of 0.013 $m^2 g^{-1}$ (Figs. 5.11b, 5.11c). There were significant differences in SLA

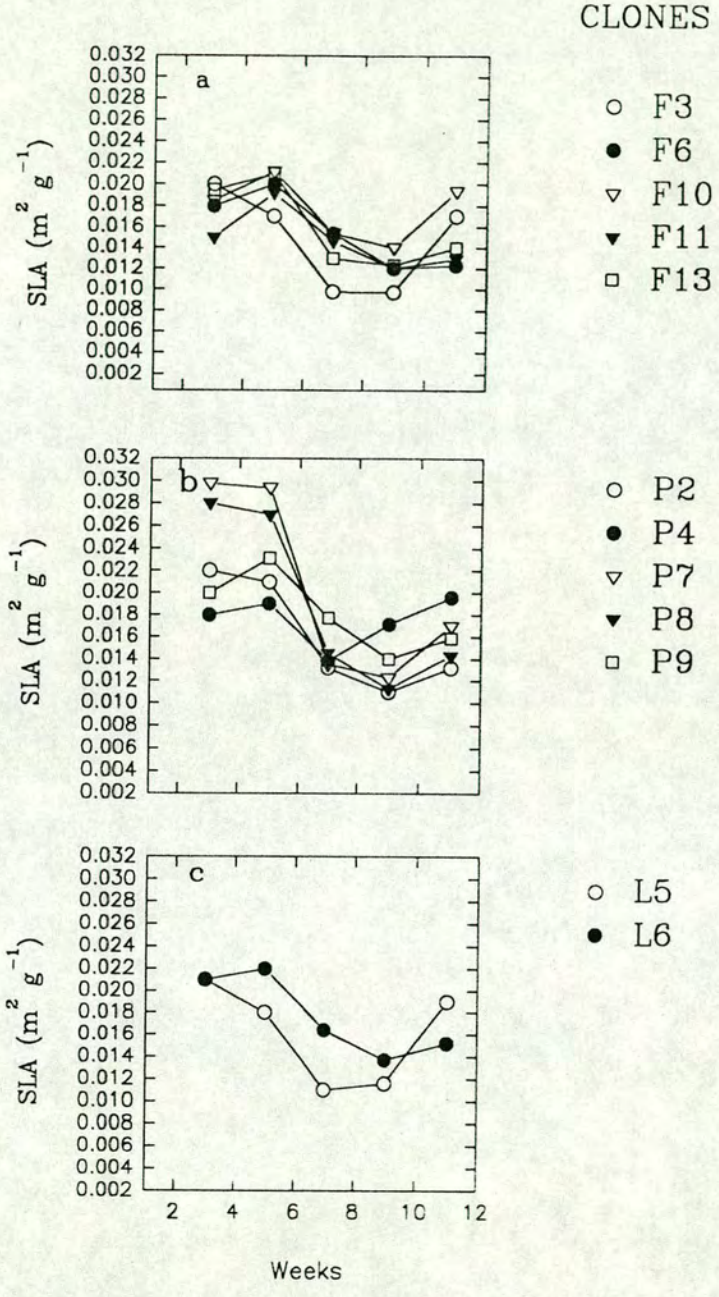

Fig. 5.11. Variation with time in Specific leaf area ($m^2 g^{-1}$) in Sesbania sesban clones at Maseno.
(a) Clones selected for fuelwood
(b) Clones selected for poles
(c) Clones selected for leaves.

between clones at the fifth time interval ($P \leq 0.01$, Table A5.8). There was a slight increase in average SLA to 0.016±0.02 $m^2 g^{-1}$. Clones F3, F10, P4, P7 and L5 were significantly different from the other clones. Clones selected for fuelwood had SLA of 0.015 $m^2 g^{-1}$ (Fig. 5.11a) while clones selected for poles had SLA of 0.016 $m^2 g^{-1}$ (Fig. 5.11b) and clones selected for leaves had SLA averaging 0.017 $m^2 g^{-1}$ (Fig. 5.11c).

5.5.2.5. Leaf mass ratio (LMR).

There were no significant differences in leaf mass ratio (LMR) between clones at the first time interval but there were differences between blocks ($P \leq 0.01$, Table A5.8). The mean clone LMR was 0.35±0.08 g^{-1} (Figs. 5.12a, 5.12b and 5.12c). At second time interval no significant differences were observed in LMR between clones but there were block differences ($P \leq 0.05$, Table A5.8). The mean LMR of clones was 0.34±0.08 g g^{-1}. There were no significant differences between clones in LMR at the third and fourth time intervals (Table A5.8). The mean LMR of clones was 0.32±0.08 and 0.31±0.09 g g^{-1} for third and fourth time intervals respectively. At fifth time interval significant differences in LMR were observed between clones ($P \leq 0.05$, Table A5.8). The mean LMR for the clones was 0.30±0.08 g g^{-1}. Clones P8, F13, F11 and F6 had significantly different LMR's than other clones. Clones selected for fuelwood had average LMR of 0.31 g g^{-1} (Fig. 5.12a) while clones selected for poles had average LMR of 0.28 g g^{-1} (Fig. 5.12b) and clones selected for leaves had LMR averaging 0.30 g g^{-1} (Fig. 5.12c). Maximum LMR were recorded in the early stages of plant growth after which there was a decline in LMR with increase in age in clones (Figs. 5.12a, 5.12b and 5.12c).

5.5.2.6. Shoot mass ratio (SMR).

Shoot mass ratio (SMR) here includes stem and branch dry mass. There was a

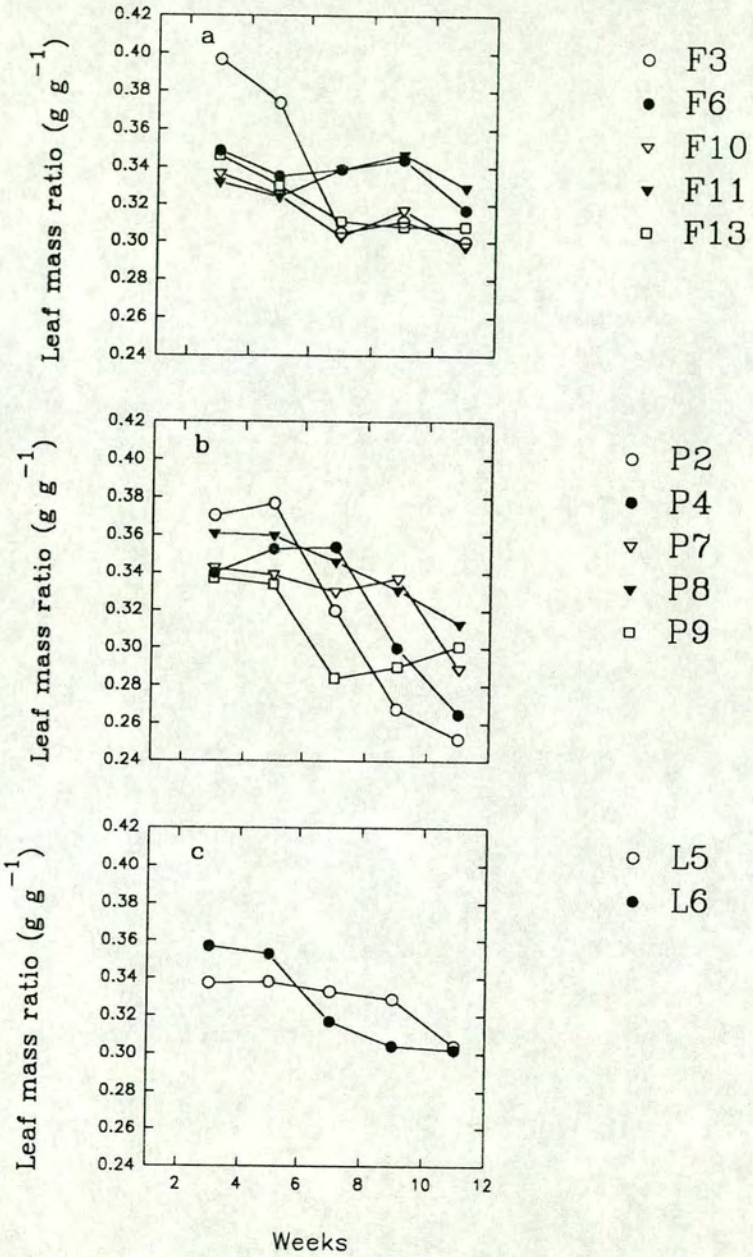

Fig. 5.12. Variation with time in Leaf mass ratio (g g^{-1}) in Sesbania sesban clones at Maseno.
(a) Clones selected for fuelwood
(b) Clones selected for poles
(c) Clones selected for leaves.

general increase in SMR in all clones with increase in age (Figs. 5.13a, 5.13b and 5.13c). At the first time interval there was no significant differences between clones in SMR (Table A5.8). The mean SMR in clones was 0.41±0.08 g g^{-1}. A similar trend was noted at subsequent time intervals (Table A5.8). The mean SMR's was 0.45±0.08, 0.48±0.09, 0.50±0.09 and 0.52±0.08 g g^{-1} for second, third, fourth and fifth time intervals respectively (Table A5.8).

5.5.2.7. Root mass ratio (RMR).

There was a general decline in Root mass ratio (RMR) with age of the clones (Figs. 5.14a, 5.14b and 5.14c). At first time interval there were significant differences between blocks and clones in RMR ($P \leq 0.001$, Table A5.8). The mean RMR for clones was 0.23±0.07 g g^{-1}. The RMR for clones F10, F11, F13, P4, P8, P9 and L5 were significantly different from other clone. Clones selected for fuelwood had average RMR of 0.22 g g^{-1} (Fig. 5.14a) while clones selected for poles had average RMR of 0.21 g g^{-1} (Fig. 5.14b) and clones selected for leaves had average RMR of 0.26 g g^{-1} (Fig. 5.14c). At second time interval significant differences were observed in RMR between clones ($P \leq 0.05$, Table A5.8) and there was a drop of 18% in RMR for all clones to a mean of 0.18±0.08 g g^{-1}. Clones F10, F11, F13, P4, P8 and L5 were significantly different from other clones. Clones selected for fuelwood had average RMR of 0.19 g g^{-1} (Fig. 5.14a) while clones selected for poles had average RMR of 0.18 g g^{-1} (Fig. 5.14b) and clones selected for leaves had RMR average of 0.18 g g^{-1} (Fig. 5.14c). At the third, fourth and fifth time intervals there were no significant differences between clones in RMR (Table A5.8). The mean RMR for clones was 0.18±0.07, 0.17±0.07 and 0.18±0.07 g g^{-1} for third, fourth and fifth time intervals respectively.

5.5.3. Growth processes.

The seasonal changes in relative growth rate (RGR), net assimilation rate (NAR)

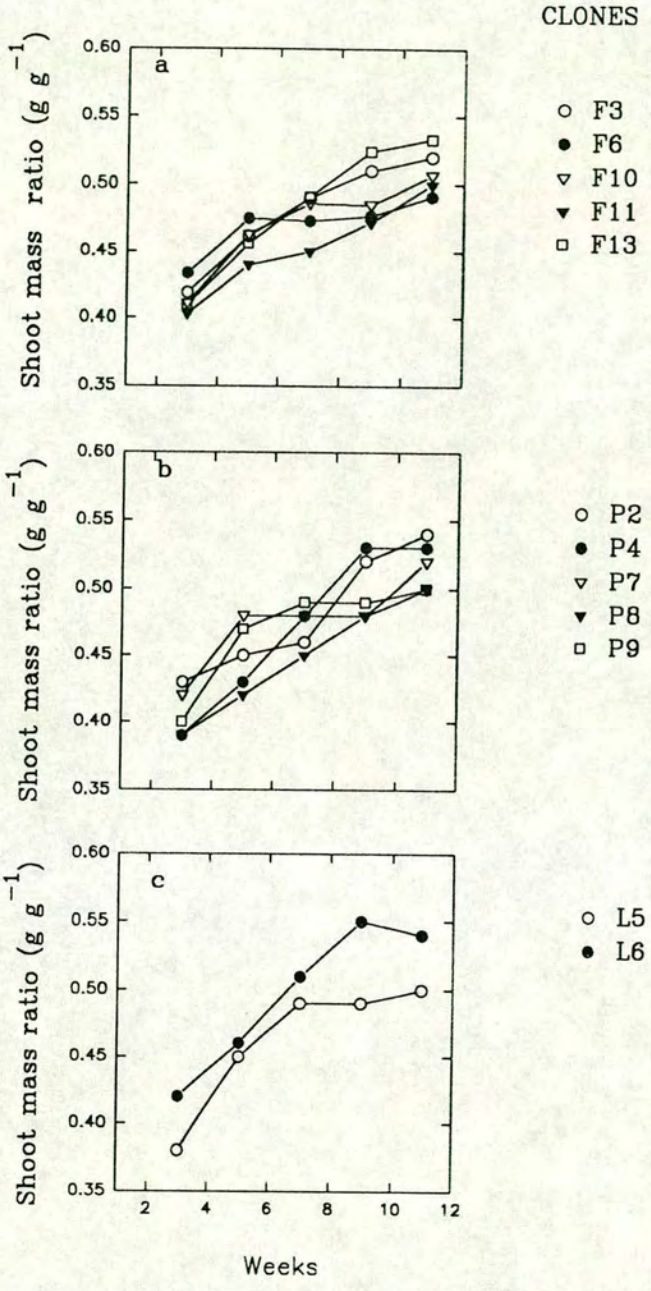

Fig. 5.13. Variation with time in Shoot mass ratio (g g^{-1}) in Sesbania sesban clones at Maseno.
(a) Clones selected for fuelwood
(b) Clones selected for poles.
(c) Clones selected for leaves.

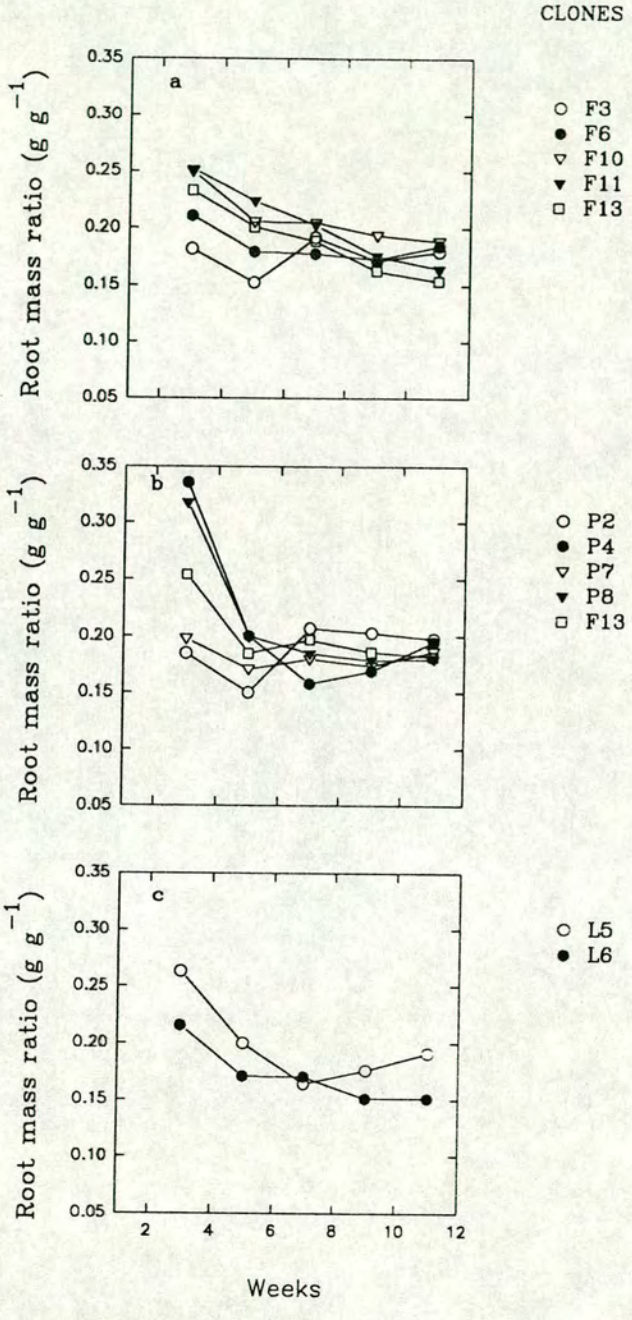

Fig.. 5.14 Variation with time in Root mass ratio (g g^{-1}) in Sesbania sesban clones at Maseno.
(a) Clones selected for fuelwood
(b) Clones selected for poles
(c) Clones selected for leaves.

and leaf area ratio (LAR) are presented according to the product for which the trees are selected (Figs. 5.15, 5.16 and 5.17):- (a) clones selected for fuelwood, (b) clones selected for poles and (c) clones selected for leaf. Statistical analyses of these components are presented in Table A5.9. Time corresponds to weeks after start of experiment.

5.5.3.1. Relative growth rate (RGR).

There were no significant differences in RGR between clones from the first to fifth time intervals (harvests) (Table A5.8). There was a general increase in mean RGR among clones for first, second and third time intervals (Fig. 5.15a, 5.15b and 5.15c). At first time interval the mean RGR for clones was 0.36±0.19 g g^{-1} $week^{-1}$ increasing by 20% to 0.44±0.21 g g^{-1} $week^{-1}$ at second time interval. The RGR in clones was maximum at time interval three with 0.61±0.22 g g^{-1} $week^{-1}$ which was an increase of 40% over the second time interval. There was a drop of 65% in mean RGR of clones at fourth time interval to 0.21±0.27 g g^{-1} $week^{-1}$ and at fifth time interval there was slight increase in RGR to 0.48±0.26 g g^{-1} $week^{-1}$. The RGR values for third time interval were considerably higher than for other time intervals (Fig. 5.15a, 5.15b and 5.15c).

5.5.3.2. Net assimilation ratio (NAR).

Net assimilation rate followed almost a similar trend like RGR as there were no significant differences between clones in NAR for all harvests (Table A5.9). As with RGR, the NAR was maximum for all clones at the third time interval with an average of 164.4±3.9 g m^{-2} $week^{-1}$ (Figs. 5.16a, 5.16b and 5.16c). The average NAR for clones at first time interval was 53.6±2.5 g m^{-2} $week^{-1}$. At second time interval the mean NAR increased by 34.6% to 72.2±3.02 g m^{-2} $week^{-1}$. Net assimilation rates at third time interval was 164.4±3.9 g m^{-2} $week^{-1}$ which was an increase of 131% over the previous time interval. There was a decrease in NAR

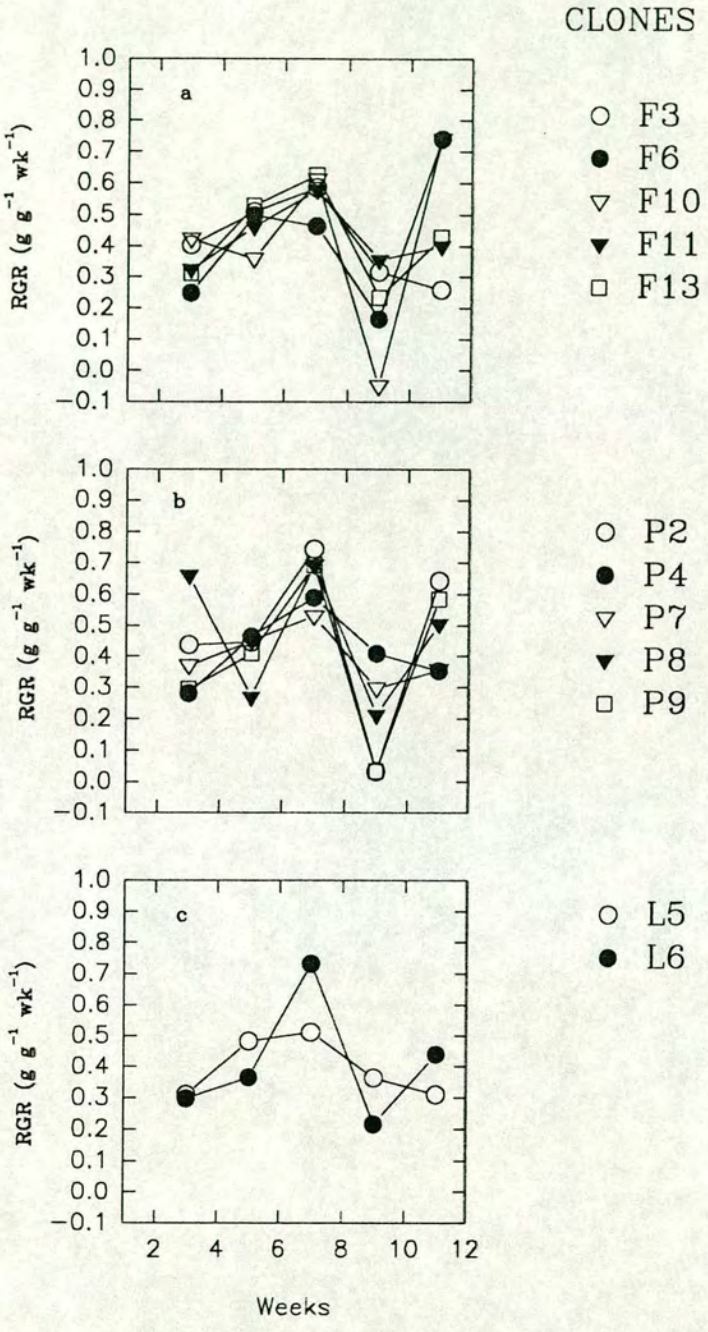

Fig. 5.15. Seasonal changes in Relative growth rate (g g^{-1} $week^{-1}$) in Sesbania sesban clones at Maseno.
(a) Clones selected for fuelwood
(b) Clones selected for poles
(c) Clones selected for leaves.

