EFFECTS OF NITROGEN AND PHOSPHORUS FERTILIZER ON GROWTH AND YIELD OF *Vernonia galamensis*

BY

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A THESIS SUBMITTED IN PARTIAL FULFILMENT OF
THE REQUIREMENT FOR THE AWARD OF
MASTER OF SCIENCE DEGREE

IN

AGRONOMY

UNIVERSITY OF NAIROBI

2000

DECLARATION

I declare that this thesis is of my own composition and, apart from the acknowledged assistance, is a record of my own research. The material has never been presented before to the University of Nairobi or any other establishment for an academic award.

22/11/2000
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To Mr. and Mrs. Bernard Mati Ngari, my parents and source of inspiration.

ABSTRACT

Vernonia galamesis is a promising new crop for industrial oil but information on its performance response to fertilizer is scanty. Two field experiments were conducted at the University of Nairobi, Kabete field station in January to May 1998 and March to July 1998. The objectives were to determine the effects of different nitrogen (N) and phosphorus (P) fertilizer rates on growth, solar radiation (PAR) interception and seed yield of two vernonia varieties (ethiopica and gibbosa). N was applied as calcium ammonium nitrate (CAN) at 0, 75 and 150 kg N/ha, and P as triple superphosphate (TSP) at 0, 45 and 90 kg P_2O_5/ha. The experimental design was a factorial laid out as randomized complete block with three replications.

Number of leaves/plant and number branches/plant was not significantly (p=0.05) influenced by N and P application in the two varieties throughout the growing season. N and P application significantly (p=0.05) increased total dry matter (TDM, g/plant), photosynthetically active radiation (PAR) interception and leaf area index (LAI) of both varieties in late vegetative and reproductive stages. Gibbosa consistently had higher TDM and LAI compared to ethiopica throughout the growing season. Gibbosa was taller and intercepted more solar radiation (PAR) than ethiopica throughout the growing season. Average seed yield of gibbosa was 2.3 times higher than ethiopica (averaged over all N and P levels) in both experiments. The highest seed yield was obtained with the highest N and P levels. Gibbosa had significantly (p=0.001) higher number of capsules/plant and harvest index (HI) compared to ethiopica. Both N and P increased seed and dry matter.

Acknowledgement

Special thanks to my supervisors Dr. Mary Mburu and Mrs Kurji for the many discussions we had together and for their invaluable critique and support during the field work and preparation of this manuscript. I wish to thank Dr. S. Shibairo for statistical data analysis without whose contribution this work would be incomplete. Special thanks to the University of Nairobi for offering me a scholarship to undertake the course. I also wish to recognise the contribution of the late Prof. J. Chweya, Head of Department of Crop Science, University of Nairobi, and his technical staff, for allowing me to work in their laboratory and for their assistance and useful suggestions

I am greatly indebted to Kenya Agricultural Research Institute (KARI) and the International Livestock Research Institute (ILRI) for availing their computer facilities during the writing of this manuscript.

Last but not least special gratitude to my parents who selflessly sacrificed their financial resources to support my field work, to my sisters (Purity Mugao, Dorcas Kaburi, Charity Muthoni and Susan Kanana) my brothers (Mr. Martin Muthengi, Jacob Mukabi and Timothy Murimi), cousins Steven Muthoka and Daniel Kirauko, my close friends Timothy Njeru, Francis Kiriiro, Jonathan Nzuma and Charity Kawira for their encouragement and support throughout this course.

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CHAPTER 1

1.0 INTRODUCTION

Throughout history, thousands of species of plants have been used by man for food but only a few have been commercially cultivated. This means that plant breeding, crop protection and the development of processing technology have all focused on a handful of major cash crops. This has resulted in under-exploitation of some crops whose commercial potential has not been perceived. There are always risks associated with monoculture whether from disease or pest infestation or a collapse in world prices. A diversified range of high or added value products is economically more attractive than dependence on a few high volume, low value products. Adoption of new promising high value plants for food or industry that do not compete for the same resources with existing cash crops would diversify agricultural export base of developing countries. Such one promising crop is vernonia (*Vernonia galamensis*), which is adapted to a range of environmental conditions.

Vernonia, commonly known as ironweed, has been identified as a rich source of vernolic (epoxy) oil, used in industry to manufacture plastic formulations (e.g. polyvinyl chloride – PVC), protective coatings (e.g. steel coating) and animal feed (Perdue *et al.*, 1986). Vernonia has not yet been widely adopted for cultivation because preliminary research on breeding for high yield and oil qualities are inadequate (Mills and Grinberg, 1996). This therefore means that the varieties used for cultivation are unimproved.

1.1 Vernonia as a potential dryland crop

The arid and semi-arid lands comprise 82% of the total land mass in Kenya and are characterized by low rainfall (less than 750 mm per annum) that is erratically distributed within and among seasons (Rowland, 1993). The semi-arid areas offer potential land for increased production of food and industrial crops. There is an accelerated migration of farmers from high potential to the semi-arid lands due to high population pressure (M'Ragwa and Kanyenji, 1987). This has created the need for the development of suiTable crops for the semi-arid areas. In such situations the most practical option for the farmer is to adopt drought tolerant crops along with conservation and judicious use of soil and water resources to optimise returns. *Vernonia spp.* are well adapted to a wide range of climatic conditions including arid and semi-arid regions (Gilbert, 1986; Purdue, *et al.*, 1986), and hence has the potential of being grown in these areas. Further, *Vernonia galamensis* is found growing wildly in parts of East Africa, strongly indicating that the region could be its centre of diversity.

Nitrogen and phosphorus have been implicated as the major nutrients limiting crop production in the tropics (Greenland, 1982; Weiss, 1983; IRRI, 1990; Tisdale *et al.*, 1990; Brady, 1990; ICRISAT, 1991). In the humid tropics, nitrogen is of great importance because the high rainfall received in this region accelerates nitrogen loss through leaching. In semi-arid areas, nitrogen deficiency is as a result of low soil moisture reserve hence the process of mineralization is greatly inhibited (Rowland, 1993). Apatite is the most common primary mineral carrier of phosphorus, however, it does not occur commonly in Kenyan soils (Nyandat, 1981). Further, phosphorus limitation for crop production is attributed to high fixation by clay fractions in the soils as well as presence of cations of aluminium (Al^{3+}) calcium (Ca^{2+}), iron (Fe^{2+}), magnesium (Mg^{2+}) and the oxides of iron and aluminium (Tisdale *et al.*, 1990; Greenland, 1981). Most tropical soils have low cation exchange of the clay fractions, often low amounts of exchangeable bases, relatively high aluminium saturation resulting in high phosphorus fixation and interfere of balance among nutrients (Bennema, 1977). Nitrogen and phosphorus deficits are a common phenomenon in Kenya and can be ameriolated through application of inorganic fertilizers or manure (Nyandat, 1981).

Compared to all other agronomic inputs, fertilizers have played the most important role in increasing yield; accounting for more than 50% increase in crop yield in the world (FAO, 1984). It is evident that crop yields are higher in countries with higher fertilizer consumption. Fertilizers have become vital for crop production, by supplying essential plant nutrients, especially where soil fertility and yields are low.

Among the major nutrients, requirements are highest for nitrogen, and soils in the tropics rarely have enough nitrogen to produce high sustainable yields (Rowland, 1993). It is, therefore, necessary to replenish and sustain soil nitrogen by maintaining a high level of soil organic matter, but this often needs to be supplemented with inorganic nitrogen fertilizer for efficient crop production. Phosphorus is the second most common nutrient limiting production in the tropics (Rowland, 1993). A moderate to high deficiency of phosphorus is widespread throughout tropical Africa (Wrigly, 1982) making the use of inorganic phosphorus fertilizer necessary in order to obtain good yields. *V. galamensis* is widely distributed throughout East African region. These distinctive ecological separations also exhibit different soil types as well as differences in nutrient reserve status. In areas receiving high rainfall amounts aluminium and iron cations and their oxides dominate in these soils (Brady, 1990 and Tisdale *et al.*, 1990). These cations complex available phosphorus from the exchange sites forming insoluble Al-P and Fe-P compounds, making it unavailable for plant uptake. Areas receiving low amounts of precipitation have Ca^{2+}, Mg^{2+} and Na^{2+} as the dominant cations which complex available phosphorus forming Mg-P and Ca-P making P also deficient under such conditions.