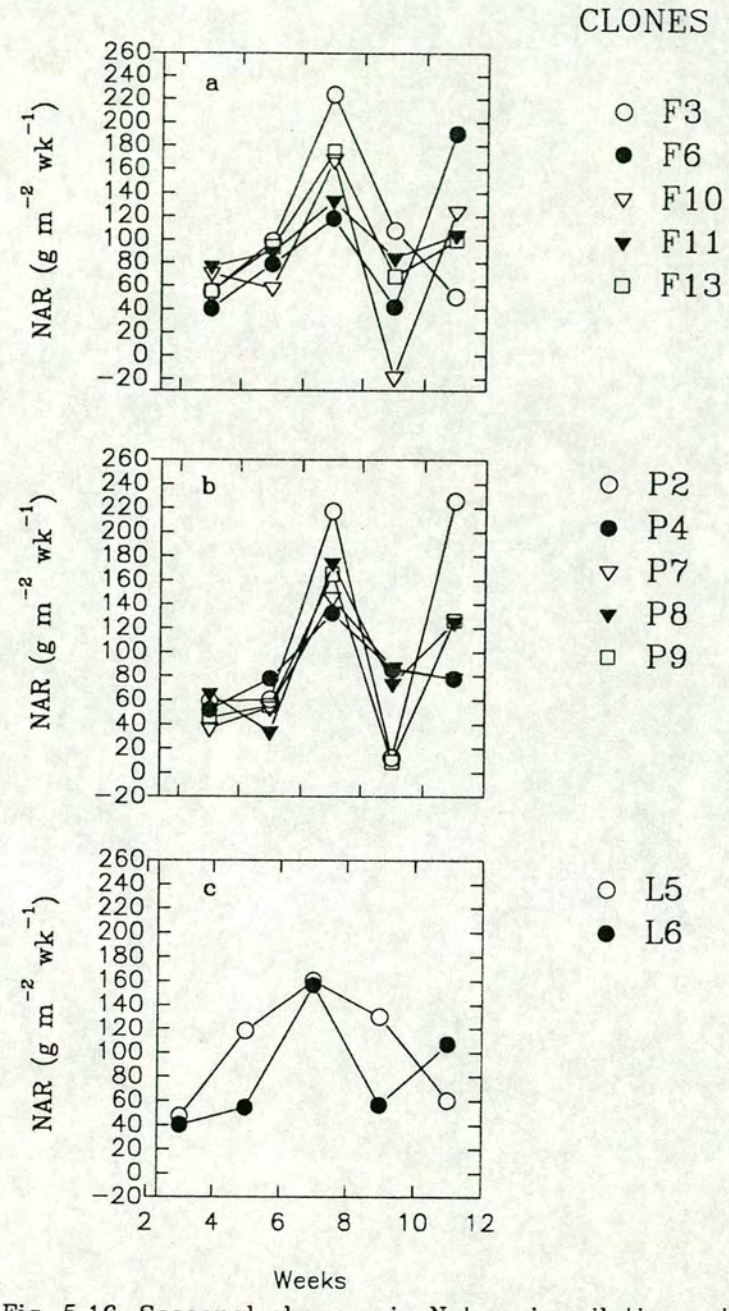

Fig. 5.16. Seasonal changes in Net assimmilation rate (g m^{-2} wk^{-1}) in Sesbania sesban clones at Maseno.
(a) Clones selected for fuelwood
(b) Clones selected for poles
(c) Clones selected for leaves.

at fourth time interval to a mean of 61.6±4.9 g m^{-2} $week^{-1}$ representing a drop of 62%. At fifth time interval the average NAR in clones increased by 85% to 114.3±4.5 g m^{-2} $week^{-1}$.

5.5.3.3. Leaf area ratio (LAR).

The seasonal variation in LAR was quite different from that of RGR and NAR between clones (Figs. 5.17a, 5.17b and 5.17c). There were significant differences in LAR between clones at first time interval ($P \leq 0.001$, Table A5.9). The mean LAR in clones was 0.0071±0.01 m^2 g^{-1}. Clones F3, P2, P7, P8 and L6 were significantly different from other clones. Clones selected for fuelwood had a mean LAR of 0.0062 m^2 g^{-1} (Fig. 5.17a) while clones selected for poles had average LAR of 0.0080 m^2 g^{-1} (Fig. 5.17b) and clones selected for leaves had average LAR of 0.0070 m^2 g^{-1} (Fig. 5.17c). At the second time interval there were significant differences between clones in LAR ($P \leq 0.001$) with a mean of 0.0070±0.02 m^2 g^{-1} (Table A5.9). The LAR's for clones P2, P7, P8, P9 and L6 were significantly different from other clones with means above the mean. Clones selected for fuelwood had average LAR of 0.007 m^2 g^{-1} (Fig. 5.17a) while clones selected for poles had average LAR of 0.008 m^2 g^{-1} (Fig. 5.17b) and clones selected for leaves had LAR average of 0.007 m^2 g^{-1} (Fig. 5.17c). Leaf area ratio at the third time interval was significantly different between clones ($P \leq 0.05$). The average LAR for the clones was 0.0045±0.01 m^2 g^{-1} which was a drop of 36% (Fig. 5.17a, 5.17b and 5.17c). The LAR was significantly different ($P \leq 0.05$) between clones at the fourth time interval with a mean of 0.0039±0.01 m^2 g^{-1}. Clones F6, F10, F11, P4, P7 and L6 were significantly different from other clones. The clones selected for fuelwood had LAR average of 0.0039 m^2 g^{-1} (Fig. 5.17a) while clones selected for poles had average LAR of 0.004 m^2 g^{-1} (Fig. 5.17b) and clones selected for leaves had average LAR of 0.004 m^2 g^{-1} (Fig. 5.17c). At the fifth time interval significant differences were observed between blocks and clones ($P \leq 0.05$). Clones F3, F10, P4, P7 and L5 were significantly different from other clones. The mean LAR in

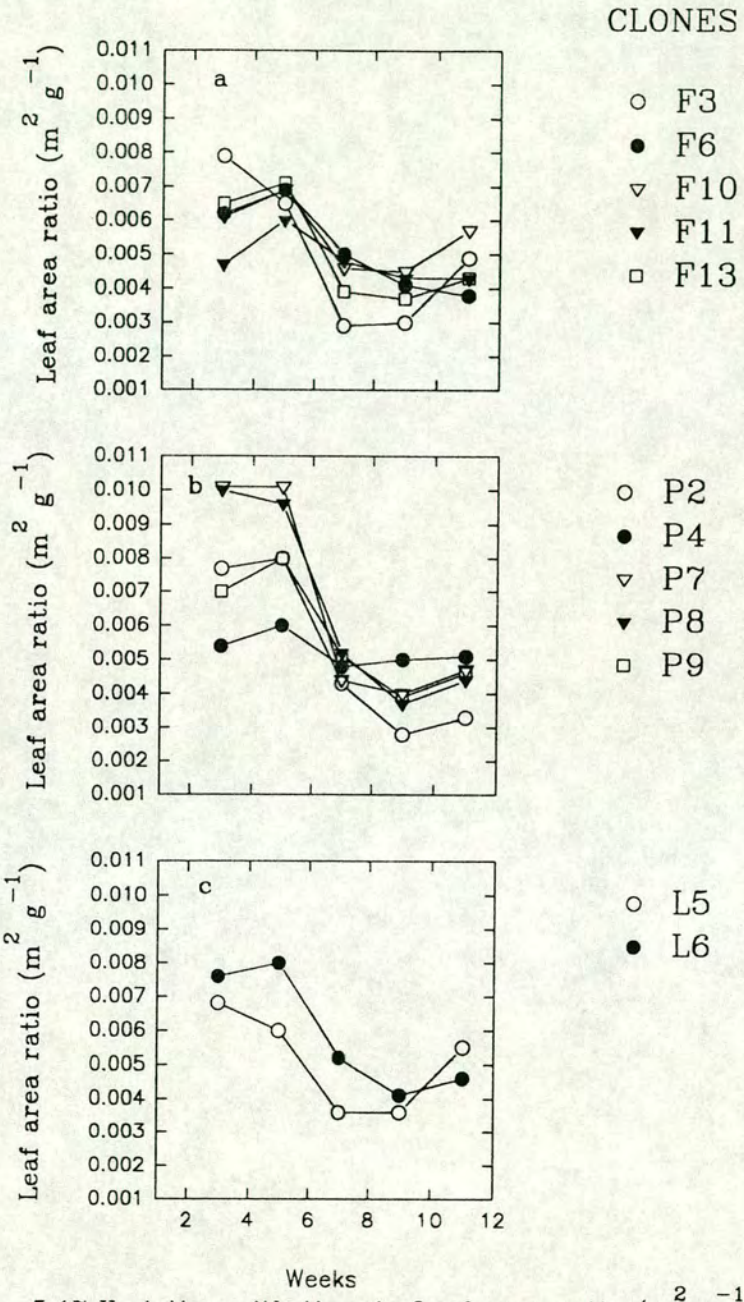

Fig. 5.17 Variation with time in Leaf area ratio (m^2 g^{-1}) in Sesbania sesban clones at Maseno.
(a) Clones selected for fuelwood.
(b) Clones selected for poles.
(c) Clones selected for leaves.

clones was 0.0046±0.01 $m^2 g^{-1}$ and clones selected for fuelwood had average LAR of 0.0046 $m^2 g^{-1}$ (Fig. 5.17a) while clones selected for poles had average LAR of 0.0044 $m^2 g^{-1}$ (Fig. 5.17b) and clones selected for leaves had LAR of 0.005 $m^2 g^{-1}$ (Fig. 5.17c).

5.6. DISCUSSION.

The attributes that describe the assimilatory surface of trees, leaf area, specific leaf area showed significant differences between clones for most of the harvests intervals. Leaf area were highest in clone L5 (at the first and final harvests with 0.086 m^2 and 5.33 m^2 respectively) which was selected for leaf production. These results confirm that leaf area is under genetic control (Loomis et al. 1971, Ceulemans et al. 1984). The significant differences in leaf areas between clones at various harvests indicate that there are genetic differences and that leaf area could be a very important growth attribute in determining and explaining the growth potential of a species (Zavitkoviski et al. 1974, Isebrands and Nelson 1982). Specific leaf area which is a measure of leaf expansion also showed some genotypic variation between clones. Studies by Kuppers (1984) and Konings (1989) noted genotypic and phenotypic variations in SLA among trees. The SLA among clones decreased with increase in leaf age and decrease in soil moisture. This decrease in SLA could be due to environmental changes (Evans 1972, Lambers and Dijkstra 1987, Konings 1989) or to leaf thickness and nutrient limitations (Waring et al. 1985). In order to explain clearly the differences in SLA in these clones there is a need to do a complete chemical analysis in combination with the morphology and anatomy of the leaves (Dijkstra 1989).

Leaf mass ratio is a measure of the fraction of plant dry matter invested in leaves. Leaf mass ratios were not significantly different between clones for most harvests and decreased with age of the plant. The decrease may be due to environmental and nutrient limitations (McDonald 1989). Shoot mass ratio which is the proportion of stem and branch mass to total plant dry mass increased with age of the plant.

As the plant grows more dry matter is invested in stem and branches for support. Root mass ratio was highest in the initial stages of plant growth and thereafter declined with age. The high readings in SLA, LWR and RMR in the initial stages of plant growth may be due to the need for the plant to acquire resources, both above and below ground for its growth and survival. The lack of stability in these ratios with time may be due to competition among plants for resources (McDonald 1989).

The study shows that there were no clear differences in primary growth characters of height, root collar diameter, crown diameter, branch number and leaf number between clones when the clones were growing. However, increases in these attributes with time were observed as the plants grew. These increases and changes are reflected in the exponential growth pattern displayed by the clones (Figs. 5.3-5.8). In all clones growth slowed between week six and eight, this was due to a drop in rainfall during this stage of growth (Fig. 5.2). The clones at this stage of growth were responding similarly to the effects of the environment. Similar trends were observed by Oduol and Akunda (1989) in S. sesban where growth rates were high during the wet season (61 cm $month^{-1}$) and low during the dry season (9 cm $month^{-1}$). The significant differences in total plant dry mass in clones observed at the first harvest indicated that the plants had not adjusted fully to the environment or it may have been a 'carry-over' effect from the stock plant (Libby 1974). However, at subsequent harvests there were no differences in total plant dry mass between clones which showed that the clones were in equilibrium with their habitat and seemed to perform similarly. Total plant dry mass production in clones showed an exponential pattern of growth between harvests.

Information on biomass distribution between different plant organs (roots, stem, branches and leaves) is necessary as the organs have different longevity and functions. The biomass distribution is expressed as percentages of the mass of each tree root, stem, branches and leaves to total plant mass. The fraction of total plant dry mass apportioned to roots, stem, branches and leaves is remarkably similar in the clones within this short period of growth (Fig. 10a-10f). In the initial

stages of growth (harvest two) the proportion of roots was high at 28.8% of total dry mass, while the branch portion was less than 3%, leaf and stem each were about 34%. Dry matter partition shifted in some organs as the plant developed. The root portion dropped to an average of 17% of the total plant dry mass while stem, branch and leaves portions were 24, 30 and 29% respectively at the final harvest. As the plants grew, they required strong stem and branches for support and enough leaves for their photosynthetic processes, so they invest much of their photosynthates in the aerial portion. The lack of significant differences in dry matter partitioning between clones may be due to the active vegetative growth phase for all the plants as well as their similarity in morphological growth attributes.

The growth processes of RGR, NAR and LAR help in explaining the structural development of plants. Relative growth rate enables the comparison of growth rates between individual plants of different sizes, by comparing the rates of increase in biomass. The RGR in clones was similar in most clones leading to constant differences, except for P8 whose RGR declined faster than other clones (Fig. 5.15b). The average RGR for the clones was highest at the third time interval when the growing conditions were ideal and the clones had adjusted to the environment. The RGR in clones dropped at the fourth time interval due to a decrease in rainfall (Fig. 5.15). Thus it is possible to use RGR in assessing the adaptation of the plant to its environment (Grime and Hunt 1975). The lack of significant differences in RGR in clones may be due to the lack of differences in the dry matter partitioning among clones and secondly the RGR within the clones may be large, so that it is not easy to detect differences between clones (Burdon and Harper 1980). Sesbania sesban is a fast growing species, capable of growing on a wide range of environments with a solar energy conversion efficiency of between 5-7% (IUCN 1987). The clones at this site after three months showed greater potential as they produced average dry mass of 0.82 kg $tree^{-1}$ an equivalent of 8.2 t ha^{-1} at a spacing of 1 x 1 m., compared to the provenance production at same age of 0.53 kg $tree^{-1}$ (3.55 t ha^{-1}) at a 1.0 x 1.5 m spacing. The clones had a 54.7% more dry mass per tree than the provenances (See Chapter

4). The measurement of RGR in clones at this stage of growth represents the approximate maximum potential growth rate of S. sesban at this site. The seasonal changes observed between time intervals can be used to compare the production efficiency between clones in relation to the weather changes.

Net assimilation rate which is a measure of the net gain in dry mass of the plant per unit leaf area, showed almost the same type of fluctuations as RGR. The differences in NAR during the harvests was due to the short-term changes in climatic factors. The seasonal changes observed are important in relation to dry matter accumulation in the clones. Maximum NAR was attained between week 6 and 8 when growing conditions were ideal and a drop in NAR at the week 8 and 10 when there was a reduction in rainfall is a direct indication that NAR is very sensitive to water stress. Trends where tree NAR decreased as a result of water stress have been reported by Konings (1989). Leaf area ratio is the proportion of the assimilatory material per unit present and basically describes the efficiency of the plant as a producer of leaf area. The significant differences in leaf area ratio between clones at various time intervals indicates that there are genetic differences in rate of production, extension and retention of the assimilatory surface among clones and that it is a major contributor to the increase in dry mass. This could not be detected in the clones at this stage of growth. The LAR also decreased with age and moisture stress. Leaf area ratio is very sensitive to environmental factors (Evans 1972 and Konings 1989).

The results showed that the clones performed similarly in the early stages of growth, (clones were in same vegetative phase of growth) and that significant differences in growth attributes could be detected as competition set in. The study also indicates that selection of clones for different multipurpose tree uses is not worthwhile because there is no variation in growth rates and allocation of dry mass among clones pre-selected for productivity of one particular trait. This conclusion could not apply if a qualitative attribute (e.g. stem form, wood quality, fodder value) had been used as a selection criteria. The only consistent difference among clones was in leaf characteristics which may be due to the rate of individual leaf growth,

rate of leaf production, development, duration of growth, retention and efficiency. These leaf characteristics were found to be under genetic control in woody plants (Kozlowski and Keller 1966 and Ceulemans et al. 1988) and the differences in leaf traits were found to be closely related to accumulated biomass in poplar clones (Ceulemans et al. 1988). Therefore significant gains could be achieved when selections based on leaf traits in S. sesban are attempted. These clones can be important fodder producers and can be used in selective breeding for fodder production in multipurpose trees. However further observations on the nutrient quality of the leaves and duration should be made to establish the actual potential production over time, as these parameters are dependent on the physiological, morphological and environmental factors (Magnussen 1985).

The reliability of using growth variables as a selection criteria for trees has some draw backs. This is due to lack of strong relationships in growth variables between different stages of development in trees. But growth variables may be used in short-rotations if there are no drastic environmental changes that affect the growth of trees. However a combination of morphological and physiological variables may improve the accuracy of early selection criteria in trees; if there are strong correlations between the juvenile and mature stage.

5.7. SUMMARY.

1). It is possible to make early selections for high growth rates in clones, but this could be supplemented with other studies on the use of organic nitrogen in the leaves in terms of photosynthesis and respiration.

2). The fast growth of S. sesban in early life may not be due to high NAR observed but on other factors for example leaf area production, development, duration and its efficiency.

3). Leaf area was a determinant of clonal differences and could be an important measure of plant growth and productivity.

CHAPTER 6

PREDICTIVE TEST (DECAPITATION TEST)

6.1. AIMS.

Decapitation tests have the potential as early selection techniques by indicating variation in apical dominance between individual trees. The aim of this study is to investigate the possibility of establishing a predictive test for branching in Sesbania sesban trees.

The hypothesis to be tested in this study is that variation in apical dominance in S. sesban clones influenced their branching frequency.

6.2. INTRODUCTION.

Tree improvement programmes involve the selection and evaluation of seedlings/clones performance in field experiments. This procedure takes a long time and requires large tracts of land for field experiments. Therefore, there is an urgent need to develop selection methods that can identify rapidly growing, productive and superior genotypes at an early age. The prediction of field performance in trees by studying the correlation between juvenile and mature growth traits, has been a major research effort in forestry, but has met with little success (Pharis et al. 1991).

This failure has been due to the lack of strong juvenile-mature correlations in overall tree performance at different stages of development. The use of physiological and morphological traits to improve the accuracy of early testing in trees has been suggested by Leakey and Longman (1986), Ladipo et al. (1991a) and Sulzer et al. (1993).

6.3.1. Branching in trees.

Branching in trees is considered to be determined by apical dominance and apical control (Brown et al. 1967, Phillips 1975). Brown et al. (1967) found that the final form of woody plants was dependent on the differential elongation of lateral buds and branches which were associated with the phenomenon of apical dominance. Kozlowski (1964) characterised trees according to their strength in apical dominance. Strong apical dominance in trees was associated with low branching frequency (excurrent form), while weak apical dominance resulted in frequent branching (decurrent form). These forms of trees were found to influence the overall yield of trees (Pickett and Kempt 1980; Leakey and Longman 1986). Studies by Ladipo (1981), Leakey and Longman (1986) showed that strong apical dominance could be detected in 3-6 month old seedlings of Triplochiton scleroxylon, through decapitation tests. In this instance it was possible to predict the branching frequency in 5 year old trees, while the trees are still in the nursery (Leakey 1986). The application of the predictive test on trees in Cameroon is reported by Leakey et al. (1993) and Newton et al. (1991) in Costa Rica.

6.3.2. Apical dominance.

Plants grow in a co-ordinated manner and all cells, tissues and organs are mutually correlated with one another (Phillips 1969). The phenomenon of apical dominance is one of the growth correlations and it directly determines the pattern of growth of individual trees. In many plant species the presence of the apical bud prevents lateral shoots from elongating; a phenomenon called apical dominance. Apical dominance in plants is manifested in three ways: (i) by complete or almost complete inhibition of growth in the axillary lateral buds by the presence of apical bud (ii) by growth inhibition of one shoot due to the presence of another dominant shoot and (iii) effect of the apical part of the shoot upon orientation and development of lateral organs, such as branches, leaves etc, (Phillips 1969). Thus

the axillary buds are usually subjected to a correlative inhibition by the apical bud. The degree of apical dominance in a shoot is determined by genetic and environmental factors but is also influenced by the physiological age of the plant (Leakey and Longman 1986). The exact mechanism for the imposition of correlative inhibition is not properly understood.

The decapitation of plants releases the axillary buds from correlative inhibition and enables the buds to grow. Decapitation tests have shown that apical dominance varies among species and can be used to determine the strength of apical dominance within a species. Several methods have been suggested for the removal of correlative inhibition in plants. The physical restriction of apical growth by covering the apical bud, was suggested by (Mulder 1941); chemical, nutritional and environmental treatments have been described by Phillips (1975) and the surgical removal of the apical bud or shoot by Snow (1925). The most effective and simple method for removal of correlative inhibition is by decapitation (see Hillman and Yeang, 1979). This method involves surgically removing the top two nodes of young plants and then studying the lateral shoot outgrowth.

6.3.3. Apical dominance theory.

The mechanisms of apical dominance in higher plants are not well understood. However, five theories have been advanced based on the role of nutrition and the interaction of growth factors.

(i) The nutritive theory.

The shoot apex in plants inhibits the axillary bud growth as it competes with them for the limited supply of nutrients (Goebel 1900). The apical bud is assumed to consist of a metabolic sink attracting nutrients to flow along a concentration gradient. The removal of leaves in Scrophularia nodosa plants by Dostál (1926) resulted in vigorous bud outgrowth. The leaves in this situation were thought to be

extracting the nutrients and water from the stem making the nutrients unavailable for bud growth. From other experiments conducted by Gregory and Veale (1957) and McIntyre (1968, 1969, 1977), it was suggested that competition by the apex for water, nitrogen and carbohydrates was responsible for apical dominance.

(ii) The direct auxin inhibition theory.

The presence of diffusible bud-inhibiting substances in plants was found in experiments conducted by Snow (1925). He found that the diffusible inhibitor could pass through a water gap between stem tissues and eventually suppress the growth of axillary buds on a decapitated stem. Loeb (1917) also found that as the bud grows it produces and transmits inhibitory substances towards the base of the stem, which directly inhibit growth of other buds. Snow (1937) working on Phaseolus vulgaris found that correlative inhibition of axillary buds by the apical bud was achieved by diffusible substances originating at the growing apex. Thimann and Skoog (1933, 1934) working with decapitated Vicia faba plants, substituted agar blocks containing auxin for the shoot apex and found that the lateral buds were inhibited, just as if the growing apical bud was present. Thus exogenous auxin in agar blocks simulated the effect of the apical bud with respect to the correlative inhibition of the axillary buds. They concluded that it was the auxin diffusing from the apical bud which was responsible for apical dominance. Studies by Šebánek (1966, 1967) suggested that auxins cannot be the sole contributor to inhibition, but that auxins act in conjunction with other inhibitors. This was demonstrated by the contrasting effects of auxins applied at low and high concentrations. When auxins were applied to decapitated plants in low concentrations, they promoted lateral bud outgrowth, while auxin high concentrations inhibited the growth of axillary buds.

(iii) Indirect theory of auxin inhibition.

This theory was advanced by Snow (1937), who suggested that the auxin does not act in a direct manner as suggested earlier. He suggested that the auxin as it passes through the stem, it stimulates the production of a secondary inhibitor which brings about correlative inhibition of buds and shoots.

(iv) Hormone balance theory.

The role of cytokinin in apical dominance was demonstrated in studies on the effects of kinetin upon the inhibition of lateral buds in isolated pea segments (Wickson and Thimann 1958). Several growth regulators have been found to influence apical dominance in plants, for example abscisic acid (White and Mansfield 1977; Šebánek 1973), ethylene, (Hillman and Yeang 1979) and gibberellin (Ruddard and Pharis 1966) with interactions, for example between auxin and gibberellin (Scot et al. 1967, Phillips 1969; Šebánek 1972) and between gibberellin and cytokinin (Šebánek and Obhlidalova 1975). The hormone-balance theory was developed from the experiments conducted by Jackson and Field (1972) where the application of gibberellic acid (GA_3), kinetin and IAA in different combinations had different effects which were partly attributed to endogenous and environmental factors. Further support of the theory was from Tomaszewski (1970) who found synergistic effects of GA_3 on IAA in maintaining apical dominance in Pinus sylvestris.

(v) Nutrient diversion theory.

The nutrient diversion theory was formulated by Went (1936, 1939) who suggested that nutrients were attracted to areas of high auxin concentration. This nutrient diversion theory differs from the nutritive theory, in that the latter was based on the premise that nutrients moved in the plant as a response to concentration gradients.

The nutrient-diversion theory suggests that some physiological effect of the auxin, apart from promoting growth, directs metabolite translocation. Studies involving isotopes such as ^{32}P (Hussain and Link 1967, Wakhloo 1970) and ^{14}C (Panigrahi and Audus 1966) showed that nutrients do travel and accumulate in areas of high auxin concentration. Thus the hormone-directed transport plays a role on correlative bud inhibition.

(vi) Environmental effects in apical dominance.

Inorganic nutrients, especially nitrogen, when in high concentrations lowers the degree of apical dominance in shoots. Light intensity, photoperiod, temperature, gravity and edaphic factors have also been found to affect apical dominance. Studies by Leakey and Longman (1986) and Ladipo et al. (1992) in T. scleroxylon found apical dominance to be very sensitive to environmental factors.

6.3.4. Development of predictive test.

The concept of a decapitation test as a measure of apical dominance in trees was tested by Leakey and Longman (1986). Studies by Ladipo (1981), Leakey and Longman (1986) found that when small potted plants (in the nursery) are decapitated the genetic characteristics of the different clones are expressed in relation to bud activity, which can be used as a measure of apical dominance. Ladipo et al. (1991b) later found positive relations between the apical dominance of T. scleroxylon clones and the performance of the same clones in the field in terms of branching habits. A positive relationship was found between percent bud activity of these clones and branching frequency in the field. This relationship was found useful as an early selection method in predicting branching in mature trees in the field. However, it is useful only for species conforming to Rauh's model of branch architecture.

Advantages of predictive testing (Lambeth 1980) are:-

(i) Genetic tests can be done on juvenile material at close spacing in the nursery rather than in more usual large field trials.

(ii) Genetic gains can be achieved more quickly at a higher efficiency.

(iii) It is easier and cheaper to do measurements and assessments in the nursery than in the field.

(iv) Breeders can be more responsive to changes in demands for improved products or new cultural methods.

(v) Early selection is less expensive and less subject to natural hazards of wind, floods, pests, fire etc. that commonly occur in the field.

The disadvantages of predictive testing are:-

(i) They cannot accurately predict the final crop, and it is the form of the final crop at rotation age that is important commercially.

(ii) A clone with high bud activity following decapitation may have a high natural branch abscission rate and so produce a useful bole. Thus the elimination of clones of this type may result loss of clones with this potentially beneficial trait.

(iii) A clone with a low degree of bud activity following decapitation may develop heavy branches which reduce the economic value of the log. On the other hand the lack of close relationship between heavy branching and bud activity suggests this problem does not occur frequently.

(iv) There are risks that pests and diseases may be specific to certain clones.

(v) Wood quality of selected clones for growth rate may be not good.

Thus it is important that the predictive test is just the first stage of a programme of multiple-trait selection.

6.3.5. The present study.

In the genetic improvement of trees for agroforestry, it is desirable to develop a predictive test for early selection of superior clones. For S. sesban, this can be similar to that for T. scleroxylon, as both spp. conform to the same branch architecture (Rauh's model) (Hallé et al. 1978) i.e. one based on relationship between apical dominance and branching habit. The objective of this study was to determine whether it is possible to identify reliably and consistently the genetic variation in apical dominance in juvenile clones and to use this variation to predict the performance of S. sesban clones at a later age in the field.

6.4. MATERIALS AND METHODS.

This experiment was conducted at Maseno, Kenya (See Chapter 2 for site details). Rooted cuttings of S. sesban were derived from stockplants in the nursery at Maseno (See Chapter 2 for propagation details) raised for a period of 60 days in polythene pots (20.5 x 26.0 cm). Fourteen S. sesban clones each represented by twenty plants, except clone L9 which had ten plants, were randomly distributed in four blocks with five plants of each clone per block. These were arranged at a spacing of 0.5 x 0.5 m between plants and rows, with a single guard row placed around the perimeter (Fig. 6.1).

In this study the top two nodes were removed surgically (on 25/4/92 marking the start of the experiment) in order to break apical dominance in the cuttings. The plants were physiologically in a vegetative phase of growth before and after decapitation. After decapitation the production of buds was followed in the potted plants at bi-weekly intervals from 6/5/1992 to 30/7/1992 a period of twelve weeks. The number of branches, number of leaves, leading lateral shoot length measured to the nearest millimetre and number of growing axillary buds (including branches) were recorded. Bud activity was calculated as the proportion of all axillary buds sprouting and growing by more than two millimetre in length between

BLOCK 1													
x	x	x	x	x	x	x	x	x	x	x	x	x	x
x	x	x	x	x	x	x	x	x	x	x	x	x	x
x	x	x	x	x	x	x	x	x	x	x	x	x	x
x	x	x	x	x	x	x	x	x	x	x	x	x	x
x	x	x	x	x	x	x	x	x	x	x	x	x	x
BLOCK 2													
x	x	x	x	x	x	x	x	x	x	x	x	x	x
x	x	x	x	x	x	x	x	x	x	x	x	x	x
x	x	x	x	x	x	x	x	x	x	x	x	x	x
x	x	x	x	x	x	x	x	x	x	x	x	x	x
x	x	x	x	x	x	x	x	x	x	x	x	x	x
BLOCK 3													
x	F	x	x	x	x	x	x	x	x	x	x	x	x
x	x	x	x	x	x	x	x	x	x	x	F	x	x
x	x	x	F	x	x	x	x	x	x	x	x	x	x
x	x	x	x	x	x	x	x	x	x	F	x	x	x
x	x	F	x	x	x	x	x	x	x	x	x	x	x
BLOCK 4													
x	F	x	x	x	x	x	x	x	x	x	x	x	x
x	x	x	x	x	x	x	x	x	x	x	F	x	x
x	x	x	F	x	x	x	x	x	x	x	x	x	x
x	x	x	x	x	x	x	x	x	x	F	x	x	x
x	x	F	x	x	x	x	x	x	x	x	x	x	x

x = Clone
F = Filler trees.

Fig. 6.1. Layout for Sesbania sesban decapitation test experiment at Maseno.

measurements and expressed as a percentage.

6.5. RESULTS.

The data for number of axillary buds (includes number of branches), bud activity as percentage, number of branches, number of leaves on each plant and length of longest shoot at two and 12 weeks were analyzed by GLM procedure in SAS and the results are presented as summaries of variance ratios, significance levels, clone means, standard errors and coefficient of variations in Table 6.1 and 6.2. The clones at start of the experiment had average heights of 0.76±0.16 m, number of branches and leaves was 2.4±0.63 and 65.1±1.73 respectively (Table 6.1). Since the analysis of variances between time intervals are correlated only the results at 2 weeks and at 12 weeks are considered here.

6.5.1. Number of axillary buds and branches.

There was a general trend in number of axillary buds and branches produced among clones increasing with time and reaching a peak after eight weeks after which there was a decline (Figs. 6.2). Even though a high number of axillary buds and branches was recorded at week 8, the large number of buds which formed at week 8 did not grow rapidly enough to be considered active. The earlier buds must have suppressed these new buds.

6.5.2. Bud activity.

Variations in percent bud activity were observed between clones at $P \leq 0.001$ after two and four weeks (Fig. 6.3). After 4 weeks, percent bud activity declined. At twelve weeks there were no significant differences between clones in percent bud activity (Table 6.2). Peak percent bud activity after decapitation varied according to clones (Fig. 6.a, 6.3b and 6.3c). Clones selected for fuelwood had maximum

Table 6.1. Results of general linear model showing variance ratios, significance levels, means, standard errors (±) and coefficient of variation of Sesbania sesban clones before decapitation, at Maseno.

Source	df	Height (m)	Number of branches	Number of leaves
Block	3	1.33ns	0.68ns	3.05*
Clones	13	24.9***	13.8***	13.72***
Mean		0.76	2.4	65.1
Se		0.44	0.63	1.73
C.V.%		10.5	68.1	18.5

Se = standard error.
C.V. = coefficient of variation.
*** = significant at P≤0.001.
** = significant at P≤0.01.
* = significant at P≤0.05.
ns = not significant.

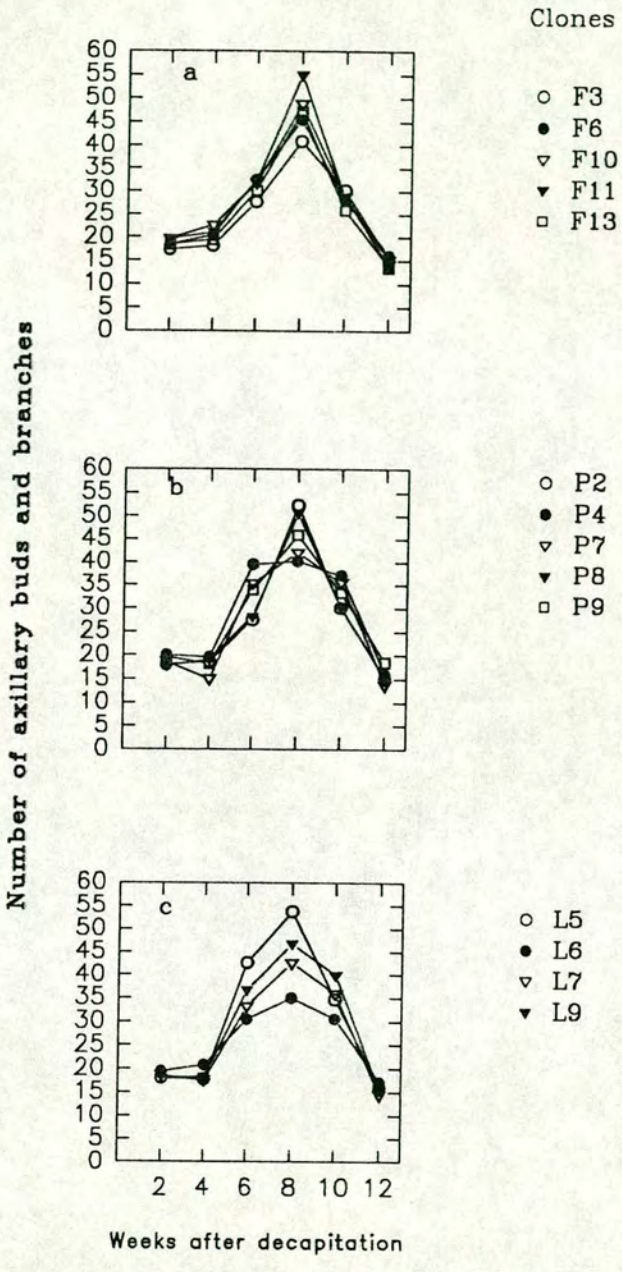

Fig. 6.2. Variation in number of axillary buds and branches in decapitated Sesbania sesban clones at Maseno nursery.

(a) Clones selected for fuelwood
(b) Clones selected for poles
(c) Clones selected for leaves.

Lsd at week 12 = 1.84.

Table 6.2. Results of general linear model showing variance ratios, significance levels, means, standard errors and coefficient of variation of Sesbania sesban at twelve weeks after decapitation at Maseno nursery.

Source	df	Number of branches (count)	Number of leaves (count)	Number of axillary buds and branches (count)	Bud activity (%)	Shoot length (m)
Block	3	0.48ns	35.5***	0.50ns	0.54ns	8.75***
Clones	13	5.09***	5.18***	3.46***	0.75ns	5.19***
Mean		14.1	577.9	15.2	-16.4	138
Se		0.7	7.3	0.91	26.0	25
C.V.%		13.6	37.4	21.56	4144.8	18.5

Se = Standard error.
C.V. = Coefficient of variation.
*** = significant at P≤0.001.
** = significant at P≤0.01.
* = significant at P≤0.05.
ns = not significant.

percent bud activity after four weeks, with F13 having the greatest at 100% and F6 the lowest with 4% a 96% difference (Fig. 6.a). Clones selected for poles had peak percent bud activity at two weeks with variation from 58% in P2 and P8 which was the greatest to 44% in P9 the lowest representing a difference of 15% (Fig. 6.3b). However clone P2 reached peak percent bud activity after four weeks with 91% and dropping to 51% at week six (Fig. 6.3b). Clones selected for leaves had peak percent bud activity after two weeks with a range from 44% in L7 to 52% in L5 and L9 (Fig. 6.3c). Clone L6 however reached its peak percent bud activity after four weeks with 59% (Fig. 6.2c). Thus the clones showed maximum percent bud activity between two and four weeks, after which there was a reduction in bud activity per clone. The clones were ranked based on percent maximum bud activity and classified as expressing high, average or low apical dominance (Table 6.3).

6.5.3. Number of branches.

There were significant differences at $P \leq 0.001$ between clones in number of branches on the main stem at the start (Table 6.1) and at 12 weeks (Table 6.2). Following decapitation the average number of branches increased dramatically after two weeks. After four weeks the number of branches levelled off among clones (Fig. 6.4). The clones showed a similar increment pattern in number of branches.

6.5.4. Leaf number.

There were significant differences ($P \leq 0.001$) between clones in leaf number at the start (Table 6.1) at 12 weeks (Fig. 6.5). Leaf number in clones showed a general increase with time up to week 8. After week 10 clones fell into 3 groups which had significant differences in the number of leaves (Fig. 6.5a, 6.5b and 6.5c). Among clones selected for fuelwood, F11 had the greatest leaf numbers at weeks 10 and 12 while F3 and F13 were in the middle range while F10 had the least leaf

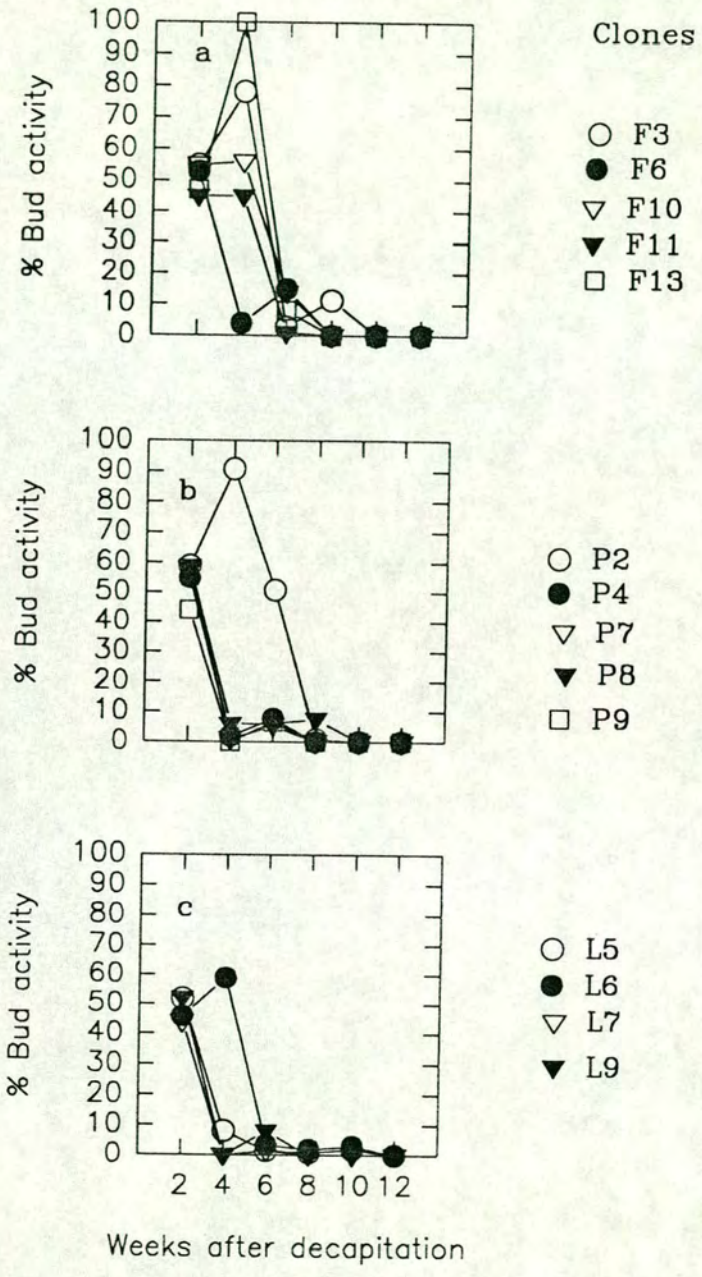

Fig. 6.3. Variation in bud activity (proportion of all axillary buds sprouting and growing by more than 2 mm in length between measurements expressed as a %) in decapitated Sesbania sesban clones at Maseno nursery.

(a) Clones selected for fuelwood
(b) Clones selected for poles.
(c) Clones selected for leaves.
Lsd at week 12 = 52.78

Table 6.3. Ranking of S. sesban based on maximum number of buds released from apical dominance by decapitation at four weeks in potted plants at Maseno.

Rank	Clone	Percent bud activity at 4 weeks	Remarks
0 - 30	L9,P9,L7 P7 P4 F6 P8 L5	0 1 2 4 6 8	High apical dominance
31 - 60	F11 F10 L6	45 56 59	Average apical dominance
61 - 100	F3 P2 F13	78 91 100	Low apical dominance

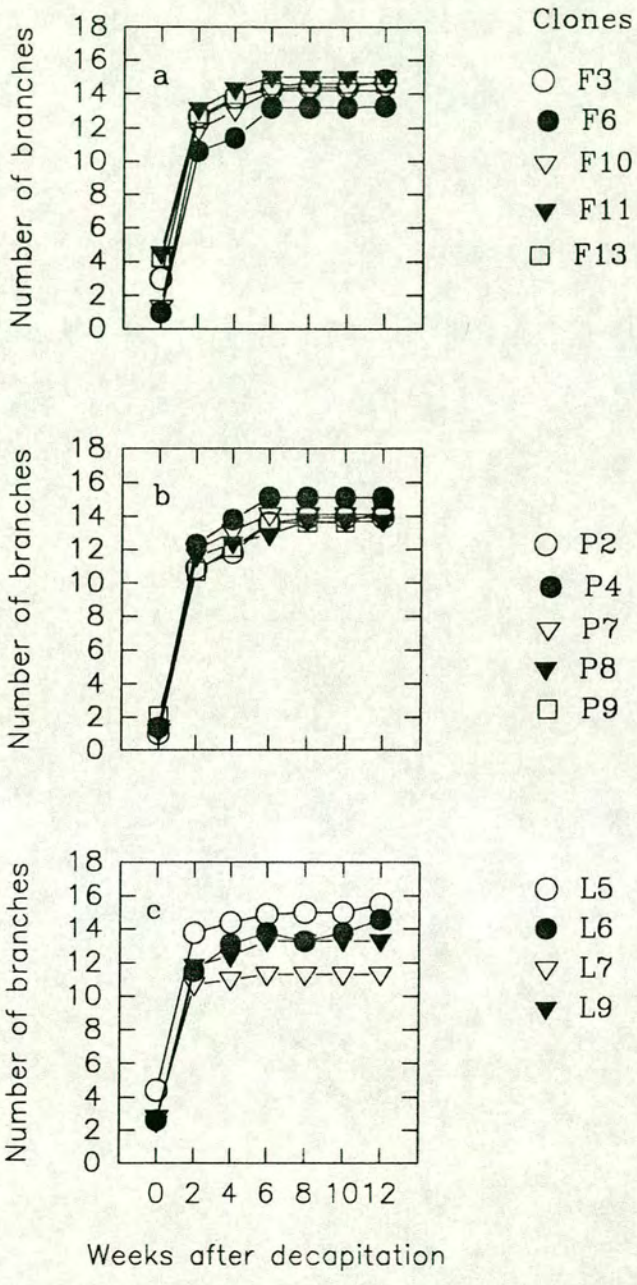

Fig. 6.4. Variation in number of branches in decapitated Sesbania sesban clones at Maseno nursery.
(a) Clones selected for fuelwood
(b) Clones selected for poles.
(c) Clones selected for leaves.
Lsd at week 12 = 1.42

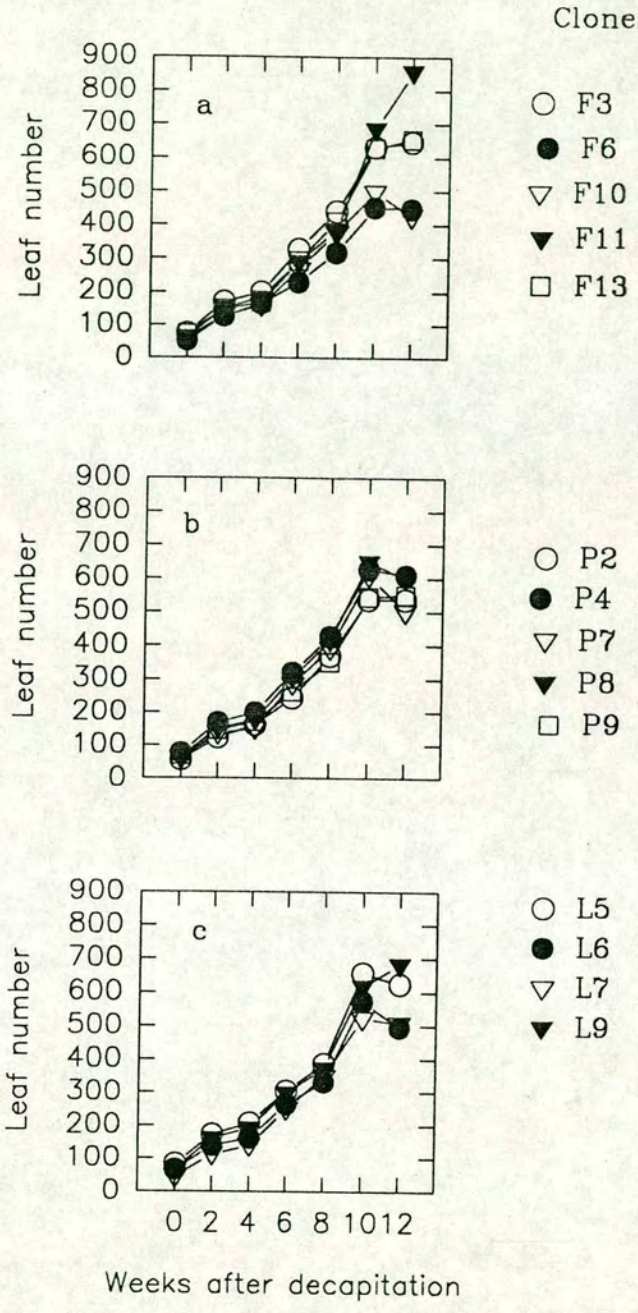

Fig. 6.5 Variation in number of leaves in decapitated Sesbania sesban clones at Maseno nursery.
(a) Clones selected for fuelwood
(b) Clones selected for poles
(c) Clones selected for leaves
Lsd at week 12 = 14.8

numbers (Fig. 6.5a). In clones selected for poles P4 and P8 tended to have greater leaf numbers (Fig. 6.5b), P2 and P9 were in the medium range while P7 had the least. L9 and L5 had more leaf numbers in clones selected for leaves while L7 and L6 had the least (Fig. 6.5c). On the overall F11 had the highest number of leaves better than those clones selected for leaves.