CHAPTER 2

2.0 LITERATURE REVIEW

2.1 Taxonomy

Gilbert (1986) recognised six subspecies of *Vernonia galamensis*, one of which includes four varieties. These are,

(1) Subspp. *galamensis*
    (a) Var. galamensis
    (b) Var. petitiana (A) Rich) M. Gilbert
    (c) Var. australis M. Gilbert
    (d) Var. ethiopica M. Gilbert
(2) Subspp. *nairobensis* M. Gilbert
(3) Subspp. *hushotoensis* M. Gilbert
(4) Subspp. *motomoensis* M. Gilbert
(5) Subspp. *afromontana* (R.E. Fries) M. Gilbert
(6) Subspp. *gibbosa* M. Gilbert

2.2 Botanical description

Detailed description of *V. galamensis* complex was done by Gilbert (1986). *V. galamensis* subspp. *galamensis* is an annual herb growing to between 15 to 150 cm or higher with leaves measuring 7 to 40 cm wide. The sub-species appear to be isolated ecologically from all the other segregates within *V. galamensis* except *V. galamensis* subspp. *motomoensis*. In eastern Africa, members of sub-spp. *galamensis* are mainly found in drier environments, forest margins and clearings. Var. ethiopica usually grows up to 30 cm with leaves 4 to 15 mm wide. It is most noTable for its short stature, the smallest one being more than 20 cm high with a single capitulum (Gilbert, 1986).

Subspp. *gibbosa* is a freely branching annual shrub. It grows to about 100 to 170 cm high with leaves measuring 13 to 30 cm wide. The capitula are approximately globose with bright blue corolla.

2.3 Agronomic trials

Research on vernonia started as a result of identification of *V. anthelmintica* as a rich source of vernolic oil used in industries to manufacture plastic formulations (e.g. polyvinyl chloride - PCV), protective coatings (e.g. steel coatings) as well as animal feed (Perdue *et al.,* 1986). Agronomic and utilisation potential research of the crop was abandoned owing to poor seed retention of all the species explored at the time (Perdue *et al.,* 1986). It was observed that plants branched profusely and bore many flower heads, and those formed first lost their seeds before the ones formed later matured. This was a major deterrent to mechanical harvesting of the crop. However, interest in vernonia research was rekindled with the identification of *V. galamensis* which unlike *V. anthelmintica* showed excellent seed retention characteristics (Perdue *et al.*, 1986).

2.4 Nitrogen and phosphorus in plant nutrition

Other than soil moisture deficiency, the other major factor limiting crop productivity in the tropics is plant nutrient deficiency (Greenland, 1982; Weiss, 1983). Low levels and rapid oxidation of available organic matter due to intense solar radiation and leaching losses reduce the levels of nitrogen in most tropical soils (Greenland, 1982). Most tropical soils are deficient in phosphorus and the domination by kaolinitic clay results in phosphorus fixation rendering it unavailable for plant uptake.

2.4.1 Nitrogen

Nitrogen plays a central role in plant nutrition because it is a major component of amino acids, proteins, nucleic acids and chlorophyll. Organic nitrogen usually constitutes 1.5 to 5% of the dry mass of plants, depending on the age, species and plant organ (Haynes, 1986). In leaves and stems approximately 60% of the nitrogen is present as enzymes or membrane protein and most of the remainder is in the form of free amino acid nitrogen while in seeds over 90% of the nitrogen is in the form of storage proteins (Haynes, 1986).

Nitrogen stimulates growth of plants, delays senescence and tends to change plant morphology by enhancing shoot elongation and inhibiting root elongation (Marschner, 1985). This shift in root:shoot ratio is undesirable because it inhibits nutrient uptake and leads to lodging problems. Excess nitrogen prolongs the growing period thus delaying crop maturity especially when supplies of other essential nutrients are inadequate (Black, 1968; Boswell *et al.*, 1985). Excess quantities may also result in susceptibility to diseases due to excessive succulence in certain crops (Tisdale *et al.*, 1990).

Nitrogen deficiency causes a decrease in cell division, expansion and elongation and therefore a reduction of morphological parts of plants (Bartholomew and Clark, 1965; Frank, 1965). Leaves appear pale yellow and small in size; stems become thin and upright and the number of lateral roots decreases (Black, 1968).

Nitrogen application increases the number of leaves per plant (Loganathan and Balakrishnamurti, 1980), number of branches per plant, crop height, number of capsules per plant (Malik *et al.*, 1992) and dry matter production (Ahmed *et al.*, 1985;

El-Nakhlawy, 1991; Rao, 1991; Hocking and Pinkerton, 1993; El-Desoky and El-Far, 1996; Vasudevan *et al.*, 1997). Nitrogen generally promotes the rate of floret development, the number of fertile florets and the number of grain set (Haynes, 1986). In small grain crops, nitrogen application increases number of tillers and therefore leaves and branches thus, increasing the potential photosynthetic capacity of the crop (Haynes, 1986). Increased number of leaves and/or large leaf area is important for dry matter production due to increased solar radiation interception. There is a high correlation between leaf area index (LAI), photosynthetically active radiation (PAR) interception and dry matter production (Squire, 1990).

In most oil crops, high nitrogen levels have been reported to depress oil production but increases seed yield and nutrient uptake (Khan *et al.*, 1986; El-Nakhlawy, 1991; Mathukia and Modhwadia, 1995; Vazquez-Ambile and Passone, 1997). However, nitrogen application significantly increased oil yield in safflower (Sagare *et al.*, 1986). In sunflower and sesame, nitrogen fertilizer application reduced seed and oil yield when phosphorus was deficient (Weiss, 1983; Bahl *et al.*, 1997). In castor, seed yield and uptake of nitrogen and phosphorus was observed to increase significantly with nitrogen application up to 50 kg N/ha, while seed oil content decreased with increased nitrogen application (Mathukia and Modwadia, 1996).

2.4.2 Phosphorous

Phosphorus is a major essential nutrient element in plants for the energy transactions such as storage and transfer processes vital to life and growth (Sauchelli, 1965; Tisdale *et al.*, 1990). Energy obtained from photosynthesis and carbohydrate metabolism is stored in phosphate compounds for subsequent use in growth and reproduction processes. The most common phosphorus energy source is that found in adenosine di- and tri-phosphates (ATP and ADP respectively) (Salisbury and Ross, 1991).

A good supply of phosphorus has been shown to increase root growth (Marschner, 1990; Tisdale *et al.*, 1990; Otani and Ae, 1996). An extensive root system provides a strong support (overcome lodging) and a large surface area for the absorption of water and nutrients, which may otherwise be deficient under conditions of restricted root development. Phosphorus uptake by crops is strongly correlated with root length in soils where P availability is high but not in soils with low phosphorus availability or where the soil volume is limited (Otani and Ae, 1996).