6.5.5. Shoot length.

There was significant difference in mean shoot length between clones at 12 weeks after decapitation (Table 6.2). Shoot length increase in all clones was linear (Fig. 6.6). The clones showed a general increase in shoot length and changed rank with time (Fig. 6.6a, 6.6b and 6.6c). Among clones selected for fuelwood, F3 had the greatest shoot length at week four, while F10 ranked first between weeks six and ten. At week twelve, clones F10 and F11 had greater shoot lengths while F3 had the least (Fig. 6.6a). Among clones selected for poles, P2 tended to have greater shoot lengths between weeks four and ten, while at twelve weeks P2, P4 and P7 had the greatest shoot lengths and P8 the least (Fig. 6.6b). Among clones selected for leaves, clone L5 had the greatest shoot length at six weeks and L6 the least, between eight and twelve weeks. L9 had the greatest shoot length while L5 had the lowest (Fig. 6.6c).

6.5.6. Predictive test.

In order to establish a relationship between juvenile clone traits in the nursery and the performance of the same clones in the field, correlations were attempted between percent bud activity of the young clones in the nursery and branch frequency of the same clones in the field at Maseno. A positive correlation (non significant) was found between percent bud activity at four weeks after decapitation and branch frequency after 9 months in the field (Fig. 6.7, $r^2 = 0.52$).

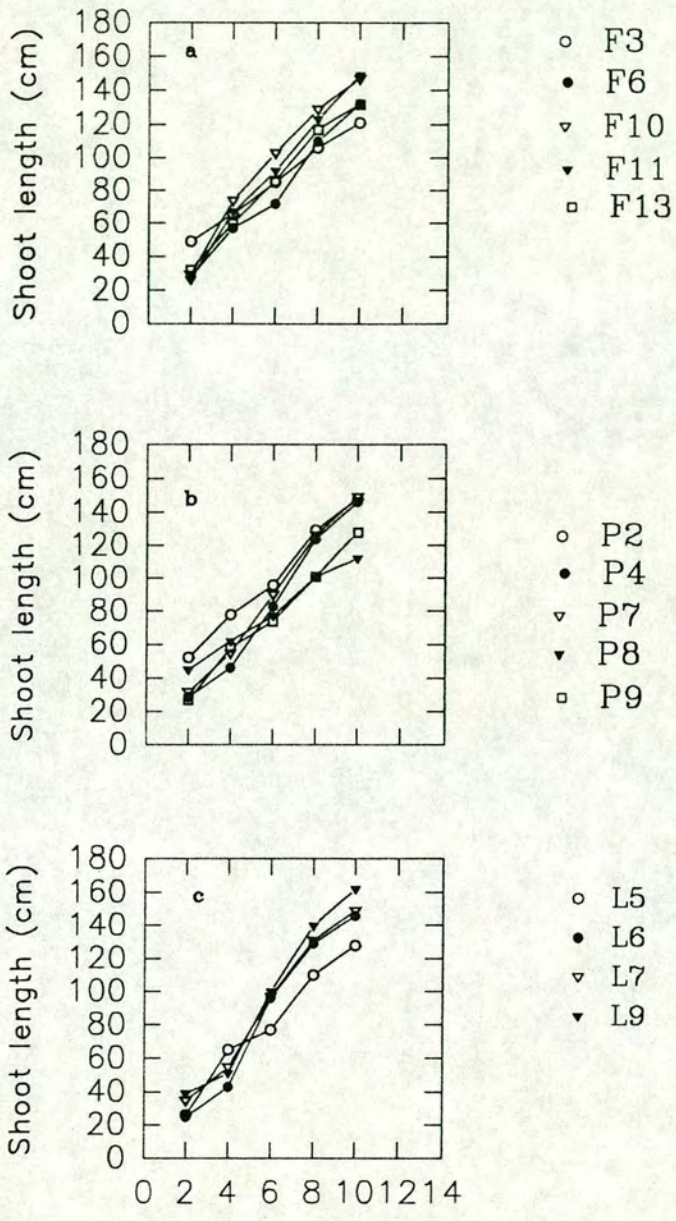

Fig. 6.6 Variation in shoot length (cm) in decapitated Sesbania sesban clones at Maseno nursery.

(a) Clones selected for fuelwood

(b) Clones selected for poles

(c) Clones selected for leaves.

Lsd at 12 weeks = 50.7

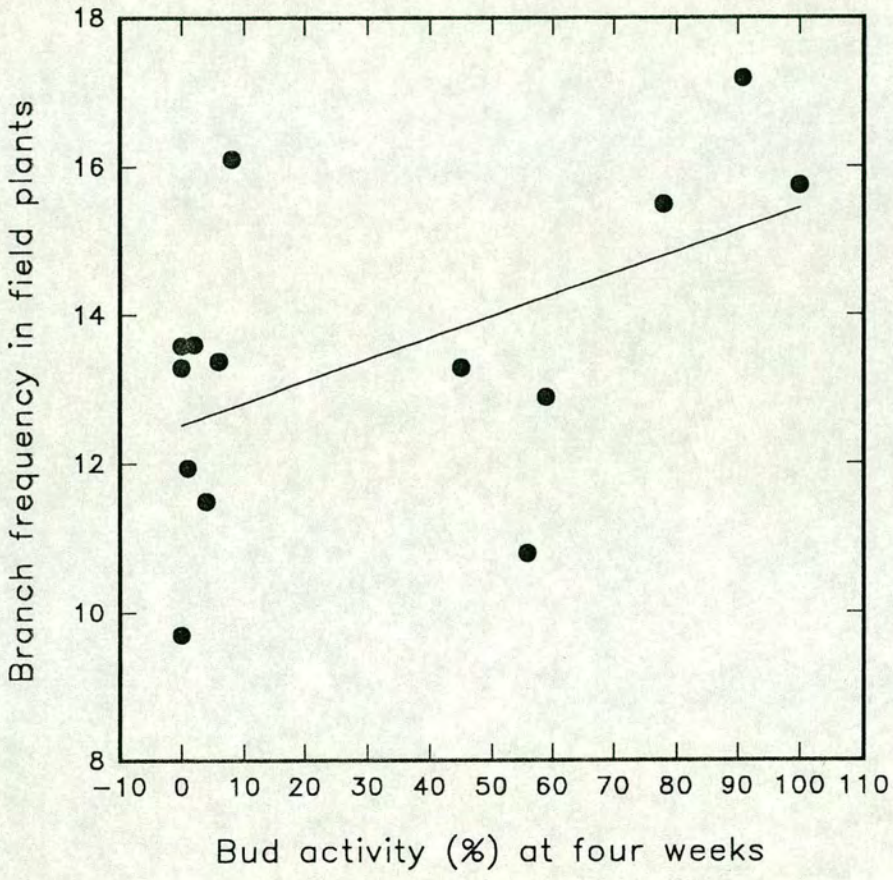

Fig. 6.7. Showing relationship between bud activity amongst a uniform batch of Sesbania sesban clones in the predictive test and branch frequency of the same clones at 9 months in the field at Maseno ($y = 12.52x + 0.029$, $r^2=0.52$).

6.6. DISCUSSION

There was variation among Sesbania sesban clones in their responses to decapitation. This response had two phases, the first was a sprouting phase where the axillary buds were released from correlative inhibition and second phase where the upper lateral shoots began to assert dominance by suppressing the growth of lower shoots and other buds. Similar responses to decapitation were noted by Leakey and Longman (1986), Ladipo (1981) and Ladipo et al. (1991b) in randomly selected T. scleroxylon clones. There was also variation between clones with regard to time taken to reach maximum peaks in number of active growing axillary buds. Some of the clones had their maximum lateral bud activity after 2 weeks, while others did so after 6 or 8 weeks. The differences in bud break among clones may be due to endogenous factors, reflecting some form of genetic influence in bud release. It was noted among the clones that not all the sprouting buds became active. Some of the active buds in the clones started to grow, but while the uppermost buds continued to grow the lower buds stopped growing and become retarded and abscissed. At this stage the proliferation of axillary buds occurred synchronously with terminal bud growth, this process may have contributed to the higher mortality of buds due to competition for the resources of nutrients and water as they were being directed to active growing points of lateral buds and branches (Boojh and Ramakrishan 1982).

There was variation among clones in percent bud activity after decapitation, similar trends were found by Longman (1978) and Leakey and Longman (1986) in T. scleroxylon. The pattern of bud activity (%) showed that apical dominance in productive S. sesban clones was influenced by the physiology, environment and genetic factors. The ranking of clones based on percent bud activity allows early classification of the clones on their potential to sprout or produce branches; a measure of their apical dominance. The ranking of clones by bud activity was an attempt to show their relative intensities of apical dominance from low bud activity which is indicative of strong apical dominance to high bud activity for weak apical

dominance. However the selection process at the beginning of this study may have eliminated much of the genetic variation, as the plants used were very uniform. There was a weak positive relationship between a physiological trait of percent bud activity in young clones in the nursery at four weeks after decapitation and the morphological factor of branch frequency in field plants (Fig. 6.7). This relationship was not significant at $P \leq 0.05$, indicating that selections among these clones with respect to branching habit was not possible.

Between 2 and 4 weeks, this period corresponded with the period of maximum bud activity for most of the clones (Fig. 6.a, 6.3b and 6.3c) and that is when the number of branches stabilised. The relative response of one clone against another with regard to branching between weeks six and twelve was consistent. The clones with high number of branches maintained their relative branchiness throughout, for example F11, P4 and L5 ranked first in clones selected for fuelwood, poles and leaves respectively (Fig. 6.4a, 6.4b and 6.4c). However trees are liable to various traumatic events which can alter their original form. For example, a break in a branch can affect the development of new branches from the already existing dormant buds according to various genetic influences. The relationship between bud inhibition and final form of trees is very complex, due to the time sequence involved in the formation and release of lateral buds which eventually form branches.

The number of leaves varied among clones and increased with time until a maximum at week 10 (Fig. 6.5a, 6.5b and 6.5c). The leafiest clone tended to be the most productive. A decline in leaf number after week 10 may be due to lack of nutrients, as the plants may have exhausted the pots. Alternatively competition for light or other intrinsic factors may have occurred at this stage (Addicott 1978). There was variation in shoot extension between clones. The differences in shoot length and branches are the main determinants of tree form. The increase of shoot lengths with time showed an exponential pattern for most clones.

Sesbania sesban shows a decurrent branching habit with a weak apical dominance. The uppermost lateral buds are normally very vigorous and elongate

most rapidly, giving rise to excessively branched stems.

The use of juvenile-mature correlations for tree selection by tree breeders is possible, only if there are stronger correlations between traits at the juvenile stage with rotation age. In this study the clones used were very uniform, as the selection criteria adopted was not random, so much of the variation must have been removed at this stage. Thus clones lacked differences in their response to decapitation. This may be attributed to the smaller number of clones evaluated which lacked large genetic variation, or the responses to decapitations may be species specific.

6.7. SUMMARY.

The use of bud activity in the nursery for predicting branch frequency in the field was not possible among the evaluated S. sesban clones.

CHAPTER 7

LIGHT INTERCEPTION AND STOMATAL CONDUCTANCE

7.1. AIMS.

Crown structure plays an important role in the process of intercepting photosynthetic active radiation (PAR) in trees. The amount of PAR intercepted by the canopy is of fundamental importance in plant growth and productivity. Stomata in plants regulate the CO_2, water-vapour exchange and control assimilation and transpiration by adjustments to the size of the stomata pores. The balance between water loss and carbon gain is directly influenced by the stomata.

The aim of the study was to determine whether biomass production is directly related to either: (a) the amount of PAR intercepted by contrasting crowns or (b) stomatal conductance of individual Sesbania sesban clones, grown at Maseno and Machakos.

7.2. INTRODUCTION.

7.2.1. Crown charateristics and light interception.

Plant communities have different ways of displaying their photosynthetic surfaces and hence intercepting photosynthetic active radiation (Nobel and Long 1987). The total amount of leaves, their distribution, orientation within the crown, play the most significant role in light interception (Wang 1988). The relationship between available light energy, photosynthetic activity and dry matter yield in trees have been established in studies by Linder (1985) and Cannell et al. (1989). The interception of light by leaves is a fundamental process of plant growth (Caldwell et al. 1986) and the pattern of leaf display influences the quantity of light intercepted by leaves (Isebrands and Mitchell 1986, Michael et al. 1990).

The knowledge of the quantity and vertical distribution of leaves in tree stands is very important to the understanding of the structure of trees and their productivity (Ford 1982, Gholz 1982). The amount of light intercepted by tree canopies depends upon their architectures and their phenological phases (Horn 1971, Hallé et al. 1978 and Honda and Fisher 1978). There is commonly significant variation in trees of leaf areas over the growing season and these differences, plus canopy characteristics affect dry matter production (Cannell 1989). The amount of light intercepted by trees also depends on the leaf orientations, sun elevation in the sky and on the reflectance properties of the canopies (Bilings and Morris 1951).

Difficulties in assessing leaf dynamics, light measurements and their relationships in tree canopies have been highlighted by Anderson (1964), Harms (1971) and Kinerson et al. (1974). These include the difficulty in conducting repeated measurements as well as the difficulty of accessing higher branches in mature tree crowns.

Trees in farming systems create microclimatic changes which are governed by the density of the canopy and the spatial arrangement of the crown characteristics. Thus, knowledge about light interception by canopies is very important in planning tree management in agroforestry.

The amount of photosynthetic active radiation (PAR) that reaches the lower canopies includes the unfiltered direct radiation and diffuse radiation from the open sky. Tree characteristics that dominate light interception are hierarchical in pattern ranging from the canopy level as a unit, to the branch, shoot level, the single leaflets and their absorption patterns (Oldeman 1983). Thus the relative amount of light available depends on the canopy structure, depth and density (leaf area) of the upper and middle crowns (Attridge 1990). Relations between canopy structure, light levels and photosynthesis have been reviewed by Morris et al. 1973. They found that always low light reduces photosynthesis and that the process of photosynthesis is linear to the amount of light available (Bjorkmann 1983).

Information on light requirements, interception and transmission potentials for most tropical trees that can be used in agroforestry is lacking (Reifsynder

1989). In agroforestry, trees and crops are grown together and each has its own light and water environment and requirements. Clonal responses to light quality could be interesting determinant of tree form in agroforestry regime as light quality has a major impact on dry matter partitioning in trees (Hoad et al. 1990). Thus it becomes necessary to study the structural properties of the crown in order to understand the photosynthetic processes of trees. Similarly studies are required on the potential shading effects of trees on the adjacent crops in agroforestry systems.

The objective of this study was determine light interception under the canopies of individual Sesbania sesban clones growing at two sites (Maseno and Machakos).

The hypothesis tested is that there are genetic differences in the interception of photosynthetically active radiation (PAR) in the crowns of Sesbania sesban clones.

7.2.2. Stomatal conductance.

Increasing demand for wood products suggests the need to increase efficiency of forest operations in order to optimize biomass production. Many clones of fast growing trees are being developed but generally there is lack of a suitable selection criteria for rapid screening of the most productive clones. Studies involving water use have received little attention and yet they seem to be very important in plants growing in mixtures. Black (1986) and Ong et al. (1990) in their studies found that trees compete strongly with crops for water resulting in yield reduction in agroforestry.

The use of field measurements of stomatal conductance using sun leaves allows the determination of seasonal water patterns of similar physiological stage of development to be compared. This study was initiated to determine whether stomatal conductance of Sesbania sesban clones grown at Maseno and Machakos in Kenya was directly related to biomass production.

7.3. MATERIALS AND METHODS.

7.3.1. Site and stand descriptions.

The study was conducted in a nine month old Sesbania sesban clonal trial (stand) at Maseno and Machakos (See Chapter 2 for site details). Leaf area was measured non-destructively as described in Chapter 2. Two trees per clone at each site of average size were used in this study for light interception and stomatal conductance.

7.3.2. Ceptometer description

The ceptometer (Decagon Devices Inc. Pullman, Washington, U.S.A. 1989) measures photosynthetic active radiation (PAR, 400-700 nm) incident on 80 sensors located at 1 cm intervals along a narrow probe 80 cm in length. Eighty sensors on the probe are scanned during every measurement and the arithmetic average for the sensors is calculated and displayed automatically. Canopy interception and total un-obstructed sunlight in the open areas were recorded for each tree sampled.

7.3.3. Below canopy and within canopy transmittance sampling.

Canopy PAR transmittance was measured from three permanently marked locations within the tree crown, termed lower zone, middle zone and top zone, depending on the height of the tree. At each location four measurements of canopy transmittance were taken, averaged and stored, thus in a tree twelve measurements were made. To obtain the four measurements per location the ceptometer was rotated 360°C above each location and PAR transmittance readings were taken at approximately 90° intervals. Thus canopy transmittance for each tree was represented by arithmetic mean of 80 sensors x 4 samples per location x 3 locations per tree. Readings were taken on clear days usually between 11.00 and 14.00 h solar time, when the sun angle variation is

minimum at the equator. The PAR transmission sampling was done for 4 days per site. Leaf area was determined to give total leaf areas per tree at both sites. The total incoming PAR was measured in open areas at the beginning of each sampling date (average incoming PAR for the 4 days was 695 and 974 μ mol m^{-2} s^{-1} at Maseno and Machakos respectively).

7.3.4. Stomatal conductance assessment.

Stomatal conductance (gs) was measured using a porometer (LI-COR Inc; LI1600; Steady-state porometer, Lincoln, Nebraska, USA). The 2 cm^2 circular aperture cuvette was used for all measurements on S. sesban leaves, in July 1992. Measurements of quantum flux density, humidity and leaf temperature were recorded simultaneously.

Diurnal measurements of gs were made on 2 trees (4 replicates per tree) three times during the day (for 3 days at each site), morning (9.00-10.30 h), midday (12.00-01.30 h) and afternoon (15.00-16.30 h) at Maseno and Machakos sites on fully expanded leaves. Early morning measurements were not possible between 07.00 h to 08.00 h due to the presence of dew on the leaves.

7.4. RESULTS.

Results at nine months showed variation in leaf areas between sites and clones, this was after canopy closure (Table 7.1). General linear model analysis for light interception for both sites are presented in Table 7.2. Significant differences in light interception were observed among clones and between zones within clone (Table 7.2, $P \leq 0.001$). Ceptometer readings were sensitive to changes in canopy PAR transmittances resulting from foliage production. Light interception among clones and canopy levels varied from 34% to 88% at Maseno (Fig. 7.1) and from 13% to 55% at Machakos (Fig. 7.2). Light interception at both sites was greater in the middle zone than the top zone. The pattern of light interception was similar among clones selected for fuelwood, poles and leaves (Figs. 7.1 and 7.2).

Table 7.1. Leaf areas (m^2) of Sesbania sesban clones assessed for light interception and stomatal conductance at Maseno and Machakos, Kenya.

Clone	Maseno Leaf area (m^2)	Machakos Leaf area (m^2)
F3	37.03	1.64
F6	26.76	2.26
F10	10.29	1.45
F11	11.99	1.14
F13	10.54	1.89
P2	7.83	1.64
P4	24.81	2.36
P7	23.15	1.41
P8	4.81	2.09
P9	3.39	1.64
L4	12.38	1.9
L5	9.68	1.27
L6	13.7	1.36
L7	2.39	1.61
L9	19.71	1.27

Table 7.2. General linear model analysis for light interception among S. sesban clones at Maseno and Machakos after 9 months of growth.