Phosphorus is an important component of phospholipids that form oil in plants. Production of most oil crops such as castor oil, groundnut, rapeseed, safflower, niger, crambe, jojoba and soybean have been reported to be increased by phosphorus application (Weiss, 1985). Safflower seed (100 seed mass) and oil yield were significantly increased by phosphorus application (Ignateva and Tokerera, 1976; Ahmed *et al.*, 1985; Singh *et al.*, 1985; Zaman, 1988; Sagare *et al.*, 1986). Weiss, (1985) concluded that phosphorus alone was the most effective element in increasing seed oil content. The source of phosphorus, time, rate and soil type influence response of oil seeds to phosphorus application (Sahrawat and Islam, 1991). Phosphorus deficient plants generally show reduced growth leading to delayed maturity and a reduction in yield while, excess phosphorus depresses yield of most cultivated crops (Tisdale *et al.*, 1990).

2.5 Factors affecting availability and uptake of nitrogen and phosphorus.

2.5.1 Nitrogen

Nitrogen is the most abundant element in the air and is the major reservoir of soil nitrogen. However, most crops cannot use it and hence it must be combined with other element for uptake. In soils, nitrogen is classified either as organic or inorganic. Organic nitrogen in soil occurs as consolidated amino acids or proteins, free amino acids and amino sugars. Inorganic forms of nitrogen include NH_4^+, NO_3^-, NO_2^-, NO and elemental N (Marschner, 1985). However, it is the inorganic forms of nitrogen that are of great importance in soil fertility. Up to 90% of total nitrogen in soil is estimated to be in organic form (Runge, 1983).

Plants may absorb nitrogen in several combined forms from the soil but the greatest amount is absorbed through the roots in ionic form as NH_4^+ or as NO_3^- (Tisdale *et al.*, 1990). The amount of these two ions availed to the roots depend largely on the amount supplied as commercial fertilizers and that released from the reserves of organically bound soil nitrogen through the process of mineralization which occur as a result of the activities of various kinds soil micro-organisms (Haynes, 1986).

Plants absorb NO_3^- more readily since it occurs in higher concentration than NH_4^+ in the soil solution. NH_4^+ due to its cationic nature is adsorbed by soil colloids which are negatively charged (Tisdale *et al.*, 1990). The rate of nitrate uptake by plants is predominantly influenced by soil water (Bartholomew and Clarke, 1965). Soil properties (aeration, temperature, pH, other mineral fractions and the amount of undecomposed organic matter present in the soil) that affect the activities of micro-organisms involved in organic matter decomposition influence the amount of nitrate ions released and consequently the nitrogen available to plants.

Plant nitrogen requirement depends on the growth rate and the nitrogen composition of new tissue (Marschner, 1986). Although crops require a continuous supply of nitrogen throughout the growing period, the demand varies with the stage of crop growth hence crop response to nitrogen application differs among crops, cultivars and hybrids of the same crop species depending on their inherent nitrogen uptake characteristics.

2.5.2 Phosphorus

Phosphorus is absorbed by plants as primary and secondary orthophosphate ions ($H_2PO_4^-$ and HPO_4^{2-} respectively). The primary orthophosphate ion is absorbed several times more readily than the secondary orthophosphate ion (Marschner; 1986; Tisdale *et al.*, 1990). The concentration of these two ions has great implication on plant growth. Plant phosphorus absorption from soil solution is directly proportion to the concentration of phosphate ions. In addition, if other factors are not limiting, plant growth will be proportional to the amounts of phosphorus absorbed (Marschner, 1986).

Physical and chemical properties of the soil largely control the availability of phosphorus to plants (Brady, 1990). Soil pH is the major factor affecting phosphorus availability in soils. It determines the kind of orthophosphate ion that is prevalent in the soil solution. Within the pH range of 5 and 7.2, the primary orthophosphate ion is the dominant species, while between pH ranges of 7.2 and 9 the secondary ion prevails (Brady 1990). Further, soil pH controls the type and solubility of soil minerals which affect the availability of phosphorus. For example, in acid soil phosphorus forms complex and often insoluble compounds with iron and aluminium which are less available to plants, whereas in alkaline soil, soluble phosphates revert to relatively insoluble calcium phosphates (Brady, 1990). Maximum phosphorus availability occurs between pH 6.0 and 6.5 (Sauchelli, 1965; Marschner, 1986; Brady, 1990; Tisdale *et al.*, 1990).

Physical characteristics of the soil such as aeration, compaction, temperature and moisture content also influence phosphorus availability in soil. Soil aeration influences the oxidative state of phosphorus, the decomposition of organic matter and release of phosphorus (Tisdale *et al.*, 1990). For example, under anaerobic conditions in paddy rice, ferric iron is reduced to ferrous form. The ferrous form reacts with phosphorus to form ferrous phosphates that are more soluble hence more available to the rice than the ferric phosphates (Young *et al.*, 1985). Soil compaction affects phosphorus availability indirectly through aeration. Increased compaction creates anaerobic conditions and also physically impedes root penetration resulting in phosphorus being positionally unavailable since it is relatively immobile in soil (Young *et al.*, 1985).

Temperature affects availability of phosphorus through its influence on the activity of soil micro-organisms involved in the decomposition of organic matter. Low temperatures have been shown to decrease phosphorus availability and response to phosphorus fertilizer application have been observed to increase under these conditions (Young *et al.*, 1985).

Soil water also affects the availability of phosphorus, since a major portion of the phosphate ions move to the roots by diffusion through the water films around the soil particles (Marschner, 1986). In corn, it has been reported that as moisture decreases, the uptake of phosphorus also decreases, because the diffusion path becomes more tortuous (Olsen *et al.*, 1961).

Plant age and varietal differences within species also influence phosphorus uptake. Young plants absorb phosphorus rapidly and when conditions are favourable up to 50% of the required for phosphorus is absorbed by the time plants accumulate 25% of their total dry matter (Tisdale *et al.*, 1990). However, the absorption of phosphorus continues throughout the entire growth cycle (Sauchelli, 1965; Young *et al.*, 1985; Tisdale *et al.*, 1990). The average uptake of phosphorus by field crops ranges from 5 to 51 kg/ha of P_2O_5/ha/crop (Sauchelli, 1965).

2.6 Solar radiation (PAR) interception and leaf area index (LAI) in relation to plant growth

The rate of dry matter production is largely dependent on incoming solar radiation and is proportional to the amount intercepted and the efficiency with which it is converted to dry matter (Monteith, 1977; Squire, 1990). Intercepted radiation is the difference between solar radiation received at the surface of the canopy, and that transmitted at the soil (Squire, 1990). The interception of solar radiation by a canopy depends on both leaf area index (LAI) and canopy architecture, which in turn is determined by leaf size, shape, orientation and spatial arrangement (Yoshinda, 1972; Campbell and van Evert, 1994).

Green leaf area index is used as an indicator of plant photosynthetic potential (Watson, 1947). Crop growth rate (CGR) has been expressed as a product of LAI and the efficiency of dry matter production per unit leaf area (Squire, 1990). There is a curvilinear relationship between LAI and dry matter production in many crops (Anguilar *et al.*, 1977). Leaves preferentially absorb visible light (0.4 – 0.7μm), also called photosynthetically active radiation (PAR). Most crops absorb 80 to 90% of incident PAR (Monteith, 1969; Campbell and van Evert, 1994). Radiation that is not intercepted is transmitted through the canopy, and reaches the soil surface and provides some of the energy for evaporation.For most canopies in moist conditions, fractional PAR interception (f) may be related to LAI (L) by the expression (Squire, 1990)

$$f = 1 - \exp(-kL) \qquad (2.1)$$

Rearranging equation 1 above, expresses k as follows,

$$k = \ln(1-f) / L \qquad (2.2)$$

Where, k is an extinction coefficient (k is a dimensionless parameter and represents the fraction of incident PAR intercepted by unit leaf area). Therefore, as the fraction of the solar radiation intercepted by a given leaf area increases, k also increases.

The extinction coefficient (k) ranges from 0.3 to 1.3 for the majority of leaf canopies, and where the leaf inclination (angle formed between the long axis of the leaf and the horizontal) are nearly vertical e.g. in many grasses light penetrates to the lower leaves readily and so k is often low, about 0.4 (Nobel et al., 1993). Canopy architecture refers to the amount and organisation of above-ground plant material, including the size, shape and orientation of plant organs such as leaves, stems, flowers and fruits (Norman and

Campbell. 1989). Canopies with most leaves in the horizontal plane are termed planophile whereas canopies in which the leaves are close to the vertical are termed erectophile (Squire, 1990); k values are lower for erectophile canopies and higher for planophile canopies (Monteith. 1969). Therefore, k can be used to determine canopy architecture and hence estimate dry matter production through solar radiation utilization for photosynthesis.

Effect of canopy structure on yield was demonstrated in the rice cultivar I.R. 8, (so called 'miracle rice') in which higher rates of crop photosynthesis were achieved by selection of varieties with canopy architecture that allowed more light to reach lower leaves (Nobel *et al.*, 1993). Indeed modification of canopy architecture can substantially improve crop yield by its influence on light interception by plants (Beadle *et al.*, 1971).

The efficiency with which crops can utilize available solar energy for the production of either dry matter or specific economic products can be affected by low or high temperature, water stress and availability of soil nutrients (Eagles, 1984). Optimal incident PAR utilization for photosynthesis generally occurs when the incident solar radiation is distributed as uniformly as possible over the exposed leaves (Nobel *et al.*, 1993).

Even in the simplest of canopies, an analysis covering all factors that affect PAR interception (leaf orientation or azimuth, sun elevation in the sky, finite width of the sun's disc, changes in spectral distribution of the fraction of PAR intercepted and the arrangement of leaves in the canopy) is usually too complex to be of any practical use (Nobel, 1991). Therefore, it can be assumed that the decrease of PAR down the canopy is analogous to absorption of light by chlorophyll or other pigments in a solution. which is described by Beer's law (Squire, 1990).

To the best of our knowledge, information on vernonia response to applied fertilizer is lacking. Therefore, this research investigated nitrogen and phosphorus requirements of two vernonia varieties, namely *Vernonia galamensis* subspp. *galamensis* var. ethiopica and *Vernonia galamensis* subspp. *gibbosa*.

2.7 Objectives of the study

This research aimed at determining the effects of fertilizer nitrogen and phosphorus on growth and yield of vernonia. The specific objectives were to determine:

(i) The effect of different N and P fertilizer application rates on growth and yield of vernonia.

(ii) The varietal response of vernonia to different N and P fertilizer application rates.

2.8 Hypothesis

1. N and P are expected to increase vernonia growth rate through increased LAI and higher radiation interception.
2. The most efficient variety in N and P uptake and utilization would be the most responsive to N and P application.

Two experiments to test the above hypothesis were designed as described in chapter 3.

CHAPTER 3

3.0 MATERIALS AND METHODS

3.1 Experimental site

Two field experiments were carried out at the University of Nairobi, Kabete field station; (latitude 1°15'S and 36°44'E; 1942 m above the sea level). The mean maximum and minimum temperatures is 23°C and 13°C respectively. The area experiences a bimodal rainfall pattern with annual mean rainfall of 950 mm. The first or long rains occur between March and May, averaging 494 mm and constitutes 52% of the annual average rainfall. The second or short rains, which fall from mid-October to December, averaging 269 mm and comprises 28% of the annual average. The long rains are more reliable for crop production than the short rains.

3.2 Soil

The FAO/UNESCO classification describes Kabete soil as Humic Nitosol, the clay mineral is predominantly kaolin and the parent material is the Kabete Trachyte (Nyandat and Michieka, 1970). The pH (in water) ranges between 5.2 and 7.2 in the topsoil and between 5.2 and 7.7 in the subsoil (Irvine, 1980; Mbugua, 1983; Mburu, 1996).

3.3 Crop establishment and husbandry

Vernonia seeds were obtained from the University of Nairobi, Kibwezi farm, i.e. *Vernonia galamensis* subspp. *galamensis* var. ethiopica and *Vernonia galamensis* subspp. *gibbosa* subsequently referred to as ethiopica and gibbosa respectively. Ethiopica is known to mature fairly fast under hot and dry conditions such as found in Kibwezi but its growth characteristics under cool conditions as in Kabete are not well understood to the best of our knowledge. However, gibbosa being a forest margin subspecies was presumed to be favoured by such cooler condition.

The first experimental field was prepared manually due to soil wetness that hampered tractor operations. The second experimental field was ploughed and harrowed using a tractor. Both fields were finally made to a fine tilth using hand labour. A granular form of triple superphosphate (46% P_2O_5) was broadcast in the furrow and covered with a thin layer of soil prior to seed placement. All the phosphate rates were applied at planting. Five seeds were placed in the furrow above the phosphate fertilizer which had been covered with about 2 to 3 cm of soil and later thinned to one. Calcium ammonium nitrate (CAN, 26%N) was applied at seedling (25 days after planting - DAP) and vegetative (50 DAP) phenological stages. Thinning was done when the crops were about 10 cm high leaving one plant per hill. The field was maintained weed free throughout the two experiments with a total of four hand weeding operations for each experiment. No pest or disease control measures were employed in both experiments because no major pest and diseases were observed. Final harvest (seed and final dry mass) was done at 139 DAP in both experiment.

The first experiment was planted on 23rd January 1998 and harvested on 14th June 1998 while the second experiment crop was sown 24th March 1998 and harvested on 10th August 1998.

3.4 Experimental design

The experiment was 2 x 3 x 3 factorial laid out in a complete block design and replicated three times. The treatments were, two Vernonia varieties, (V_1=*Vernonia galamensis* subspp. *gibbosa;* V_2=*Vernonia galamensis* subspp. *galamensis* var. ethiopica); Three levels of nitrogen, (N_1=0 kg N/ha, N_2=75 kg N/ha and N_3=150 kg N/ha) and three levels of phosphorus (P_1=0 kg P_2O_5/ha, P_2=45 kg P_2O_5/ha and P_3=90 kg P_2O_5/ha) were applied. Individual plots measured 5 m x 3 m, and crops spaced 0.5 m between rows and 0.4 m within the rows.

3.5 Data collection

3.5.1 Plant height, number of branches and leaves per plant

In both experiments, weekly data collection on growth (number of leaves/plant, number of branches/plant, number of capsules/plant and crop height) from 5 randomly selected plants commenced at 33 DAP. Crop height was obtained by measuring individual plants using a meter rule while the number of leaves and branches was obtained by counting.

3.5.2 Dry matter mass

Above ground dry mass accumulation (stems and leaves) at key phenological stages namely, seedling stage (48 DAP), vegetative stage (69 DAP), flowering stage (95 DAP), seed - ripe stage (118 DAP) and physiological maturity (139 DAP) was determined in both experiments. Three plants randomly selected from each plot were cut at ground level, put into paper bags and taken to the laboratory. Plant parts were stripped off and separated into stems and leaves. The separated plant parts were then put in an oven (model number TV80 UL 508032, Memmert, Germany) and dried at 80°C for 72 hours to constant mass.

3.5.3 Leaf area determination

Leaf area was determined at each harvest, from measurements of specific leaf area

(SLA, leaf area to dry mass ratio) multiplied by the total green leaf mass from a given land area (Nobel *et al.*, 1993). Leaf area was determined from ten fully expanded leaves selected from a sample of three vernonia plants in each plot. A cork borer, 1 cm diameter was used to excise 120 discs from the leaves. The discs were then put into 16 cm x 16.4 m envelopes, and dried in an oven at 80°C for 72 hours. Leaf area was determined at seedling stage (48 DAP), vegetative stage (69 DAP), flowering stage (95 DAP) and seed-ripe stage (118 DAP) in the two experiments. Dry mass of the dried discs was taken and LAI calculated using the following formula (Mburu, 1996),

$$LA_{total} = LWtotal * \frac{LA_{discs}}{LWt_{discs}} \qquad (3.1)$$

Where,

LA_{total} = total leaf area (m^2)

LA_{discs} = leaf disc area (m^2)

LWt_{total} = total plant leaf mass (g)

LWt_{discs} = leaf discs mass (g).