Sites		Machakos				Maseno			
Source	df	21/7/92	22/7/92	23/7/92	24/7/92	4/8/92	6/8/92	7/8/92	8/8/92
Clone	14	2.11*	4.89***	5.96***	6.49***	2.43*	8.03***	2.95**	8.01***
Zone	2	80.78***	197.14***	178.16***	245.87***	159.9***	528.95***	151.64***	643.85***
Mean		36.78	32.17	31.33	32.64	65.16	63.91	67.94	62.80
Se		2.52	1.92	1.65	2.05	2.93	2.25	3.83	2.34
C.V.%		26.55	23.14	20.39	24.32	17.46	13.63	21.85	14.44

*** = Significant at P≤0.001.
** = Significant at P≤0.01.
* = Significant at P≤0.05.
C.V.% = Coefficient of variation.

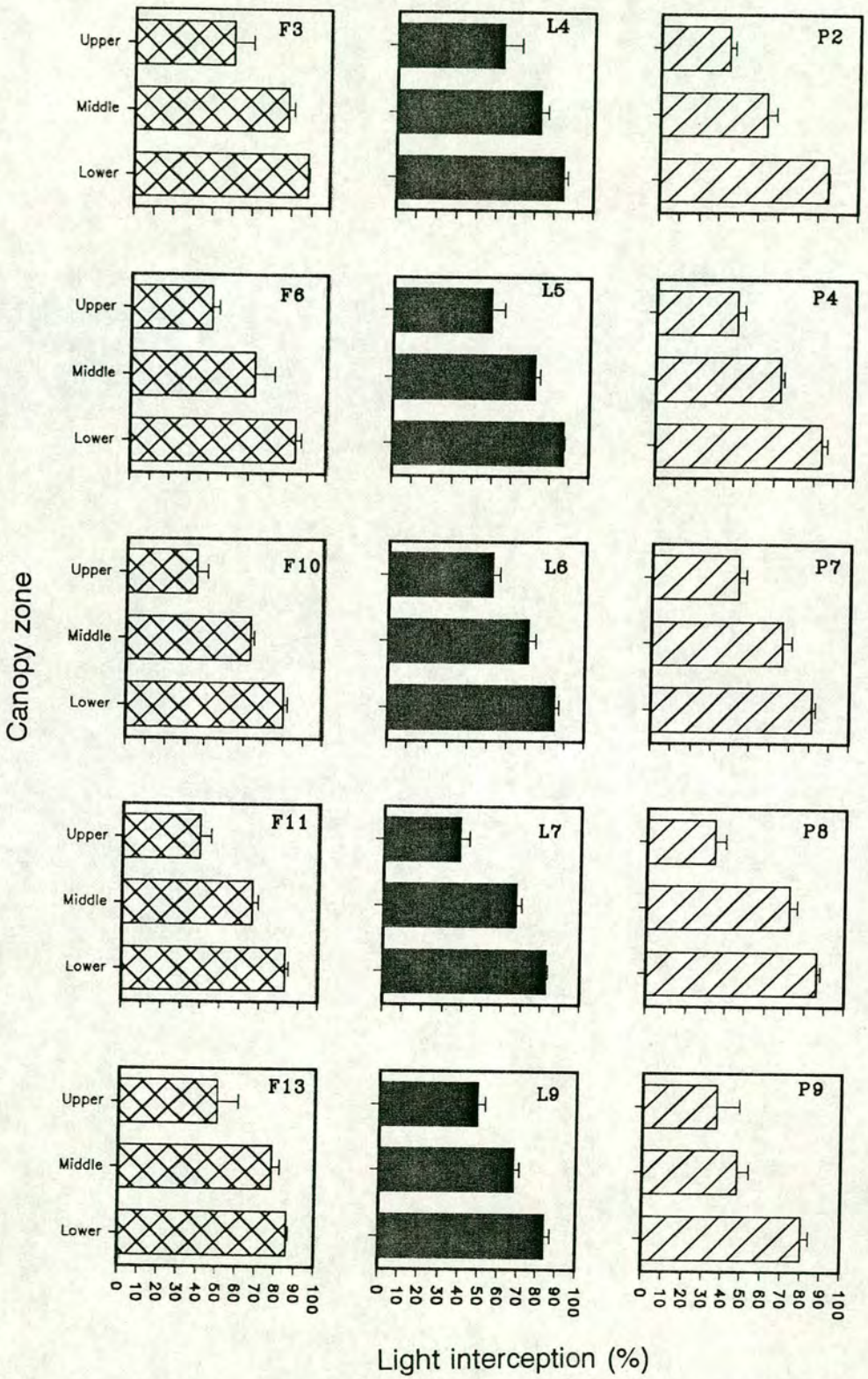

Fig. 7.1. Variation in light interception (%) among Sesbania sesban clones after 9 months at Maseno, Kenya. (1 = Lower zone, 2 = Middle zone and 3 = Upper zone).

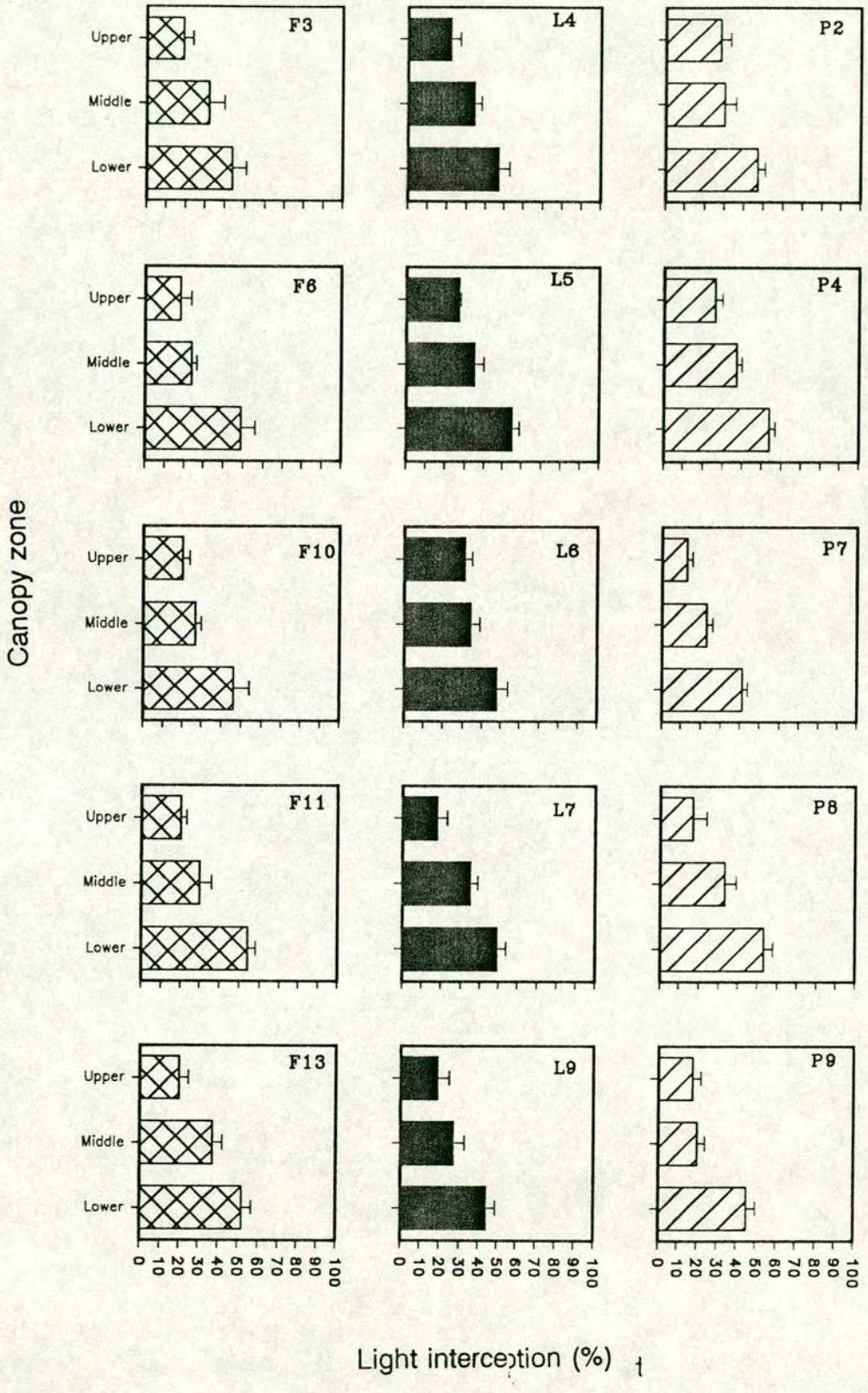

Fig. 7.2. Variation in light interception (%) among Sesbania sesban clones after 9 months at Machakos, Kenya. (1 = Lower zone, 2 = Middle zone and 3 = Upper zone).

The results for stomatal conductance are presented as averages for the three days. Significant differences in stomatal conductance were observed at $P \leq 0.05$ and $P \leq 0.001$ (Table 7.3). Stomatal conductances were high in the early part of the day with almost a linear decline during the day (Figs. 7.3 and 7.4). It is interesting to note that despite the constancy in environmental conditions, stomata conductances changed during the course of the day, this may be due to responses to changes in the internal conditions of the clones. The results also show that stomatal conductance was significantly greater ($P \leq 0.001$) in the morning than at midday or in the afternoon. At Maseno there were no differences in mean gs between the two afternoon sampling periods (Fig. 3). Stomatal conductance was lower at Machakos with a range from 500 to 1500 mmol m^{-2} s^{-1} than at Maseno with a range from 1900 to 3500 mmol m^{-2} s^{-1} (Figs. 7.3 and 7.4). There were differences in stomatal conductances at Maseno between clones selected for fuelwood, F6 and F11 tended to have greater gs in the morning while F3 and F13 had greater gs late in the afternoon. In clones selected for poles P2 , P7 and P9 had greater gs in the morning while P8 tended to have high gs at 12.00 h and 15.00 h, while P4 gs was similar throughout the day (Fig. 7.3). Among clones selected for leaves L5 and L7 had greater gs in the morning and L4, L6 and L9 gs were greater at 17.00 h.

At Machakos all clones had greater gs in the morning and less in the afternoon, the clones were responding similarly throughout the three sampling periods.

7.5. DISCUSSION.

The study reveals the way how light interception can be used in yield improvement and as a trait to be employed in clonal selection programme. There were differences in light interception between sites of Maseno (average 64%) and Machakos (32%). This was due to leaf area duration, as Maseno site tended to have higher leaf areas than Machakos (Chapter 4). The low light interception at Machakos was due to the loss of leaves during the dry season thus allowing more light through the canopies.

Table 7.3. General linear model for stomatal conductance (mmmol m^{-2} s^{-1}) for S. sesban clones at Machakos and Maseno after 9 months.

Sites		Machakos			Maseno		
Source	df	23/7/92	24/7/92	25/7/92	4/8/92	6/8/92	7/8/92
Clone	14	1.85*	1.59*	4.49***	5.22***	2.37*	11.05***
Time	2	196.66***	176.56***	193.68***	109.71***	6.29*	60.97**
Mean		973.88	790.69	923.6	2823.33	2801.94	2085.94
Se		72.25	56.98	55.58	165.75	178.19	121.29
C.V.%		28.71	27.89	23.28	22.72	24.61	22.50

*** = Significant at P≤0.001.
** = Significant at P≤0.01.
* = Significant at P≤0.05.
C.V.% = Coefficient of variation.

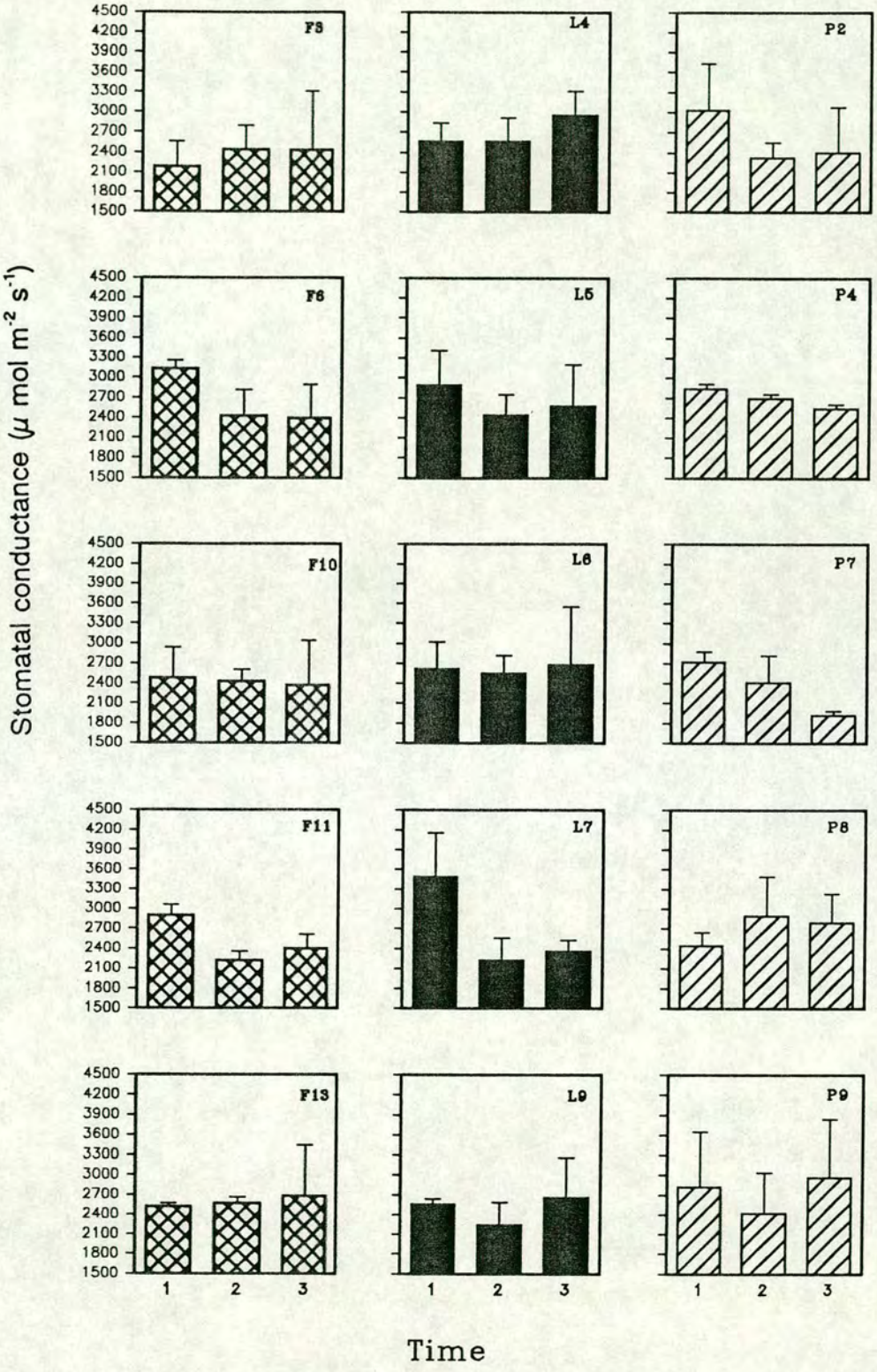

Fig. 7.3. Showing stomatal conductance (μ mol m^{-2} s^{-1}) for Sesbania sesban clones after 9 months at Maseno, Kenya.
(Time 1 = 09.00 h, 2 = 12.00 h and 3 = 15.00 h).

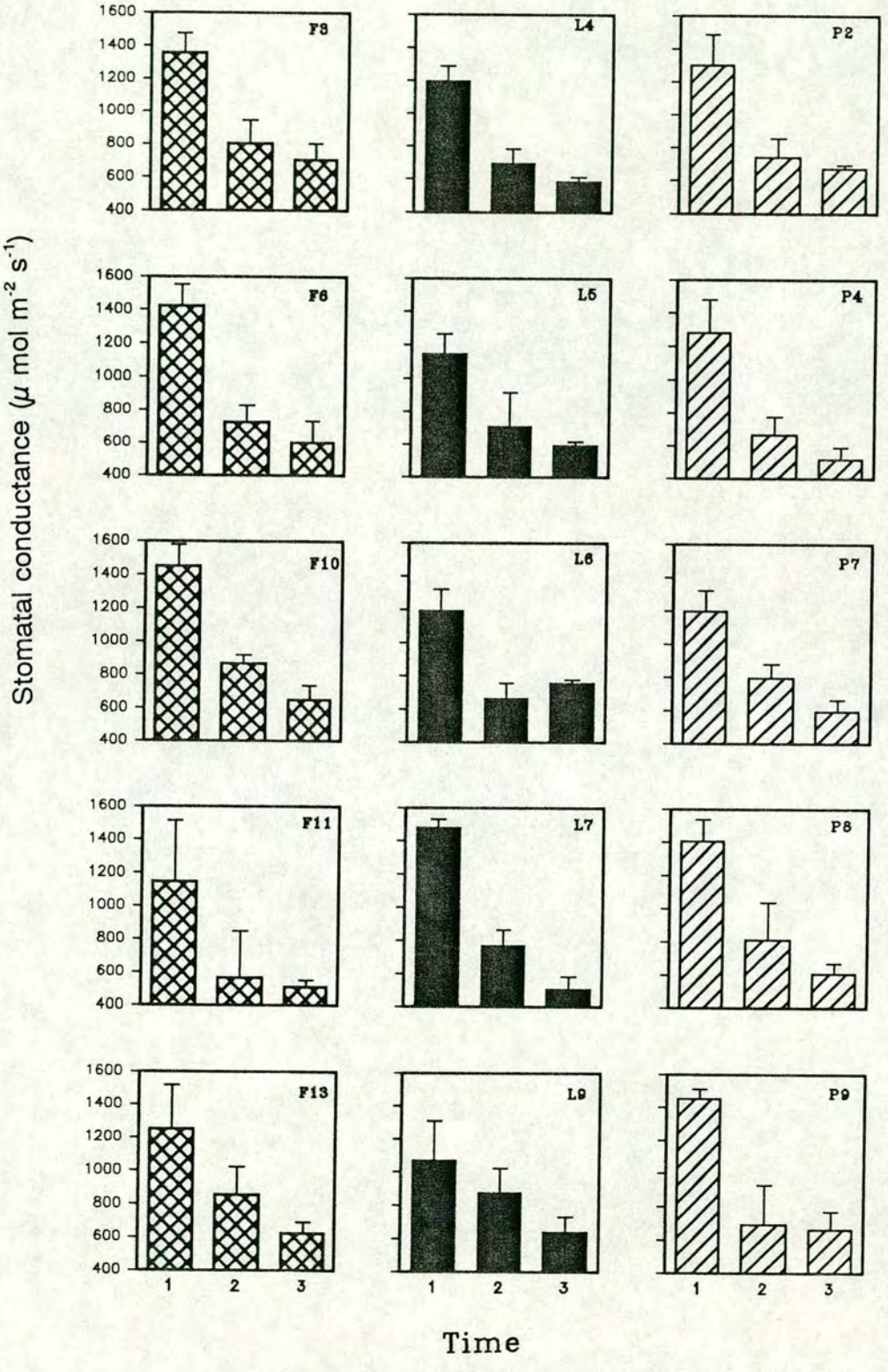

Fig. 7.4. Showing stomatal conductance (μ mol m^{-2} s^{-1}) for Sesbania sesban clones after 9 months at Machakos, Kenya.
(Time 1 = 09.00 h, 2 = 12.00 h and 3 = 15.00 h).

Those clones with higher leaf areas were effective at light capture, for example P4 and F3 at Maseno and P4, L4 at Machakos. The effective reduction in PAR transmission in the clones may explain their fast-growing habits making them succeed in both environments. But effective light capture may not lead to positive response with regard to productivity, for example if the clone has a lower fine root mycorrhizal network surface area it may not be effective at capturing the nutrients to enable it to maximize productivity. With adequate supply of water and nutrients the clones will use the intercepted radiation efficiently to produce dry matter. Thus the differences in the architectures of the canopy and root-system determine the productivity potential of trees. The highest photosynthetic production in plant mixtures is reached when each plant is provided with a minimum amount of light it needs for maximum net photosynthesis.

The spectral quality of light changes as it passes through the canopy (Jordan 1969), and this may affect the growth of understorey plants.

The development of thinning and pruning regimes to regulate light in agroforestry, costs money and time, so the emphasis should be to select for erect branching trees in order to minimize shading. Thus there is a need to use trees with a small total leaf area and relatively erect leaves in agroforestry. These trees with high radiation use efficiency and high reflectivity (light crowns with thin leaflets permitting more radiation to penetrate into the lower canopy) are best in mixed cropping systems (Connor 1983). In conclusion it is apparent that light interception in this study was greatly influenced by the leaf area of the clones (Table 7.1).

The greater range of response in stomatal conductance indicates the ability of stomata to open or close as the situation dictates and may be due to mechanisms for adaptability and survival (Reich 1984). Stomatal conductance were found to differ widely among clones of poplar (Pallardy & Kozlowski 1979). The differences in gs is due to gradations of irradiance in the canopy. These were tall trees of 5-6 metres tall so it was not possible to measure the top leaves which were always sunlit while the bottom leaves were partially shaded. The difference in gs may also have been due to differences in leaf age. The

age. The trees assessed were nine months old and had their leaves in various stages of physiological growth. Leaf area duration was found to have a direct effect on tree productivity (Nelson and Isebrands 1983). The clones at Maseno and Machakos which tended to have high leaf areas tended to have higher biomass, for example P4, P2 and F6. The lower leaves on most trees at Machakos had been shed as the site experiences severe drought. This may have led to low leaf water potentials, stomatal closure, and thus reducing photosynthesis and productivity. Hsiao (1973) and Salisbury and Ross (1985) found that the stomata tended to close with reduction in leaf water potential. While at Maseno the maintenance of leaf area duration may have contributed to the greater gs and thus to higher biomass productivity in S. sesban clones, than at Machakos. Similar effects of variation in leaf area duration and productivity were observed in poplar clones by Cannell and Willet (1976). The greater gs in the morning at Machakos is probably due to the better growth conditions so that stomata can maximize CO_2 uptake and photosynthesis while minimizing water loss Wang et al. (1979), Farquar and Sharkey (1982). Studies by Whitehead et al. (1984) in Pinus sylvestris and Reich (1984) in poplar noted similar results where stomatal conductances were greater in the morning than in the afternoon. The solar tracking behaviour of Sesbania sesban clones may have contributed to greater gs in the morning at Machakos. The leaves of the clones tended to open at different times between 07.00 h and 09.00 h. By midday/afternoon depending on the intensity of the sun, the leaves tended to fold and then to open again later after 17.00 h. This is a direct mechanism for regulating stomatal conductance. Lastly, despite the differences in water relations, variables which might have contributed to the maintenance of leaf area and higher productivity, the use of gs as a selection criteria would only be effective if the different mechanisms to drought avoidance and tolerance employed by the different clones are understood.

SUMMARY.

1. Light interception was variable among the clones especially in the top

canopy.

2. Light interception can be used to identify those clones which capture the most light.

3. There were significant differences in stomatal conductance among clones, however this variation was smaller than time of measurement which caused the greatest variation.

CHAPTER 8

GENERAL DISCUSSION AND RECOMMENDATIONS.

The aim of the thesis was to establish whether clones could be selected for single or multipurpose products by conducting studies involving the evaluation of phenotypic characteristics and their influence on biomass production using Sesbania sesban provenances and clones.

The results obtained in the studies are useful in that they have helped in understanding the genetic variation available in S. sesban provenances and clones, with regard to the changes in growth, biomass and canopy structure in relation to age and their response to environmental factors. There is no information reported regarding the genetic variation in provenances and clones of S. sesban under field conditions, despite the considerable interest in this species in agroforestry.

In this chapter, the results from the experiments will be examined in order to understand how S. sesban grows and develops at several sites.

8.1. General growth and development.

There was variation in growth rates of S. sesban provenances (Chapter 3) and clones (Chapter 4 and 5). The variation in height was reflected in the provenances where height differences between the best and worst was 192%, while in clones there was less variation at each of the sites. The variation between the best clones and worst clones was about 57% at Maseno and Kisii while at Machakos was 39%. The exponential growth of S. sesban clones at Maseno and Kisii was mainly associated with the good climate and soils, when compared to the drought prone and nutrient deficient soils at Machakos.

The physiological basis of growth was investigated in Chapter 5, where clonal development was found to be similar. Differences were only detected when competition set in. Leaf area and specific leaf area were found to be the only determinant of clonal differences in growth and development. The lack of

differences in growth was due to the initial selection criteria of the clones which were of same productivity potential. The provenance study established that there was genetic differences and that it was possible to select outstanding individual trees (phenotypes) identified for further tests on different sites. The growth analysis study showed that faster growth in S. sesban was due to high leaf area production and leaf area duration and that leaf area was a major determinant of clonal differences and is a good measure of plant growth and productivity. Secondly, it was also found that all clones were very sensitive to moisture stress, this was noted by the reduction in their NAR with the drop in rainfall. Another physiological attribute of stomatal conductance (Chapter 7) showed differences in clone adaptability between sites, where high gs were observed at Maseno throughout the day while at Machakos there was a reduction in gs especially in the afternoon. S. sesban clones had striking differences in canopy structure. The form of the clones was basically determined by their branch lengths and branch angles. Light interception was variable and was dependent on crown form. The rate of growth in leaf biomass and area at Maseno provided a large area to intercept PAR and eventual higher productivity at this site than at Machakos which had less leaf area. Cannell et al. (1987) report significant relationships between light interception and productivity of tree species.

8.2. Biomass production and partitioning.

Dry mass assessment is very important in agroforestry, since different products are required at different times. Biomass distribution in trees varies between species and is also dependent on site characteristics. The competition in trees affects the overall biomass production as well as partioning into components (Pearson et al. 1984). Thus the first step in MPTs evaluation in agroforestry, should be to determine the biomass production and its distribution into root, stem, branch and leaves. The clones at the three sites (Maseno, Kisii and Machakos) differed greatly in absolute dry mass, but were more similar in their percentage distribution of dry matter. The results of the study showed that branch component was very high in all clones at the three sites (Table 4.12), and it is a major preferred sink for carbon

in S. sesban clones. The differential reaction among the clones to the environment was observed. Clones at Maseno and Kisii were on fertile soils, this enabled them to develop large leaf area which was effective in light capture eventually leading to better growth (Cromer and Jarvis 1990). The trees which diverted more assimilate to the leaves were better in growth and light interception. The high growth and biomass production at Maseno and Kisii were due to the stability in foliar N and high leaf area duration throughout the growth period.

Roots accounted for between 21 to 36% of the tree biomass. Root study helped in understanding the carbon allocation strategies and possible zones of exploitation, and potential competition as well as the overall root system of S. sesban clones.

The use of allometric relationships as indirect assessment methods for determining biomass in trees is very important in agroforestry. Significant correlations between dry mass and tree dimensions for different components in S. sesban provenances and clones were established. These relationships indicated that simple regression equations involving one or two variables were adequate in predicting tree biomass. The use of stem diameter is very appropriate in S. sesban provenances and clones as it is directly related to biomass and volume.

Lastly, the study also indicated that biomass productivity could be increased by improving yield and quality by a process of clonal selection in short rotations.

8.3. Predictive test and early selection.

The study also identified juvenile traits which can be used as early selection criteria for S. sesban clones. Inter-relationships among independent variables were observed between various ages. Though not conclusive, the data confirms that short-term screening tests (using stem diameter and/or height) are possible and that early selection can be done in 6-9 month old S. sesban clones.

The use of apical dominance in S. sesban clones in the nursery to predict future field performance, was not very strong (r^2=0.50) as compared to Leakey and Ladipo (1987) of r^2=0.76 for T. scleroxylon. This was due to the use of a uniform batch of S. sesban clones for the test. However the predictive test can be

improved by use of randomly selected clones based on tree form.

Although individual juvenile traits have been identified as useful in predicting mature performance, the system needs perfection due to the inconsistency in prediction due to:-

(i) Low heritabilities for the juvenile traits.

(ii) There might have been maternal effects on juvenile performance. For example, at Maseno the performance of clones might have been influenced by "C" effects from a common shared environment of the mother tree (Cahalan 1981).

(iii) Imprecise genetic parameter estimates due to inadequate numbers of clones.

8.4. Selection.

The study results showed that selection of high yielding and adaptable clones was possible as some performed better than others at the three sites. It is also possible to increase wood production by selecting and using clones. However, the selection gain and heritability values must be interpreted with caution, as the results only apply to a particular set of clones or provenances in the environment tested (Cahalan 1981). But the strong correlations calculated at clonal level are good as they reflect the actual behaviour of the individuals clones in the field. These selected clones can be used for advanced breeding as they had been tested earlier in the provenance trial.

The study also showed that selection of superior clones based on biomass was not suitable. This was reflected in the inability of the clones being superior in the product they were selected for. Biomass is very much influenced by the environmental factors. Qualitative traits of stem form, crown form, wood quality and fodder value should be used, as they are under strong genetic control. Leaf characteristics of individual growth, production rates, development, duration and efficiency were the only consistent variables indicating differences between clones (Chapter 4, 5 and 7).

8.5. Management implications.

The ability of S. sesban to increase soil N content through the symbiotic interaction with bacteria adds value for their planting for soil stabilization and other purposes. The increase in S. sesban clone biomass productivity by genetic means through clonal selection increases the premium on the land being used. S. sesban can be grown in a tier system where it can be lopped for fodder, stems and branches for fuelwood while its roots through nodulation will add nitrogen. The leaves can be used for green manure, stems and branches for fuelwood. These management operations will open the crown and allow intercropping to continue.

8.6. CONCLUSIONS.

The following null hypotheses were tested.

Hypothesis 1. That Sesbania sesban provenances do not differ in their growth and morphometric characteristics. In Chapter 3 significant variation was found in the provenances with respect to growth and morphological characteristics.

Hypothesis 2. Sesbania sesban clones selected for fuelwood do not produce more branch and stem dry mass, that S. sesban clones selected for poles do not produce more stem dry mass, that S. sesban clones selected for leaves do not produce more leaf dry mass. In Chapter 4, S. sesban clones did not differ significantly in their growth patterns, but this was disapproved as there were significant differences in heights as clones selected for poles had greater heights and that is a useful result.

Hypothesis 3. Individual S. sesban clones do not differ in growth patterns, development and productivity. In Chapter 5, it was found that the clones performed similarly until competition set in. The uniformity in growth traits among juvenile clones was due to the selection criteria adopted earlier which was based on superiority in productivity. This selection criteria virtually eliminated the variation

among the clones. But it was found that leaf area was the only determinant of clonal differences and productivity.

Hypothesis 4. That variation in apical dominance in S. sesban clones did not influence their branching frequency. In Chapter 6, a non significant relationship was observed between bud activity at 4 weeks and branch frequency at 9 months in the field. This lack of relationship may have been due to prior selection of the clones.

Hypothesis 5. That there are no genetic differences in the interception of photosynthetically active radiation (PAR) and stomatal conductance in S. sesban clones. In Chapter 7, significant differences were found in clone canopies with respect to light interception. Stomatal conductance variation among clones was small than the time of measurement which accounted for most of the variation.

8.7. RECOMMENDATIONS FOR FUTURE STUDY.

1. Need to select large number of clones from the provenances and test them on at least five (variable) sites in order to get g x e interaction. In this study Maseno and Kisii can be classified as a single site as the clones tended to have very small phenotypic mean differences between the sites. The large number of clones will enable you to calculate precise genetic parameters as well as provide you with a large genetic base from which to select clones to form a breeding population.

2. Clonal selection should be based on physiological traits such as specific gravity for fuelwood, form for poles and nutrient content for leaf fodder in combination with morphological traits.

3. The following variables should be tested to see whether they are the most suitable for selecting clones (stem diameter, height and crown diameter as morphological variables supplemented by physiological attributes, such as leaf production, leaf area duration, leaf nitrogen content, leaf photosynthetic capacity and light interception). In addition component relative growth rates should be

established. This will be very useful in understanding the interactions between plant growth, resource allocation and utilization of energy.

4. The selected clones should be tested in combination with crops. Tree/crop interactions should be evaluated both above and below ground. For example, the diversity and specialization of roots, characteristics of root turnover and nutrient cycling.

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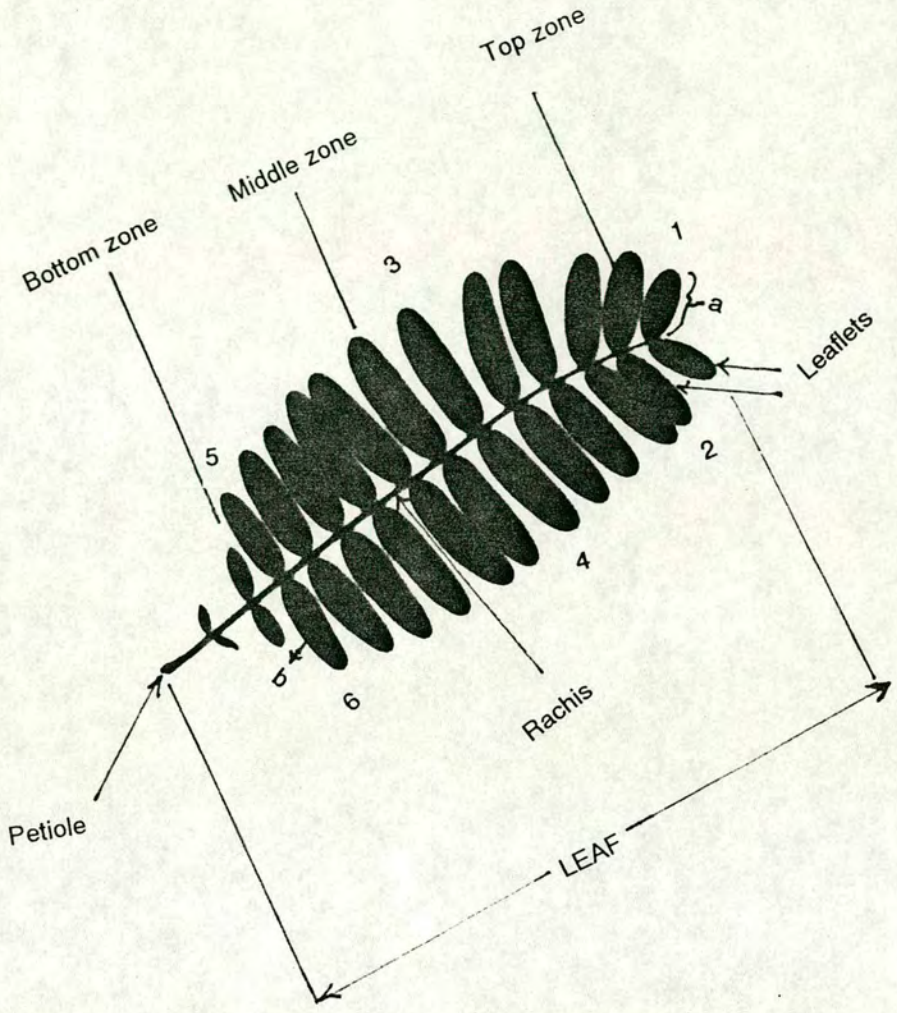
APPENDICES

Appendix 2.1. Leaf area estimation by the six-leaflet method.



Six leaflets are selected on a single leaf from the top, middle and bottom zones. Their leaf areas are then determined as below.
Calculation of leaflet areas:-

Area of leaflet 1 = a x b = la1
Area of leatlet 2 = a x b = la2
Area of leaflet 3 = a x b = la3
Area of leaflet 4 = a x b = la4
Area of leaflet 5 = a x b = la5
Area of leaflet 6 = a x b = la6

$$\text{Average leaflet area } L = \frac{[la1+la2+la3+la4+la5+la6]}{6}$$

Leaf area cm^2 LA = L x N

Where L = average leaflet area.
N = number of leaflets on the leaf.

Table A3.1 : Sesbania sesban provenance ranking by means and their standard errors for branchiness index, total dry mass (above ground), stem, branch and leaf dry mass at Maseno, Kenya..

RANK	Prov. code	Branchiness index	Prov. code	Total dry mass (kg/tree)	Prov. code	Stem dry mass (kg/tree)	Prov. code	Branch dry mass (kg/tree)	Prov. code	Leaf dry masst (kg/tree)
1	TZ23	0.63(0.02)	ET6	2.96(0.28)	ET6	1.19(0.09)	KN59	1.55(0.44)	ET7	0.61(0.09)
2	TZ21	0.61(0.02)	BR74	2.88(0.33)	BR74	1.09(0.13)	BR74	1.28(0.17)	ET6	0.53(0.04)
3	HW68	0.57(0.02)	ET7	2.72(0.38)	HW63	1.08(0.13)	TZ28	1.24(0.16)	BR74	0.5(0.06)
4	TZ11	0.56(0.02)	KN59	2.66(0.66)	HW66	1.07(0.12)	ET6	1.23(0.17)	KN59	0.44(0.11)
5	HW67	0.55(0.03)	TZ28	2.64(0.31)	TZ26	1.01(0.15)	HW70	1.16(0.18)	HW63	0.43(0.07)
6	TZ13	0.54(0.02)	HW66	2.46(0.33)	TZ28	0.98(0.11)	TZ22	1.15(0.22)	HW70	0.42(0.04)
7	TZ17	0.53(0.02)	TZ26	2.45(0.51)	TZ27	0.97(0.11)	ET7	1.15(0.24)	TZ28	0.42(0.05)
8	TZ14	0.53(0.02)	HW63	2.41(0.32)	ET7	0.95(0.09)	TZ23	1.13(0.22)	KN58	0.41(0.07)
9	HW62	0.51(0.02)	HW70	2.32(0.28)	TZ24	0.89(0.16)	TZ26	1.05(0.30)	TZ26	0.38(0.09)
10	TZ33	0.5(0.02)	KN58	2.27(0.31)	HW64	0.84(0.13)	KN58	1.05(0.16)	KN60	0.38(0.07)
11	TZ12	0.5(0.03)	TZ27	2.26(0.29)	KN58	0.81(0.10)	TZ24	1.04(0.24)	HW64	0.38(0.07)
12	TZ36	0.5(0.03)	TZ24	2.25(0.46)	KN59	0.79(0.16)	TZ29	1.03(0.16)	HW66	0.36(0.05)
13	TZ34	0.5(0.02)	HW64	2.22(0.41)	KN60	0.79(0.12)	HW66	1.02(0.17)	TZ29	0.33(0.05)
14	TZ22	0.49(0.03)	TZ22	2.20(0.32)	TZ22	0.79(0.06)	TZ19	1.01(0.30)	ET8	0.32(0.06)
15	HW69	0.49(0.03)	TZ29	2.12(0.28)	HW70	0.76(0.10)	TZ12	1.00(0.17)	TZ24	0.32(0.06)
16	TZ16	0.49(0.03)	KN60	2.01(0.39)	TZ29	0.75(0.09)	HW64	0.99(0.23)	TZ27	0.31(0.05)
17	TZ19	0.48(0.05)	TZ12	1.96(0.31)	TZ18	0.74(0.08)	TZ27	0.98(0.17)	ET3	0.30(0.06)

Rank	Prov. code	Branchiness index	Prov. code	Total dry mass (kg/tree)	Prov. code	Stem dry mass (kg/tree)	Prov. code	Branch dry mass (kg/tree)	Prov. code	Leaf dry mass (kg/tree)
18	HW70	0.48(0.03)	TZ19	1.79(0.44)	TZ39	0.72(0.16)	TZ17	0.94(0.12)	TZ12	0.28(0.04)
19	ET1	0.47(0.02)	TZ23	1.74(0.32)	TZ54	0.69(0.12)	HW63	0.88(0.16)	TZ25	0.28(0.03)
20	TZ46	0.46(0.04)	TZ17	1.69(0.19)	TZ49	0.69(0.10)	TZ33	0.83(0.19)	TZ20	0.26(0.07)
21	TZ25	0.46(0.01)	TZ32	1.66(0.42)	TZ12	0.68(0.11)	KN60	0.83(0.22)	TZ18	0.26(0.04)
22	TZ28	0.46(0.01)	TZ18	1.65(0.22)	TZ50	0.67(0.11)	TZ32	0.83(0.27)	TZ47	0.25(0.07)
23	TZ15	0.46(0.04)	TZ49	1.63(0.30)	HW65	0.67(0.09)	TZ36	0.78(0.21)	HW71	0.25(0.04)
24	TZ29	0.46(0.02)	TZ39	1.62(0.42)	TZ57	0.67(0.08)	TZ49	0.76(0.17)	TZ22	0.25(0.05)
25	KN59	0.45(0.04)	TZ33	1.57(0.32)	ET3	0.65(0.11)	TZ39	0.74(0.22)	TZ36	0.24(0.05)
26	TZ42	0.44(0.02)	ET3	1.54(0.28)	TZ51	0.61(0.07)	TZ11	0.73(0.12)	TZ32	0.22(0.06)
27	HW71	0.44(0.03)	TZ25	1.51(0.20)	TZ32	0.60(0.10)	TZ13	0.72(0.13)	TZ17	0.21(0.02)
28	TZ49	0.44(0.01)	ET8	1.46(0.26)	TZ53	0.57(0.10)	TZ46	0.72(0.27)	TZ51	0.20(0.07)
29	ML75	0.44(0.03)	TZ51	1.45(0.21)	TZ19	0.57(0.11)	TZ25	0.71(0.11)	TZ15	0.20(0.03)
30	BR74	0.44(0.02)	TZ57	1.43(0.19)	TZ33	0.57(0.10)	TZ38	0.71(0.23)	TZ19	0.19(0.04)
31	KN58	0.44(0.03)	TZ36	1.41(0.32)	ET1	0.56(0.08)	TZ34	0.70(0.17)	TZ57	0.18(0.03)
32	TZ32	0.43(0.03)	TZ54	1.40(0.33)	ET4	0.56(0.09)	TZ21	0.66(0.04)	TZ49	0.18(0.04)
33	TZ38	0.43(0.04)	TZ38	1.39(0.39)	ET9	0.54(0.06)	TZ53	0.66(0.14)	TZ38	0.18(0.05)
34	TZ39	0.43(0.01)	ET1	1.38(0.19)	TZ17	0.54(0.05)	ET1	0.66(0.10)	TZ53	0.18(0.04)
35	TZ51	0.42(0.03)	TZ53	1.36(0.28)	TZ30	0.52(0.09)	TZ15	0.65(0.12)	TZ46	0.18(0.06)
36	TZ53	0.42(0.02)	TZ34	1.33(0.29)	TZ25	0.51(0.06)	TZ18	0.64(0.10)	TZ13	0.18(0.18)
37	TZ24	0.42(0.02)	TZ20	1.32(0.12)	TZ56	0.51(0.11)	TZ51	0.63(0.11)	TZ54	0.17(0.04)

Rank	Prov. code	Branchiness index	Prov. code	Total dry mass (kg/tree)	Prov. code	Stem dry mass (kg/tree)	Prov. code	Branch dry mass (kg/tree)	Prov. code	Leaf dry mass (kg/tree)
38	TZ20	0.41(0.03)	TZ46	1.31(0.43)	ET8	0.51(0.08)	ET8	0.62(0.12)	TZ23	0.17(0.03)
39	TZ27	0.41(0.03)	TZ15	1.30(0.25)	TZ38	0.50(0.11)	ML75	0.58(0.11)	TZ34	0.16(0.05)
40	TZ55	0.41(0.03)	TZ13	1.27(0.21)	TZ35	0.49(0.15)	ET3	0.58(0.11)	TZ33	0.16(0.04)
41	TZ30	0.41(0.02)	HW71	1.24(0.14)	ML75	0.49(0.05)	TZ57	0.57(0.08)	TZ39	0.15(0.05)
42	ET9	0.41(0.02)	TZ11	1.22(0.17)	TZ48	0.49(0.08)	HW69	0.57(0.07)	ET1	0.15(0.01)
43	NI61	0.4(0.02)	ML75	1.20(0.18)	TZ20	0.48(0.04)	TZ20	0.56(0.08)	TZ11	0.14(0.02)
44	TZ57	0.4(0.02)	ET9	1.18(0.16)	TZ42	0.48(0.05)	HW67	0.55(0.11)	TZ56	0.14(0.04)
45	TZ26	0.4(0.02)	HW65	1.17(0.19)	TZ44	0.46(0.08)	HW71	0.55(0.06)	HW69	0.14(0.02)
46	HW64	0.4(0.04)	TZ30	1.15(0.28)	TZ34	0.45(0.07)	TZ16	0.53(0.11)	ET4	0.13(0.02)
47	TZ48	0.4(0.02)	ET4	1.13(0.20)	TZ47	0.45(0.15)	TZ14	0.53(0.08)	HW65	0.13(0.02)
48	TZ40	0.4(0.06)	HW69	1.12(0.13)	TZ15	0.45(0.09)	TZ54	0.53(0.16)	NI61	0.12(0.04)
49	ET6	0.4(0.02)	TZ42	1.11(0.17)	TZ23	0.44(0.07)	HW68	0.53(0.10)	TZ21	0.12(0.01)
50	HW66	0.39(0.02)	TZ50	1.09(0.20)	ET2	0.43(0.06)	TZ42	0.52(0.10)	TZ48	0.12(0.02)
51	TZ52	0.39(0.04)	TZ56	1.09(0.32)	HW71	0.43(0.05)	ET9	0.51(0.08)	TZ30	0.12(0.04)
52	ET7	0.39(0.03)	TZ21	1.09(0.06)	TZ46	0.41(0.09)	HW62	0.5(0.06)	ML75	0.12(0.02)
53	ET8	0.38(0.03)	TZ48	1.07(0.21)	HW69	0.41(0.04)	TZ30	0.49(0.15)	TZ16	0.12(0.01)
54	ET3	0.38(0.02)	TZ47	1.04(0.36)	ET5	0.40(0.03)	NI61	0.46(0.15)	ET9	0.12(0.01)
55	TZ44	0.37(0.02)	TZ16	1(0.16)	NI61	0.39(0.08)	TZ48	0.45(0.09)	TZ44	0.11(0.03)
56	TZ18	0.36(0.02)	TZ14	0.98(0.14)	TZ55	0.39(0.07)	TZ56	0.43(0.17)	HW62	0.11(0.02)
57	ET5	0.35(0.02)	HW62	0.97(0.11)	TZ36	0.38(0.08)	ET4	0.43(0.09)	TZ14	0.11(0.02)