3.5.4 Solar radiation interception measurement

Attenuation of photosynthetically active radiation (PAR), through the crop canopy was measured between 11.30 and 13.30 hr (local time) using a sunfleck ceptometer (SF - 80 Decagon, Pulman, Washington). Five measurements in each plot were taken by holding the ceptometer perpendicular to the rows. Incident PAR reading was taken above the canopy and below the canopy, at the lowest level of green leaves.

3.5.5 Number of capsules, 1000 seed mass and seed yield

At harvest ten randomly selected plants were cut at the base and separated into various parts. The number of capsules were counted and then threshed in sacks (vernonia seeds are tiny and light hence can easily be blown by wind). After careful winnowing the seeds from each treatment were weighed using a weighing balance (Denver instrument, XL – 1810). The 1000 seed mass from each plot was determined by counting and then weighing.

Data was analysed using SYSTAT (Wilkinson, *et al.*, 1992) and the results are presented in chapter four.

CHAPTER 4

4.0 RESULTS

4.1 Effect of nitrogen and phosphorus on crop height, number of branches and number of leaves per plant

4.1.1 Height

Crop height increased with time in all treatments (Figure 1) in the two experiments. Gibbosa was consistently (p=0.001) taller than ethiopica at all the stages of growth and treatment levels (Appendix 1). Ethiopica grew to a maximum of about 1 m while gibbosa reached a maximum of about 1.5 m in both experiments (Figure 1). The differences in height of the two varieties was conspicuous during early growth stages (Figure 1); gibbosa was taller than ethiopica throughout the growing season. Nitrogen and phosphorus application rates did not influence crop height significantly in both experiments (Appendix 1).

4.1.2 Number of branches per plant

Branches emerged by 47 DAP, and each was subtended by a leaf. Only primary branches were counted. Nitrogen and phosphorus fertilizer application did not influence the number of branches/plant produced by either variety significantly, in the two experiments (Appendix 1). Both varieties produced almost equal number (about 28) of primary branches/plant (data not shown), however gibbosa produced larger and longer branches compared with ethiopica.

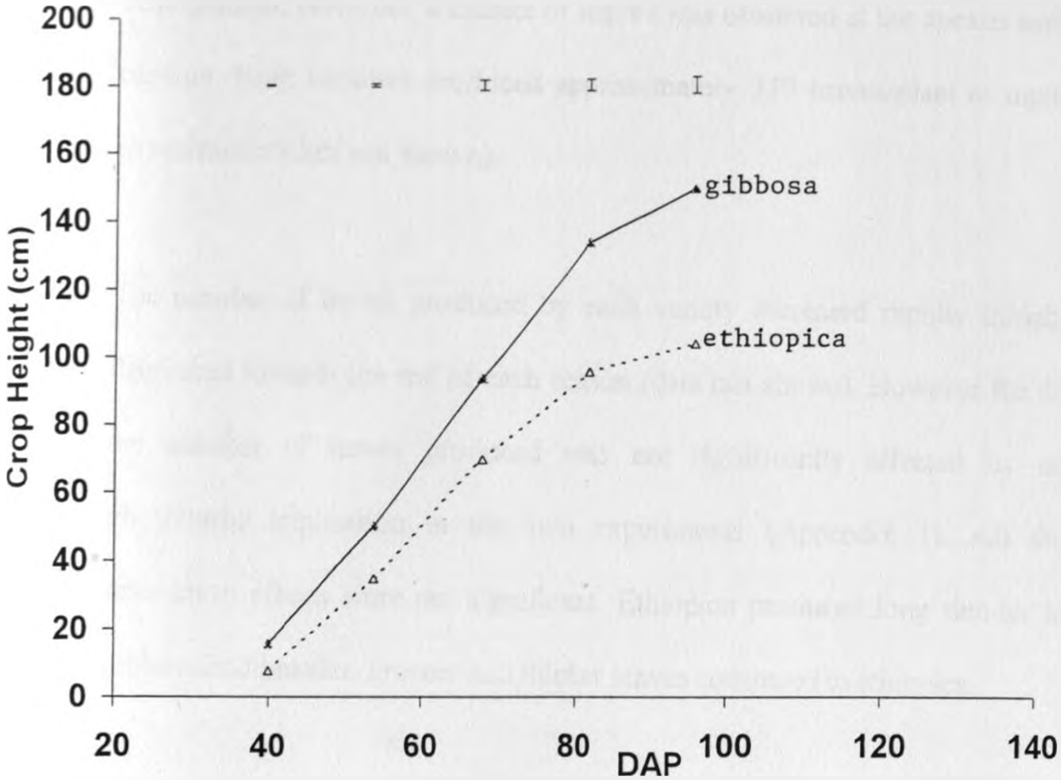


Figure 1:The height (cm) of two vernonia varieties (V1=gibbosa and V2=ethiopica) treated with different nitrogen and phosphorus fertilizer rates at Kabete (data for nitrogen and posphorus is pooled for the two experiments). The bars represent LSD values (p=0.05)

4.1.3 Number of leaves per plant

Leaves were borne directly from the main axis or from the branches in an alternate arrangement. However, a cluster of leaves was observed at the apexes surrounding the capsule. Both varieties produced approximately 350 leaves/plant at maturity in both experiments (data not shown).

The number of leaves produced by each variety increased rapidly initially, and then decreased towards the end of each season (data not shown). However the differences in the number of leaves produced was not significantly affected by nitrogen and phosphorus application in the two experiments (Appendix 1). All the treatment interaction effects were not significant. Ethiopica produced long slender leaves while gibbosa had broader, greener and thicker leaves compared to ethiopica.

4.2 Effect of nitrogen and phosphorus on dry matter accumulation

4.2.1 Dry leaf mass

Leaf dry mass increased with time up to 118 DAP in all the treatments, then decreased in both experiments (Figure 2). Initial increase was similar up to 69 DAP in both experiments (Figure 2). At 95 DAP treatment effects on leaf dry mass started to emerge. Gibbosa consistently had higher leaf dry mass than ethiopica at all N and P levels in both experiments (Figure 2). The rate of leaf dry mass increase in gibbosa between 69 and 95 DAP was higher than that of ethiopica but increase rates of the two varieties were similar between 95 and 118 DAP. All the rates of N applied significantly (p=0.05) increased leaf dry mass of both varieties during the two experiments (Appendix 2)

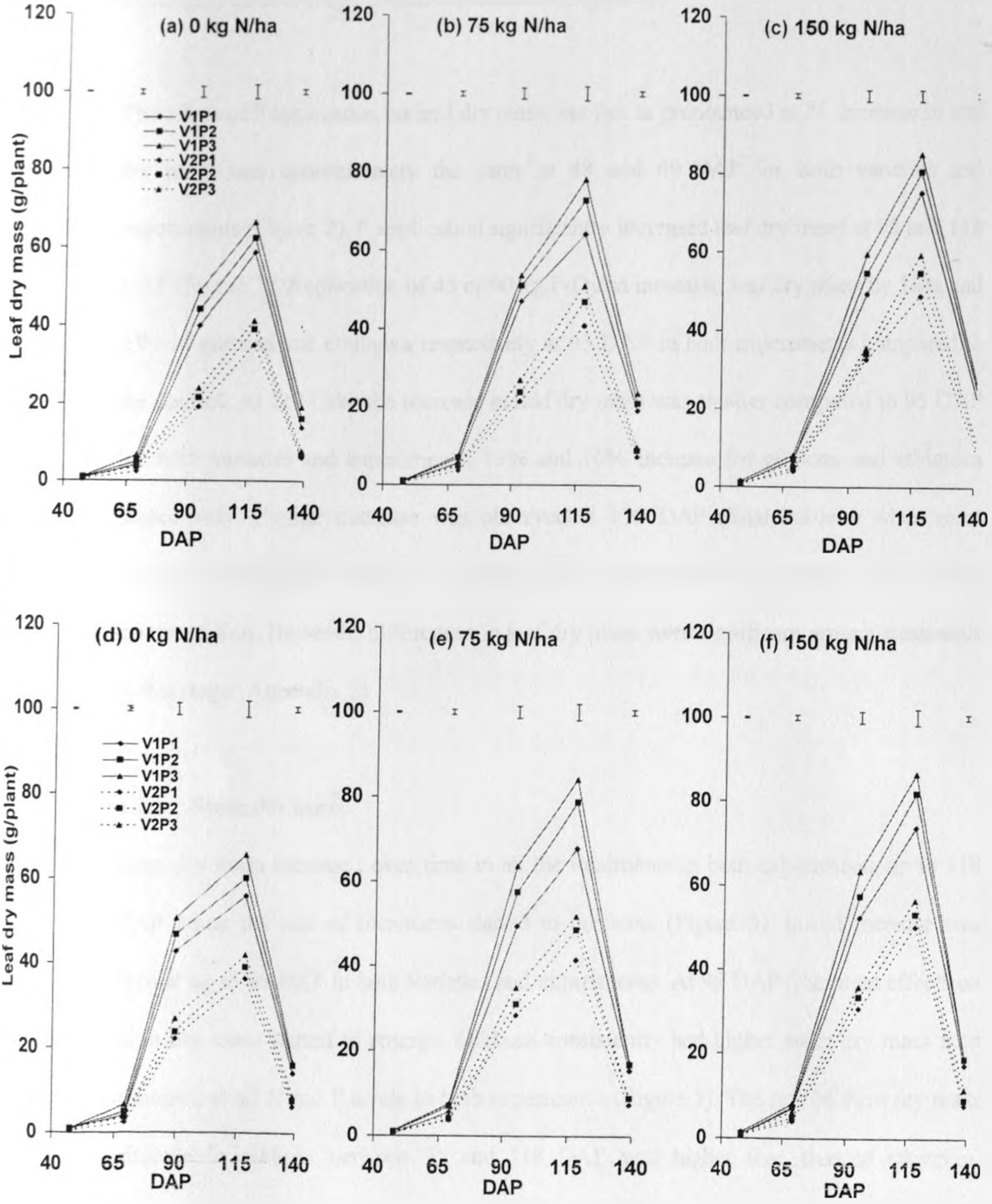


Figure 2: Effect of nitrogen and phosphorus (P_1=0, P_2=45 and P_3=90 kg P_2O_5/ha) on the green leaf dry mass of two vernonia varieties (V_1=gibbosa and V_2=ethiopica) grown in Kabete; graph (a-c) represent experiment 1 and (d-f) represent experiment 2. The bars represent LSD values (p=0.05).

(Figure 2). The maximum leaf dry matter mass was lowest in all the control treatments in both varieties and experiments (Figure 2).

The effect of P application on leaf dry mass was not as pronounced as N. Increase in leaf dry mass was approximately the same at 48 and 69 DAP for both varieties and experiments (Figure 2). P application significantly increased leaf dry mass at 95 and 118 DAP (Figure 2). Application of 45 or 90 kg P_2O_5/ha increased leaf dry mass by 18% and 23% in gibbosa and ethiopica respectively at 95 DAP in both experiments compared to the control. At 118 DAP the increase in leaf dry mass was smaller compared to 95 DAP for both varieties and experiments; 13% and 16% increase for gibbosa and ethiopica respectively. Further decrease was observed at 139 DAP (final harvest) when most leaves had dropped and only the remaining few plus litter was collected for dry matter determination. However, differences in leaf dry mass were significant among treatments at this stage (Appendix 2).

4.2.2 Stem dry mass

Stem dry mass increased over time in all the treatments in both experiments up to 118 DAP when the rate of increment started to decrease (Figure 3). Initial increase was similar up to 69 DAP in both varieties and experiments. At 95 DAP treatment effects on stem dry mass started to emerge. Gibbosa consistently had higher stem dry mass than ethiopica at all N and P levels in both experiments (Figure 3). The rate of stem dry mass increase in gibbosa between 95 and 118 DAP was higher than that of ethiopica, however, increase rate of the two varieties was almost similar between 118 and 139 DAP.

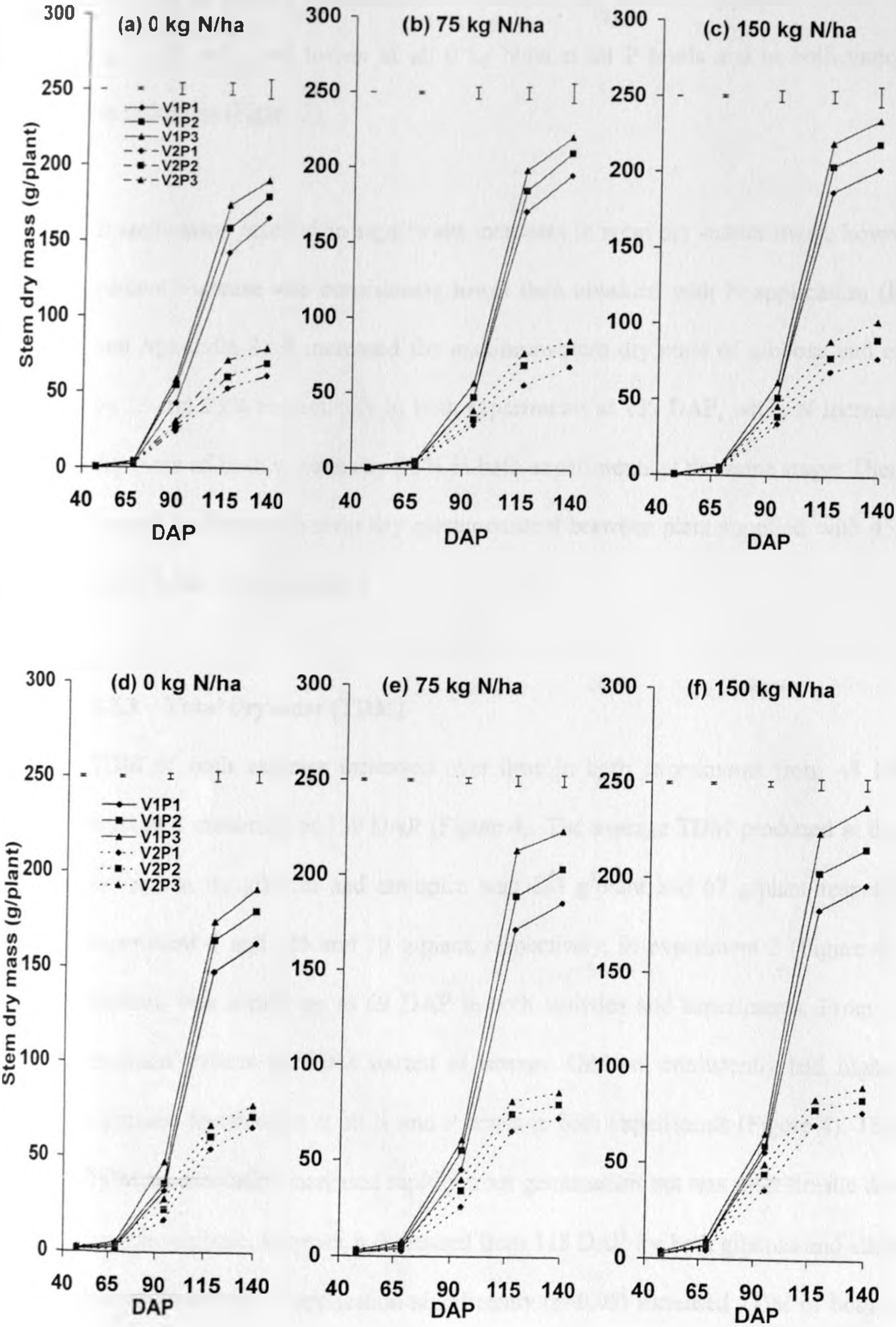


Figure 3: Effect of nitrogen and phosphorus (P_1=0, P_2=45 and P_3=90 kg P_2O_5/ha) on the stem dry mass of two vernonia varieties (V_1=gibbosa and V_2=ethiopica) grown in Kabete; (a-c) represent experiment 1 and (d-f) represent experiment 2. The bars represent LSD values (p=0.05).