Rank	Prov. code	Branchiness index	Prov. code	Total dry mass (kg/tree)	Prov. code	Stem dry mass (kg/tree)	Prov. code	Branch dry mass (kg/tree)	Prov. code	Leaf dry mass (kg/tree)
58	ET4	0.35(0.02)	NI61	0.95(0.27)	TZ10	0.38(0.04)	HW65	0.39(0.11)	TZ50	0.11(0.02)
59	TZ10	0.35(0.02)	TZ44	0.94(0.19)	TZ13	0.36(0.04)	TZ55	0.36(0.07)	TZ42	0.11(0.02)
60	ET2	0.35(0.03)	HW67	0.93(0.16)	TZ16	0.36(0.04)	TZ44	0.35(0.07)	TZ37	0.1(0.02)
61	KN60	0.35(0.03)	TZ35	0.91(0.31)	HW62	0.35(0.04)	ET2	0.35(0.10)	ET2	0.1(0.02)
62	HW63	0.33(0.02)	ET2	0.89(0.17)	TZ11	0.34(0.04)	TZ47	0.33(0.14)	TZ35	0.1(0.04)
63	TZ43	0.32(0.02)	HW68	0.89(0.16)	TZ14	0.33(0.04)	TZ35	0.31(0.12)	TZ40	0.09(0.03)
64	TZ56	0.32(0.04)	TZ55	0.83(0.15)	TZ37	0.31(0.06)	TZ50	0.36(0.06)	HW67	0.09(0.02)
65	TZ35	0.32(0.03)	ET5	0.80(0.09)	TZ21	0.30(0.03)	ET5	0.30(0.05)	ET5	0.08(0.01)
66	TZ31	0.31(0.02)	TZ10	0.74(0.12)	HW67	0.28(0.04)	TZ10	0.29(0.07)	HW68	0.08(0.02)
67	TZ54	0.31(0.03)	TZ37	0.62(0.14)	HW68	0.28(0.04)	TZ37	0.20(0.05)	TZ55	0.07(0.01)
68	TZ41	0.3(0.03)	TZ31	0.49(0.12)	TZ31	0.25(0.05)	TZ40	0.18(0.03)	TZ31	0.06(0.01)
69	TZ47	0.3(0.03)	TZ41	0.46(0.13)	TZ45	0.24(0.07)	TZ31	0.17(0.05)	TZ41	0.06(0.02)
70	HW65	0.29(0.03)	TZ40	0.44(0.05)	TZ41	0.22(0.06)	TZ41	0.17(0.07)	TZ10	0.06(0.01)
71	TZ45	0.29(0.03)	TZ45	0.44(0.14)	TZ43	0.20(0.03)	TZ45	0.17(0.05)	CS73	0.05(0.02)
72	TZ37	0.29(0.02)	TZ43	0.38(0.05)	TZ52	0.16(0.04)	TZ52	0.16(0.05)	TZ45	0.05(0.01)
73	CS73	0.26(0.06)	TZ52	0.37(0.10)	TZ40	0.16(0.03)	TZ43	0.13(0.02)	TZ52	0.04(0.01)
74	TZ50	0.26(0.01)	CS72	0.19(0.08)	CS72	0.10(0.03)	CS73	0.08(0.04)	TZ43	0.04(0.01)
75	CS72	0.17(0.05)	CS73	0.18(0.09)	CS73	0.06(0.03)	CS72	0.05(0.03)	CS72	0.03(0.01)
Mean		0.42		1.42		0.56		0.66		0.2
Se		0.01		1.12		0.39		0.61		0.2

Table A3.2: Stepwise regression analysis to determine the best model for predicting (i) Stem dry mass (ii) Branch dry mass (iii) Leaf dry mass and (iv) Total dry mass of S. sesban trees in kg tree^{-1} after 8 months growth at Maseno, Kenya.

(a) Stem dry mass model with all variables.

Source	df	SS	MS	F	P	R^2
Regression	5	105.5495	21.1099	567.65	0.0001	0.76
Error	874	32.5026	0.0372			
Total	879	138.0522				
Variable	Parameter estimate	Standard error	SS	F	P	R^2
Intercept	-0.8679					
Height	0.2065	0.0143	7.7716	208.98	0.0001	0.75
Rcd	0.1552	0.0098	9.1980	247.34	0.0001	0.65
Secbr	0.0003	0.0001	0.4756	12.79	0.0004	0.76
Br	-0.0022	0.0008	0.2460	6.62	0.0103	0.76
Crdi	0.0676	0.0165	0.6212	16.71	0.0001	0.76
Two best variable model for stem dry mass						
Source	df	SS	MS	F	P	R^2
Regression	2	103.8758	51.9379	1332.78	0.0001	0.75
Error	877	34.1763	0.0389			
Total	879	138.0522				
Variable	Parameter estimate	Standard error	SS	F	P	R^2
Intercept	-0.8977					
Height	0.2118	0.0111	14.2720	366.23	0.0001	0.75
Rcd	0.1860	0.0082	20.0358	514.14	0.0001	0.65

Table A3.2. Contd.

b) Branch dry mass model with all variable.

Source	df	SS	MS	F	P	R^2
Regression	5	217.1218	43.4243	336.25	0.0001	0.66
Error	869	112.2250	0.1291			
Total	874	329.3469				
Variable	Parameter estimate	Standard error	SS	F	P	R^2
Intercept	-0.8988					
Height	0.0299	0.0267	0.1623	1.26	0.2625	0.66
Rcd	0.2595	0.0187	24.6896	191.18	0.0001	0.56
Secbr	0.0014	0.0001	10.3543	80.18	0.0001	0.62
Br	-0.0078	0.0016	2.9808	23.08	0.0001	0.66
Crdl	0.2714	0.0313	9.6707	74.88	0.0001	0.65
Three variable best model for branch dry mass						
Source	df	SS	MS	F	P	R^2
Regression	3	216.8694	71.2898	537.71	0.0001	0.66
Error	871	112.4774	0.1325			
Total	874	329.3469				
Variable	Parameter estimate	Standard error	SS	F	P	R^2
Intercept	-1.0475					
Rcd	0.2348	0.0177	23.1821	174.85	0.0001	0.56
Secbr	0.0014	0.0001	11.1145	83.83	0.0001	0.62
Crdl	0.2388	0.0280	9.6291	72.63	0.0001	0.65

Table A3.2 . Contd.

c) Leaf dry mass model with all variables

Source	df	SS	MS	F	P	R^2
Regression	5	19.5052	3.9010	208.07	0.0001	0.54
Error	867	16.2550	0.0187			
Total	872	35.7602				
Variable	Parameter estimate	Standard error	SS	F	P	R^2
Intercept	-0.3273					
Height	0.0210	0.0102	0.0786	4.20	0.0408	0.54
Rcd	0.0894	0.0070	2.9718	158.51	0.0001	0.50
Secbr	0.0001	0.00005	0.1384	7.39	0.0067	0.54
Br	-0.0017	0.00006	0.1582	8.44	0.0038	0.54
Crdi	0.0743	0.01179	0.7440	36.69	0.0001	0.54
Two variable best model for leaf dry mass						
Source	df	SS	MS	F	P	R^2
Regression	2	19.2027	9.6013	504.49	0.0001	0.54
Error	870	16.5576	0.0190			
Total	872	35.7603				
Variable	Parameter estimate	Standard error	SS	F	P	R^2
Intercept	-0.3615					
Rcd	0.0939	0.0063	4.1727	219.25	0.0001	0.50
Crdi	0.0807	0.0100	1.2241	64.32	0.0001	0.54

Table A3.2 . Contd.

d) Total dry mass model all variables.

Source	df	SS	MS	F	P	R^2
Regression	5	840.3670	168.073	541.57	0.0001	0.75
Error	874	271.2431	0.3103			
Total	879	1111.610				
Variable	Parameter estimate	Standard error	SS	F	P	R^2
Intercept	-2.0455					
Height	0.2607	0.0412	12.3962	39.94	0.0001	0.74
Rcd	0.5018	0.0285	96.1207	309.72	0.0001	0.67
Secbr	0.0018	0.0002	19.1680	61.76	0.0001	0.74
Br	-0.0124	0.0024	8.0274	25.87	0.0001	0.75
Crdl	0.4065	0.0478	22.4357	72.29	0.0001	0.73
Three best model for total dry mass						
Source	df	SS	MS	F	P	R^2
Regression	3	826.3824	275.46	846.00	0.0001	0.75
Error	876	285.2276	0.3256			
Total	879	1111.610				
Variable	Parameter estimate	Standard error	SS	F	P	R^2
Intercept	-2.2559					
Rcd	0.5828	0.0267	163.677	474.77	0.0001	0.67
Crdi	0.5552	0.0421	59.9538	173.90	0.0001	0.73
Height	0.1572	0.0360	5.9571	18.66	0.0001	0.75

Table A4.1. Results of General linear model showing variance ratios, significance levels, means, standard errors and coefficient of variation of growth traits for (combined site analysis) Sesbania sesban clones after 8 months growth in the field at three sites (Maseno, Kisii and Machakos) in Kenya.

Sources	df	HT	RCD	CW
Site	2	58.7***	20.6***	14.23***
Site(block)	23	3.26***	2.02**	2.05*
Gp	2	16.68***	0.23ns	1.52ns
Clone	12	5.24***	9.84***	7.14***
Clone x Site	26	2.16**	1.47ns	1.75ns
Mean		3.97	4.78	3.58
Se		0.14	0.27	0.14
C.V.%		17.73	28.9	19.6

HT = Height (m)
RCD = Root collar diameter at 0.15m (cm).
CW = Crown diameter (m).
Se = Standard error.
C.V. = Coefficient of variation.
*** = Significant at P<0.001.
** = Significant at P<0.01.
* = Significant at P<0.05.
ns = Not significant.

Table A4.2 . Results of General linear model showing variance ratios, significance levels, means, standard errors and coefficient of variation of growth traits (single site analysis) in Sesbania sesban after 8 months growth in the field at Maseno, Kisii and Machakos, Kenya.

Site	MASENO				KISII				MACHAKOS			
Sources	df	HT (m)	RCD (cm)	CW (m)	df	HT (m)	RCD (cm)	CW (m)	df	HT (m)	RCD (cm)	CW (m)
Block	9	2.07*	1.16ns	1.16ns	5	4.26*	3.16*	2.35ns	9	2.31*	1.55ns	2.4*
Gp	2	10.73***	0.28ns	2.65ns	2	5.70*	1.95ns	1.38ns	2	7.91**	2.03ns	0.76ns
Clone	12	4.65***	7.25***	5.12***	11	1.77ns	2.21*	2.01*	12	3.81**	3.21**	4.59***
Mean		4.48	5.41	3.85		3.88	4.39	3.42		3.50	4.37	3.41
Se		0.18	0.42	0.18		0.43	0.75	0.42		0.17	0.35	0.10
C.V. %		12.5	24.7	14.6		28.1	41.9	30.6		15.2	25.2	16.9

HT = Height.
RCD = Root collar diameter at 0.15m.
CW = Crown diameter.
Se = Standard error.
C.V. % = Coefficient of variation.
*** = Significant at P≤0.001.
** = Significant at P≤0.01.
* = Significant at P≤0.05.
ns = Not significant.

Table A4.3. Results of General linear model, variance ratios, means, standard errors and coefficient of variation for crown characteristics of Sesbania sesban clones after 4 months growth at Maseno, Kisii and Machakos (three sites), Kenya.

Source	df	Length of primary branch (m)	Basal diameter of primary branch (cm)	Angle of origin of primary branch (°)	Angle of termination of primary branch (°)	Leaf number per branch (count)	Leaf area per branch (m^2)	Crown diameter (m)
Site	2	3.88*	7.57**	19.66***	39.34***	4.52*	0.80ns	2.22ns
Clone	14	1.89*	1.75*	3.05**	3.89**	2.05*	2.05*	2.40*
Zone	2	1.06ns	0.21ns	0.84ns	0.97ns	0.64ns	0.86ns	0.48ns
Clone x Site	26	0.52ns	0.27ns	1.75*	1.99*	0.33ns	0.53ns	0.79ns
Mean		0.95	0.64	68.94	58.87	114.03	0.19	1.57ns
Se		0.12	0.08	2.37	2.05	33.50	0.06	0.19
C.V. %		64.9	64.4	17.69	17.8	150.5	150.36	63.6

Se = Standard error.
C.V. % = Coefficient of variation.
*** = Significant at P≤0.001.
** = Significant at P≤0.01.
* = Significant at P≤0.05.
ns = Not significant.

Table A4.4. Results of General linear model, variance ratios, means, standard error and coefficient of variation for crown characteristics of Sesbania sesban after 8 months growth in the field at Maseno, Kisii and Machakos (three sites), Kenya.

Source	df	Length of primary branch (m)	Basal diameter of Primary branch (cm)	Angle of origin of primary branch (°)	Angle of termination of primary (°)	Leaf number per branch (count)	Leaf area per branch (m^2)	Crown diameter (m)
Site	2	12.3***	1.96ns	23.91***	79.20***	1.33ns	7.93*	7.93**
Clone	14	1.34ns	1.22ns	7.08***	11.99***	2.01*	2.72**	2.72**
Zone	2	1.27ns	0.64ns	0.59ns	0.53ns	1.26ns	1.22ns	1.22ns
Clone x site	26	0.52ns	0.45ns	3.08***	3.40***	0.64ns	1.15ns	1.15ns
Mean		1.81	1.22	71.07	57.32	234.59	0.44	0.44
Se		0.16	0.13	1.38	1.70	50.70	0.09	0.09
C.V. %		45.2	56.7	9.9	15.2	108.6	110.5	110.5

Se = Standard error.
C.V. % = Coefficient of variation.
*** = Significant at P≤0.001.
** = Significant at P≤0.01.
* = Significant at P≤0.05.
ns = Not significant.

Table A4.5. Results of General linear model showing variance ratios, significance levels, means, standard errors and coefficient of variation for growth traits in Sesbania sesban clones after 9 months growth in the field at Maseno, Kisii and Machakos (three sites), Kenya.

Source	df	Height (m)	Number of branches (count)	Stem diameter at 0.15m (cm)	Stem diameter at 0.30m (cm)	Crown diameter at 1.3m (m)	Branch frequency per metre
Site	2	110.14***	101.65***	21.93***	34.63***	144.7***	15.4***
Gp	2	15.95***	6.74*	0.39ns	1.11ns	4.46*	3.10*
Clone	12	2.92***	3.74***	4.65***	5.35***	3.23***	8.47***
Clone x site	26	1.20ns	1.45ns	1.37ns	1.54ns	1.55ns	1.29ns
Mean		4.77	59.16	5.88	4.98	3.17	12.49
Se		0.22	3.17	0.47	0.36	0.23	0.51
C.V.%		16.4	18.5	27.7	25.4	25.1	14.2

Se = Standard error.
C.V.% = Coefficient of variation.
*** = Significant at P≤0.001.
** = Significant at P≤0.01.
* = Significant at P≤0.05.
ns = Not significant.

Table A4.6. Results of general linear model showing variance ratios, significance levels, means, standard errors and coefficient of variation for growth traits in Sesbania sesban clones after nine months growth in the field at Maseno, Kenya.

Source	df	Height (m)	Number of branches (count)	Stem diameter 0.15m (cm)	Stem diameter at 0.30m (cm)	Crown diameter at 1.3m (m)	Branch frequency per meter
Block	3	0.98ns	0.23*	0.01ns	0.09ns	1.64ns	0.05ns
Gp	2	22.25***	3.61*	1.38ns	4.00*	1.83ns	1.07ns
Clone	12	5.86***	2.07*	2.88*	3.82**	2.24*	3.0*
Mean		5.58	73.46	6.77	5.81	3.83	13.34
Se		0.30	6.08	0.90	0.62	0.27	1.10
C.V. %		9.8	16.5	26.3	21.5	22.1	16.6

Se = Standard error.
C.V. % = Coefficient of variation.
*** = Significant at P≤0.001.
** = Significant at P≤0.01.
* = Significant at P≤0.05.
ns = Not significant.

Table A4.7. Results of general linear model showing variance ratios, significance levels, means, standard errors and coefficient of variation for growth traits in Sesbania sesban clones after nine months growth in the field at Kissi, Kenya.

Source	df	Height (m)	Number of branches (count)	Stem diameter 0.15m (cm)	Stem diameter at 0.30m (cm)	Crown diameter at 1.3m (m)	Branch frequency per meter
Block	3	3.44*	3.53*	2.29ns	1.92ns	0.99ns	1.93ns
Gp	2	3.17ns	0.68ns	2.39ns	1.41ns	1.58ns	4.16*
Clone	10	0.81ns	2.37*	1.49ns	1.51ns	2.35*	5.97***
Mean		5.24	59.57	6.09	5.26	4.06	11.46
Se		0.56	6.23	0.98	0.80	0.47	0.66
C.V. %		21.5	20.9	32.3	30.7	23.0	11.6

Se = Standard error.
C.V. % = Coefficient of variation.
*** = Significant at P≤0.001.
** = Significant at P≤0.01.
* = Significant at P≤0.05.
ns = Not significant.

Table A4.8. Results of general linear model showing variance ratios, significance levels, means, standard errors and coefficient of variation for growth traits in Sesbania sesban clones after nine months growth in the field at Machakos, Kenya.

Source	df	Height (m)	Number of branches (count)	Stem diameter 0.15m (cm)	Stem diameter at 0.30m (cm)	Crown diameter at 1.3m (m)	Branch frequency per meter
Block	3	0.65ns	0.58ns	0.93ns	0.50ns	0.79ns	0.26ns
Gp	2	7.36*	10.88**	0.29ns	1.95ns	11.48***	3.12ns
Clone	12	2.49*	3.04*	4.20**	4.12**	0.81ns	3.33*
Mean		3.58	44.70	4.82	3.92	1.77	12.54
Se		0.20	3.50	0.49	0.43	0.30	0.86
C.V. %		11.4	15.7	20.4	22.2	34.1	13.8

Se = Standard error.
C.V. % = Coefficient of variation.
*** = Significant at P≤0.001.
** = Significant at P≤0.01.
* = Significant at P≤0.05.
ns = Not significant.

Table A4.9. Results of General linear model showing variance ratios, significance levels, means, standard errors and coefficient of variation of traits on Sesbania sesban clones after 9 months growth in the field at Maseno, Kisii and Machakos (three sites) in Kenya.

Sources	df	Stem dry mass (kg)	Branch dry mass (kg)	Leaf dry mass (kg)	Above ground dry mass (kg)	Root dry mass (kg)	Lateral root dry mass (kg)	Vertical root dry mass (kg)	Total tree dry mass (kg)	Root/S hoot ratio
Site	2	49.5***	16.84***	70.82***	36.08***	40.33***	18.13***	4.83*	44.12***	6.48*
Gp	2	3.88*	0.82ns	1.61ns	0.83ns	10.86***	13.42***	1.14ns	2.98ns	7.00*
Clone	12	3.13**	6.60***	3.08**	5.55***	7.95***	7.14***	1.92*	6.18***	7.13***
Clone x site	26	1.37ns	2.38**	1.75*	2.04*	2.99***	2.47*	2.07*	2.37**	2.62**
Mean		1.31	3.67	1.23	6.21	2.50	1.38	0.46	8.67	0.42
Se		0.21	0.60	0.26	0.96	0.41	0.25	0.12	1.29	0.05
C.V. %		55.0	56.4	74.3	53.8	57.9	64.9	94.8	51.3	39.4

Se = Standard error.
C.V.% = Coefficient of variation.
*** = Significant at P≤0.001.
** = Significant at P≤0.01.
* = Significant at P≤0.05.
ns = Not significant.

Table A4.10. Results of General linear model showing variance ratios, significance levels, means, standard errors and coefficient of variation of traits on Sesbania sesban clones after nine months growth in the field at Maseno, Kenya.

Source	df	Stem dry mass (kg)	Branch dry mass (kg)	Leaf dry mass (kg)	Above ground dry mass (kg)	Root dry mass (kg)	Lateral root dry mass (kg)	Vertical root dry mass (kg)	Total tree dry mass (kg)	Root/shoot ratio
Block	3	1.34ns	0.61ns	1.17ns	0.73ns	1.31ns	0.71ns	2.08ns	1.01ns	0.05ns
Gp	2	3.58*	1.08ns	1.07ns	1.05ns	2.25ns	4.30*	0.84ns	0.14ns	4.10*
Clone	12	2.31*	5.38***	3.47*	4.75***	6.61***	5.28***	2.78*	5.43***	3.07*
Mean		1.75	4.82	1.67	8.24	3.59	1.87	0.52	11.82	0.48
Se		0.39	1.19	0.40	1.83	0.76	0.51	0.23	2.40	0.11
C.V. %		45.6	49.5	48.3	44.4	42.4	54.3	89.0	40.52	45.1

Se = Standard error.
C.V. % = Coefficient of variation.
*** = Significant at P≤0.001.
** = Significant at P≤0.01.
* = Significant at P≤0.05.
ns = Not significant.

Table A4.11. Results of General linear model showing variance ratios, significance levels, means, standard errors and coefficient of variation of traits on Sesbania sesban clones after nine months growth in the field at Kisii, Kenya.

Source	df	Stem dry mass (kg)	Branch dry mass (kg)	Leaf dry mass (kg)	Above ground dry mass (kg)	Root dry mass (kg)	Lateral root dry mass (kg)	Vertical root dry mass (kg)	Total tree dry mass (kg)	Root/shoot ratio
Block	3	0.69ns	0.47ns	0.46ns	0.49ns	2.35ns	0.86ns	2.96*	1.02ns	1.47ns
Gp	2	2.11ns	5.16*	2.97ns	4.26*	10.55**	10.54**	2.64ns	6.67*	2.67ns
Clone	10	1.47ns	1.42ns	1.45ns	1.42ns	3.50*	3.44*	2.08*	1.92ns	5.95***
Mean		1.68	3.57	2.02	7.27	2.72	1.39	0.57	9.99	0.37
Se		0.49	1.30	0.72	2.30	0.94	0.63	0.26	3.01	0.07
C.V. %		58.3	73.0	71.4	63.0	68.9	81.2	93.6	60.2	36.6

Se = Standard error.
C.V. % = Coefficient of variation.
*** = Significant at P≤0.001.
** = Significant at P≤0.01.
* = Significant at P≤0.05.
ns = Not significant.

Table A4.12. Results of General linear model showing variance ratios, significance levels, means, standard errors and coefficient of variation of traits on Sesbania sesban clones after nine months growth in the field at Machakos, Kenya.

Source	df	Stem dry mass (kg)	Branch dry mass (kg)	Leaf dry mass (kg)	Above ground dry mass (kg)	Root dry mass (kg)	Lateral root dry mass (kg)	Vertical root dry mass (kg)	Total tree dry mass (kg)	Root/shoot ratio
Block	3	0.26ns	0.22ns	0.84*	0.10ns	0.09ns	0.47ns	1.14ns	0.11ns	0.13ns
Gp	2	3.84*	0.14ns	0.25ns	0.26ns	0.15ns	0.35ns	2.63ns	0.19ns	0.91ns
Clone	12	2.37*	4.50***	1.13ns	4.15**	3.70**	3.84**	1.69ns	3.78**	5.24***
Mean		0.57	2.62	0.12	3.30	1.22	0.89	0.32	4.52	0.42
Se		0.11	0.55	0.05	0.66	0.26	0.24	0.10	0.87	0.07
C.V. %		38.5	41.8	99.5	40.1	42.5	51.7	61.2	38.7	35.5

Se = Standard error.
C.V. % = Coefficient of variation.
*** = Significant at P≤0.001.
** = Significant at P≤0.01.
* = Significant at P≤0.05.
ns = Not significant.

Table A4.13. Results of General linear model showing variance ratios, significance levels, means, standard errors and coefficient of variation of traits on Sesbania sesban clones after nine months growth in the field at Maseno, Kisii and Machakos in Kenya.

Source	df	Number of primary roots (count)	Length primary root (m)	Diameter of primary root (cm)	Angle of primary root (°)	Number of secondary roots (count)	Length of secondary roots (m)	Diameter of secondary roots (cm)	Angle of secondary root (°)	Horizontal root spread (m)	Vertical root spread (m)	Root spread/ crown spread ratio
Site	2	26.73***	16.54***	24.04***	0.10ns	6.41*	52.01***	17.56***	231.75***	1.68ns	44.57***	81.89***
Clone	14	1.82*	2.02*	3.43***	3.11***	2.53*	4.17***	4.92***	4.55***	1.13ns	1.04ns	2.51*
Clone x site	26	1.38ns	2.37***	2.53***	3.24***	1.13ns	4.46***	2.44***	2.96***	1.97*	2.45**	2.11*
Mean		7.73	1.39	2.57	108.35	116.76	0.77	0.85	94.04	3.99	1.00	1.65
Se		0.81	0.24	0.60	11.26	40.62	0.15	0.18	8.75	0.42	0.08	0.26
C.V.%		36.5	59.1	81.5	36.0	120.5	70.0	75.8	32.22	36.6	45.7	53.9

Se = Standard error.
C.V.% = Coefficient of variation.
*** = Significant at P≤0.001.
** = Significant at P≤0.01.
* = Significant at P≤0.05.
ns = Not significant.

Table A4.14. Results of General linear model showing variance ratios, significance levels, means, standard errors and coefficient of variation of traits on Sesbania sesban clones after nine months growth in the field at Maseno, Kenya.

Source	df	Number of primary roots (count)	Length of primary roots (m)	Diameter of primary roots (cm)	Angle of primary root (°)	Number of secondary root (count)	Length of secondary root (cm)	Diameter of secondary root (cm)	Angle of secondary root (°)	Horizontal root spread (m)	Vertical root spread (m)	Root spread / crown spread ratio
Block	3	0.90ns	2.18*	2.14ns	5.24ns	0.71ns	5.32*	0.45ns	3.79*	0.91ns	1.81ns	1.88ns
Clone	14	1.26ns	2.65**	4.88***	2.42*	1.69ns	4.36***	2.61*	4.19***	3.87**	2.59*	2.38*
Mean		9.52	1.33	2.33	108.9	153.4	0.83	0.99	72.47	3.94	0.78	1.07
Se		1.95	0.43	0.88	15.72	73.6	0.32	0.35	14.3	0.60	0.20	0.20
C.V. %		41.1	64.9	75.4	28.9	96.0	76.5	71.5	39.5	30.3	51.3	37.9

Se = Standard error.
C.V. % = Coefficient of variation.
*** = Significant at P≤0.001.
** = Significant at P≤0.01.
* = Significant at P≤0.05.
ns = Not significant.

Table A4.15. Results of General linear model showing variance ratios, significance levels, means, standard errors and coefficient of variation of traits on Sesbania sesban clones after nine months growth in the field at Kisii, Kenya.

Source	df	Number of primary roots (count)	Length of primary roots (m)	Diameter of primary roots (cm)	Angle of primary root (°)	Number of secondary root (count)	Length of secondary root (cm)	Diameter of secondary root (cm)	Angle of secondary root (°)	Horizontal root spread (m)	Vertical root spread (m)	Root spread / crown spread ratio
Block	3	1.04ns	9.12***	0.76ns	4.37*	1.53ns	0.40ns	2.78*	3.49*	9.70**	1.08ns	9.45***
Clone	12	3.79**	1.33ns	1.46ns	1.29ns	2.27*	4.67***	5.11***	1.86*	1.12ns	0.64ns	1.21ns
Mean		5.57	1.23	3.32	108.2	59.72	0.55	0.74	93.5	3.74	0.66	0.92
Se		0.79	0.44	1.76	23.3	19.93	0.20	0.31	18.62	0.76	0.16	0.19
C.V. %		28.6	71.4	105.9	43.0	66.7	73.0	84.5	39.8	40.9	49.9	41.0

Se = Standard error.
C.V. % = Coefficient of variation.
*** = Significant at P≤0.001.
** = Significant at P≤0.01.
* = Significant at P≤0.05.
ns = Not significant.

Table A4.16. Results of General linear model showing variance ratios, significance levels, means, standard errors and coefficient of variation of traits on Sesbania sesban clones after nine months growth in the field at Machakos, Kenya.

Source	df	Number of primary roots (count)	Length of primary roots (m)	Diameter of primary roots (cm)	Angle of primary root (°)	Number of secondary root (count)	Length of secondary root (cm)	Diameter of secondary root (cm)	Angle of secondary root (°)	Horizontal root spread (m)	Vertical root spread (m)	Root spread / crown spread ratio
Block	3	0.97ns	1.43*	0.34ns	2.58ns	2.85*	1.45ns	5.51*	1.80ns	0.63ns	0.77ns	1.18ns
Clone	14	1.49ns	2.40*	3.32***	5.14***	1.74ns	3.94***	2.40*	5.99***	1.87ns	1.67ns	2.48*
Mean		7.82	1.56	2.39	107.8	129.87	0.91	0.81	115.1	4.24	1.43	2.83
Se		1.17	0.34	0.53	20.70	86.63	0.27	0.29	11.89	0.56	0.27	0.67
C.V. %		29.9	44.3	44.1	38.4	133.4	59.2	72.3	20.6	26.8	38.7	47.8

Se = Standard error.
C.V. % = Coefficient of variation.
*** = Significant at P≤0.001.
** = Significant at P≤0.01.
* = Significant at P≤0.05.
ns = Not significant.

Table A4.17. Analysis of variance for soil nutrients in Sesbania sesban clone plantings at three sites (Maseno, Kisii and Machakos) at different times.

Source	df	LOI	pH	K	Ca	Mg	$N\text{-}NO_3$	$N\text{-}NH_4$	P
Site	2	125.28***	486.15***	72.50***	28.54***	175.96***	17.62***	2.87ns	5.28**
Date	1	0.07ns	0.28ns	4.63*	10.94*	0.00ns	5.01ns	42.78***	3.91ns
Block	8	1.02ns	6.19***	1.93ns	3.79**	9.76***	1.70ns	1.38ns	1.72ns
Depth	1	0.86ns	0.06ns	0.06ns	0.17ns	0.0ns	2.38ns	1.25ns	0.06ns
Mean		9.04	5.48	24.75	53.57	11.95	1.25	2.01	0.29
Se		0.33	0.04	1.74	3.20	0.51	0.20	0.23	0.05
C.V. %		20.2	3.8	37.3	30.1	18.4	86.5	61.4	97.5

Se = Standard error.
C.V. % = Coefficient of variation.
*** = Significant at $P \leq 0.001$.
** = Significant at $P \leq 0.01$.
* = Significant at $P \leq 0.05$.
ns = Not significant.
Means for K, Ca, Mg, $N\text{-}NO_3$, $N\text{-}NH_4$ and P = expressed as mg/100 g^{-1}.
LOI = Loss on ignition %.

Table A4.18. ANOVA for foliar P, K, Mg, Ca and N for Sesbania sesban clones growing at Maseno, Kisii and Machakos, Kenya.

Source	df	P%	K%	Mg%	Ca%	N%
Site	2	37.41***	66.27***	20.52***	84.23***	33.34***
Date	1	2.83ns	52.57***	53.84**	13.07**	46.07***
Clone	14	4.92***	5.41***	12.41***	5.13***	4.14***
Clone x site	26	2.14*	2.51**	4.59***	1.50ns	2.17*
Mean		0.22	1.73	0.30	2.87	4.08
Se		0.01	0.06	0.01	0.11	0.06
C.V. %		17.5	17.6	14.9	19.9	9.6

Se = Standard error.
C.V. % = Coefficient of variation.
*** = Significant at P≤0.001.
** = Significant at P≤0.01.
* = Significant at P≤0.05.
ns = Not significant.

Table A5.2: Results of General Linear model showing variance ratios, significance levels, means, standard errors and coefficient of variation of primary growth traits on S. sesban clones after 2 weeks growth in the field at Maseno.

Source	df	Height (m)	Root collar diameter (cm)	Branch number (Count)	Leaf number (Count)	Leaf area (m^2)	Root dry weight (g)	Stem dry weight (g)	Branch dry weight (g)	Leaf dry weight (g)	Total Plant dry weight (g)
Block	4	0.83ns	1.02ns	1.28ns	0.92ns	0.78ns	1.83ns	1.64ns	2.24ns	11.78***	2ns
Clone	11	0.44ns	0.66ns	0.55ns	0.68ns	5.27***	3.92**	4.92**	2.18*	2.83**	5.22**
Mean		0.71	0.57	7.16	53.21	0.06	3.48	4.05	0.31	4.07	12.08
Se		0.13	0.11	0.8	1.48	0.05	0.42	0.38	0.19	0.4	0.64
C.V.%		12.7	10.8	45.4	20.6	21.7	25.4	18.2	57.1	20.2	17.1

Se = Standard error
C.V.% = Coefficient of variation
*** = Significant at P≤0.001
** = Significant at P≤0.01
* = Significant at P≤0.05
ns = Not significant.

Table A5.3. Results of General linear model showing variance ratios, significance levels, means, standar errors and coefficient of variation of primary growth traits on S. sesban clones after 4 weeks growth in the field at Maseno.

Source	df	Height (m)	Root collar diameter (cm)	Branch number (count)	Leaf number (count)	Leaf area (m^2)	Root dry weight (g)	Stem dry weight (g)	Branch dry weight (g)	Leaf dry weight (g)	Total plant dry weight (g)
Block	4	0.45ns	1.09ns	0.44ns	1.08ns	1.54ns	2.20ns	1.99ns	0.83ns	1.32ns	1.43ns
Clone	11	0.74ns	0.35ns	0.30ns	0.63ns	7.68***	4.54***	0.68ns	0.78ns	0.25ns	0.76ns
Mean		1	0.77	15.15	118	0.22	4.28	8.53	2.94	9.19	25.26
Se		0.16	0.14	0.91	2.5	0.1	0.55	0.71	0.54	0.76	1.19
C.V.%		14.1	13.6	27.1	26	25.4	35.2	29.5	50.1	31.6	28.3

Se = Standard error
C.V.% = Coefficient of variation
*** = Significant at P≤0.001
** = Significant at P≤0.01
* = Significant at P≤0.05
ns = Not significant

Table A5.4. Results of General linear model showing variance ratios, significance levels, means, standard errors and coefficient of variation of primary growth traits on S. sesban clones after 6 weeks growth in the field at Maseno.

Source	df	Height (m)	Root collar diameter (cm)	Crown diameter (m)	Branch number (count)	Leaf number (count)	Leaf area (m^2)	Root dry weight (g)	Stem dry weight (g)	Branch dry weight (g)	Leaf dry weight (g)	Total plant dry weight (g)
Block	4	1.85ns	1.84ns	1.64ns	1.03ns	0.87ns	0.90ns	0.47ns	0.93ns	0.29ns	0.76ns	0.49ns
Clone	11	1.54ns	0.79ns	1.30ns	1.87ns	0.36ns	1.18ns	1.67*	2.27*	1.14ns	1.02ns	1.17ns
Mean		1.36	1.02	0.85	19.36	205	0.32	112.13	16.90	10.80	19.53	60.28
Se		0.17	0.16	0.21	0.79	3.56	0.14	0.82	0.96	1.02	1.05	1.79
C.V.%		10.6	12.9	25.6	16.4	31	30.6	27.8	27.2	48.8	28.6	26.8

Se = Standard error
C.V.% = Coefficient of variation
*** = Significant at P≤0.001
** = Significant at P≤0.01
* = Significant at P≤0.05
ns = Not significant

Table A5.5. Results of General linear model showing variance ratios, significance levels, means, standard errors and coefficient of variation of primary growth traits on S. sesban clones after 8 weeks growth in the field at Maseno.

Source	df	Height (m)	Root collar diameter (cm)	Crown diameter (m)	Branch number (count)	Leaf number (count)	Leaf area (m^2)	Root dry weight (g)	Stem dry weight (g)	Branch dry weight (g)	Leaf dry weight (g)	Total dry weight (g)
Block	4	0.65ns	0.20ns	2.68*	0.29ns	1.10ns	1.36ns	0.77ns	0.62ns	0.07ns	0.68ns	0.32ns
Clone	11	0.28ns	0.42ns	0.95ns	0.35ns	0.92ns	4.59***	0.73ns	0.32ns	0.58ns	0.43ns	0.41ns
Mean		2.05	1.82	1.83	25.26	398	0.64	34.69	52.61	53.34	64.96	206.5
Se		0.25	0.24	0.24	1.07	3.9	0.17	1.65	1.93	2.11	1.96	3.48
C.V.%		15.4	15.6	16.2	22.7	19.4	22.0	39.5	35.5	41.8	29.5	29.4

Se = Standard error
C.V.% = Coefficient of variation
*** = Significant at P≤0.001
** = Significant at P≤0.01
* = Significant at P≤0.05
ns = Not significant

Table A5.6. Results of General linear model showing variance ratios, significance levels, means, standard errors and coefficient of variation of primary growth traits on S. sesban clones after 10 weeks growth in the field at Maseno.

Source	df	Height (m)	Root collar diameter (cm)	Crown diameter (m)	Branch number (count)	Leaf number (count)	Leaf area (m^2)	Root dry weight (g)	Stem dry weight (g)	Branch dry weight (g)	Leaf dry weight (g)	Total plant dry weight (g)
Block	4	1.59ns	1.19ns	0.71ns	1.69ns	0.54ns	0.56ns	0.82ns	0.97ns	1.09ns	2.0ns	1.31ns
Clone	11	0.73ns	0.54ns	1.47ns	1.44ns	1.15ns	2.98*	1.03ns	0.57ns	1.18ns	0.94ns	0.87ns
Mean		2.23	2.04	1.97	32.8	832	1.40	62.43	79.04	96.28	109.19	348.95
Se		0.29	0.28	0.32	1.19	8.53	0.36	2.29	2.71	3.03	3.25	5.42
C.V.%		19.0	20.2	27.3	21.6	44.0	43.9	42.2	46.7	47.8	48.4	42.2

Se = Standard error
C.V. % = Coefficient of variation
*** = Significant at P≤0.001
** = Significant at P≤0.01
* = Significant at P≤0.05
ns = Not significant.

Table A5.7. Results of General linear model showing variance ratios, significance levels, means, standard errors and coefficient of variation of primary growth traits on S. sesban clones after 12 weeks of growth in the field at Maseno.

Source	df	Height (m)	Root collar diameter (cm)	Crown diameter (m)	Branch number (count)	Leaf number (count)	Leaf area (m^2)	Root dry weight (g)	Shoot dry weight (g)	Branch dry weight (g)	Leaf dry weight (g)	Total plant dry weight (g)
Block	4	0.68ns	0.93ns	0.56ns	1.99ns	1.00ns	0.42ns	1.55ns	0.16ns	1.81ns	0.62ns	0.82ns
Clone	11	0.70ns	0.96ns	0.61ns	1.42ns	0.66ns	2.45*	1.59ns	0.72ns	1.00ns	1.99*	1.18ns
Mean		2.82	2.97	2.43	38.15	1768	3.65	141.15	193.57	247.7	237.15	821.83
Se		0.27	0.28	0.26	0.92	10.61	0.46	2.93	3.66	4.26	3.85	6.97
C.V.%		13.6	13.3	14.5	11.2	31.8	29.5	30.5	34.7	36.7	33.1	29.6

Se = Standard error
C.V.% = Coefficient of variation
*** = Significant at P≤0.001
** = Significant at P≤0.01
* = Significant at P≤0.05
ns = Not significant

Table A5.8. Results of General Linear model showing variance ratios, significance levels, means, standard errors and coefficient of variation for Specific leaf area ($m^2\ g^{-1}$), Leaf mass ratio ($g\ g^{-1}$), Shoot mass ratio ($g\ g^{-1}$) and Root mass ratio ($g\ g^{-1}$) at various harvest intervals for Sesbania sesban clones at Maseno.

		First time interval (Week 2 to 4)				Second time interval (Week 4 to 6)				Third time interval (Week 6 to 8)			
Source	df	SLA	LMR	SMR	RMR	SLA	LMR	SMR	RMR	SLA	LMR	SMR	RMR
Block	4	3.45*	7.04**	0.80ns	9.45***	3.58*	3.47*	1.28ns	2.25ns	1.39ns	1.25ns	0.46ns	1.58ns
Clone	11	5.78***	1.98ns	1.10ns	4.54***	3.29**	1.3ns	1.67ns	2.40*	1.81ns	1.62ns	1.17ns	1.93ns
Mean		0.02	0.35	0.41	0.23	0.02	0.34	0.45	0.186	0.014	0.32	0.48	0.185
Se		0.03	0.08	0.08	0.08	0.03	0.08	0.08	0.08	0.03	0.08	0.08	0.07
C.V.%		18.6	8.4	10.4	13.3	20.1	10.2	11.4	17.1	25.7	11.1	13.3	14.0

SLA = Specific leaf area
LMR = Leaf mass ratio
SMR = Shoot mass ratio (stem + branch portions)
RMR = Root mass ratio
Se = Standard error
C.V.% = Coefficient of variation
*** = Significant at $P \leq 0.001$
** = Significant at $P \leq 0.01$
* = Significant at $P \leq 0.05$
ns = Not significant

Table A5.8 Contd. Results of General Linear model showing variance ratios, significance levels, means, standard errors and coefficient of variation for Specific leaf area (m^2 g^{-1}), Leaf mass ratio (g g^{-1}), Shoot mass ratio (g g^{-1}) and Root mass ratio (g g^{-1}) at various harvest intervals for Sesbania sesban clones at Maseno.

		Fourth time interval (Week 8 to 10)				Fifth time interval Week 10 to 12)			
Source	df	SLA	LMR	SMR	RMR	SLA	LMR	SMR	RMR
Block	4	2.99*	0.73ns	0.23ns	1.13ns	2.04ns	1.81ns	1.19ns	0.10ns
Clone	11	2.06*	1.49ns	1.87ns	1.15ns	2.76*	2.33*	1.65ns	1.74ns
Mean		0.01	0.31	0.50	0.18	0.02	0.30	0.52	0.18
Se		0.02	0.09	0.09	0.07	0.03	0.08	0.08	0.07
C.V.%		23.64	13.9	8.1	16.1	22.1	10.4	6.0	14.4

SLA = Specific leaf area
LMR = Leaf mass ratio
SMR = Shoot mass ratio (stem + branch portions)
RMR = Root mass ratio
Se = Standard error
C.V. % = Coefficient of variation
*** = Significant at P≤0.001
** = Significant at P≤0.01
* = Significant at P≤0.05
ns = Not significant

Table A5.9. Results of General Linear model showing variance ratios, significance levels, means, standard errors and coefficient of variation for Relative growth rates (g g^{-1} wk^{-1}), Net assimmilation rates (g m^{-2} wk^{-1}) and Leaf area ratios (m^2 g^{-1}) at various time intervals for Sesbania sesban clones at Maseno (mean values over intervals).

		First time interval (Week 2 to 4)			Second time interval (Week 4 to 6)			Third time interval (Week 6 to 8)			Fourth time interval (Week 8 to 10)			Fifth time interval (Week 10 to 12)		
Source	df	RGR	NAR	LAR	RGR	NAR	LAR	RGR	NAR	LAR	RGR	NAR	LAR	RGR	NAR	LAR
Block	4	2.65*	3.57*	2.12ns	1.13ns	0.78ns	1.34ns	0.40ns	0.30ns	0.97ns	0.96ns	1.02ns	2.33ns	0.61ns	0.38ns	4.93*
Clone	11	1.87ns	0.82ns	11.56***	0.60ns	1.27ns	4.94***	0.70ns	0.60ns	1.78*	0.81ns	0.63ns	2.09*	1.08ns	1.27ns	2.83*
Mean		0.36	53.64	0.0071	0.44	72.23	0.0071	0.61	164.4	0.004	0.21	66.6	0.004	0.48	114.3	0.005
Se		0.19	2.5	0.015	0.210	3.02	0.020	0.22	3.9	0.015	0.27	4.9	0.013	0.26	4.5	0.013
C.V.%		49.7	58.2	15.4	49.44	63.3	18.1	38.37	47.1	26.1	180.3	197.9	23.5	73.3	88.4	19.1

RGR = Relative growth rates
NAR = Net assimmilation rates
LAR = Leaf area ratio
Se = Standard error
C.V.% = Coefficient of variation
*** = Significant at $P \leq 0.001$
** = Significant at $P \leq 0.01$
* = Significant at $P \leq 0.05$
ns = Not significant