All the levels of N applied increased stem dry matter significantly (p=0.05) in both varieties in the two experiments compared to the control (Appendix 3). At 139 DAP stem dry mass was lowest at all 0 kg N/ha at all P levels and in both varieties and experiments (Figure 3).

P application resulted in significant increases in stem dry matter mass, however, the percent increase was consistently lower than obtained with N application (Figure 3 and Appendix 3). P increased the maximum stem dry mass of gibbosa and ethiopica by 23 and 25% respectively in both experiments at 139 DAP, while N increased stem dry mass of both varieties by 33% in both experiments at the same stage. There was a marked difference in stem dry matter content between plant supplied with 45 and 90 kg P_2O_5/ha in experiment 2.

4.2.3 Total dry mass (TDM)

TDM of both varieties increased over time in both experiments from 48 DAP and reached a maximum at 139 DAP (Figure 4). The average TDM produced at the end of the season by gibbosa and ethiopica was 183 g/plant and 67 g/plant respectively in experiment 1 and 185 and 70 g/plant, respectively, in experiment 2 (Figure 4). Initial increase was similar up to 69 DAP in both varieties and experiments. From 95 DAP treatment effects on TDM started to emerge. Gibbosa consistently had higher TDM compared to ethiopica at all N and P levels in both experiments (Figure 4). The rate of TDM accumulation increased rapidly from germination but was most drastic during the vegetative phase, however it decreased from 118 DAP for both gibbosa and ethiopica in both experiments. N application significantly (p=0.05) increased TDM of both varieties during the two experiments compared to the control (Appendix 4). The maximum TDM

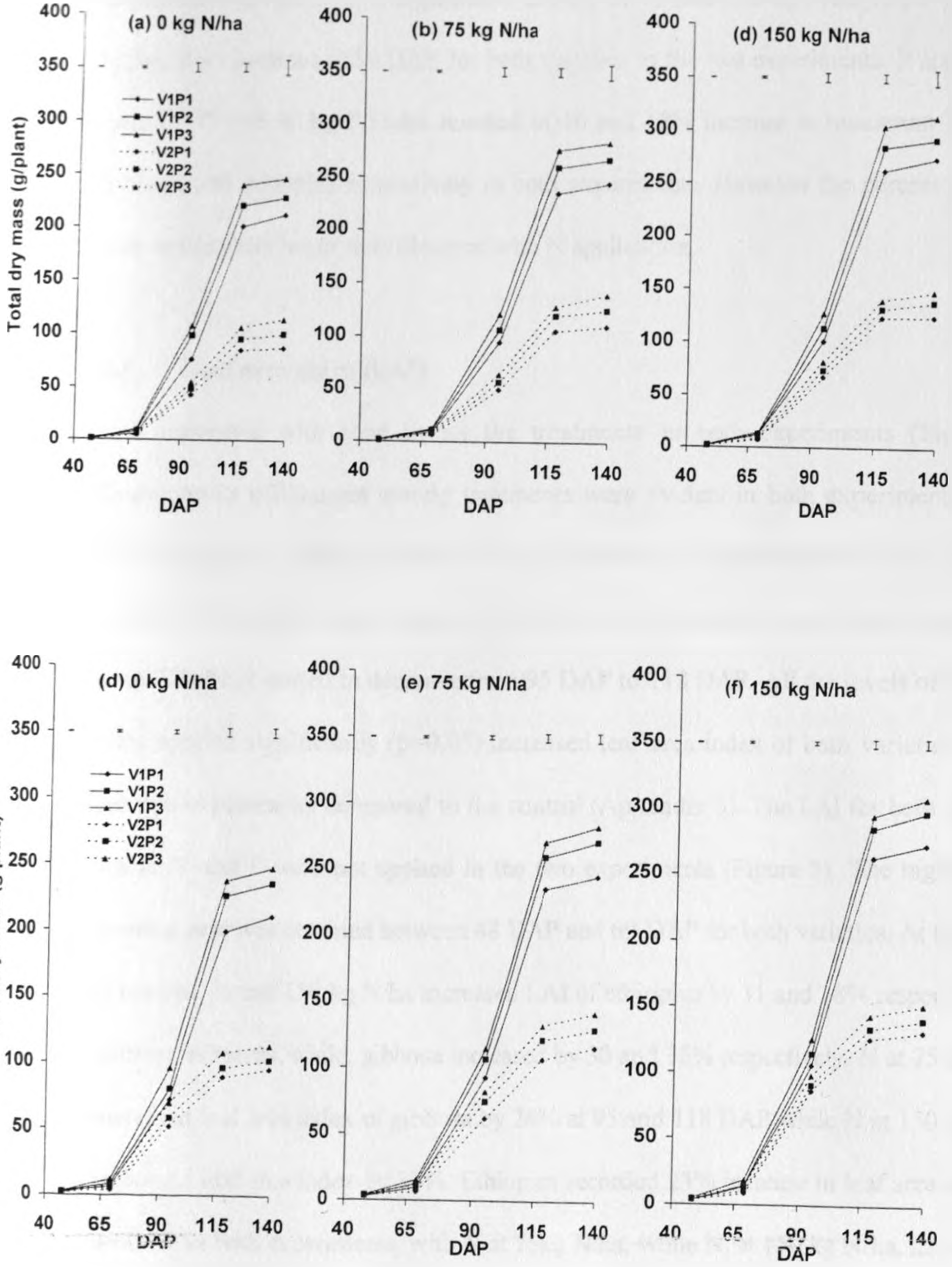


Figure 4: Effect of nitrogen and phosphorus ($P_1 = 0$, $P_2 = 45$, and $P_3 = 90$ kg P_2O_5/ha) on total dry mass of two vernonia varieties grown (V_1=gibbosa and V_2=ethiopica) in Kabete; (a-c) represent experiment 1and (d-f) represent experiment 2. The bars represent LSD values (p=0.05).

(139 DAP) was lowest at all 0 kg N/ha at all P levels and in both varieties and experiments (Figure. 4). N application at rates of 75 and 150 kg N/ha TDM was 34% higher than control at 139 DAP for both varieties in the two experiments. P application rates of 45 and 90 kg P_2O_5/ha resulted in 16 and 18% increase in maximum TDM of gibbosa and ethiopica respectively in both experiments. However the percent increase was consistently lower than obtained with N application.

4.3 Leaf area index (LAI)

LAI increased with time in all the treatments in both experiments (Figure 5). Conspicuous differences among treatments were evident in both experiments by 69 DAP (Figure 5). Gibbosa had consistently higher LAI than ethiopica at all N and P rates in both experiments (Figure 5). The rate of LAI increase was highest between 48 to 69 DAP but started to decrease from 95 DAP to 118 DAP. All the levels of N and P rates applied significantly (p=0.05) increased leaf area index of both varieties during the two experiments compared to the control (Appendix 5). The LAI for both varieties where N and P were not applied in the two experiments (Figure 5). The highest LAI increase rate was obtained between 48 DAP and 69 DAP for both varieties. At this stage N rates of 75 and 150 kg N/ha increased LAI of ethiopica by 31 and 38% respectively in both experiments, while, gibbosa increased by 30 and 35% respectively. N at 75 kg N/ha increased leaf area index of gibbosa by 28% at 95 and 118 DAP while N at 150 kg N/ha increased leaf area index by 31%. Ethiopica recorded 23% increase in leaf area index at 95 DAP in both experiments, with N at 75kg N/ha, while N, at 150 kg N/ha, increase by 23% and 22% was recorded in experiment 1 and 2 respectively. Ethiopica had 27% and 30% higher leaf area index compared to the control at 118 DAP in both experiments.

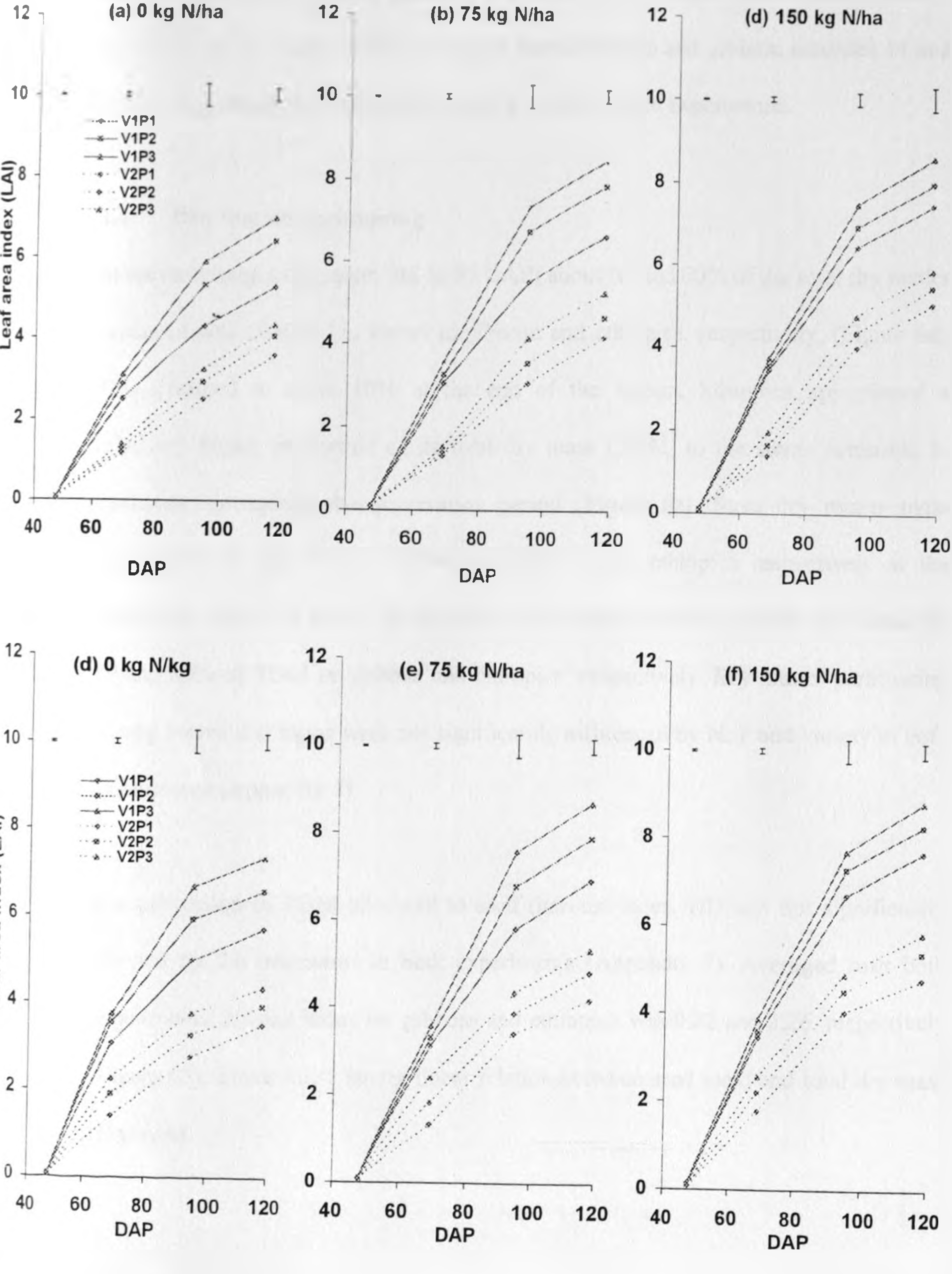


Figure 5: Effect of nitrogen and phosphorus (P_1=0, P_2=45 and P_3=90 kg P_2O_5/ha) on the leaf area index (LAI) of two vernonia varieties (V_1=gibbosa and V_2=ethiopica) grown in Kabete; (a-c) represent experiment 1 and (d-f) represent experiment 2. The bars represent LSD values (p=0.05)

Effects of P application rates on LAI were slightly lower compared to N effects. At 95 and 118 DAP both varieties recorded 8% higher LAI compared to the control with P at 45 P_2O_5 kg/ha, while at 90 P_2O_5 kg/ha both ethiopica and gibbosa recorded 14 and 13% LAI increase throughout the growing period in both experiments.

4.4 Dry matter partitioning

In the early stages of growth (48 to 95 DAP) about 64 and 60% of the total dry matter produced was allocated to leaves in gibbosa and ethiopica, respectively, (Figure 6a). This declined to about 10% at the end of the season. Ethiopica apportioned a relatively higher proportion of its total dry mass (TDM) to the stems compared to ethiopica, throughout the observation period (Figure 6a). Stem dry matter mass constituted 39 and 41% of TDM for gibbosa and ethiopica respectively at the vegetative phase (48 DAP). At the end of the season, stem dry matter accounted for 79 and 80% of TDM in gibbosa and ethiopica, respectively. Dry matter partitioning among leaves and stems were not significantly influenced by N, P and variety in both experiments (Appendix 7).

The proportion of TDM allocated to seed (harvest index, HI) was not significantly affected by the treatments in both experiments (Appendix 7). Averaged over both experiments, harvest index for gibbosa and ethiopica was 0.22 and 0.26, respectively (Figure 6b). There was a strong linear relation between seed yield and total dry mass (Figure 6).

4.5 Canopy photosynthetically active radiation (PAR) interception.

The proportion of incident PAR intercepted increased over time from 50 DAP to 118 DAP (Figure 7). Gibbosa consistently intercepted more PAR compared to ethiopica at all stages of growth (Figure 7). N and P application significantly increased PAR interception by both varieties at all stages of growth (Appendix 8). Plants supplied with 75 and 150 kg N/ha recorded 25 and 30% higher PAR interception, respectively, than the control. P application resulted in 20% higher PAR intercepted at 45 and 90 kg P_2O_5 kg/ha, respectively, at 118 DAP.

On the assumption of the applicability of Beer's law, the logarithm of the fraction of PAR transmitted through the canopy was plotted against LAI for the two vernonia varieties (Figure 8). The slope of this relationship is the light extinction coefficient (k) a measure of canopy architecture that is independent of LAI (Squire, 1990). The average extinction coefficient for gibbosa was (0.122) and that of ethiopica was (0.096) (Figure 8) but overall treatments had no significant influence on extinction coefficient. There was a high correlation between total dry matter and percentage intercepted PAR (Figure 9a), and leaf area index and total dry matter (Figure 9b) for both varieties. Slow build up of fractional intercepted PAR was observed in both varieties especially at LAI of 4 and 8 (Figure 10).

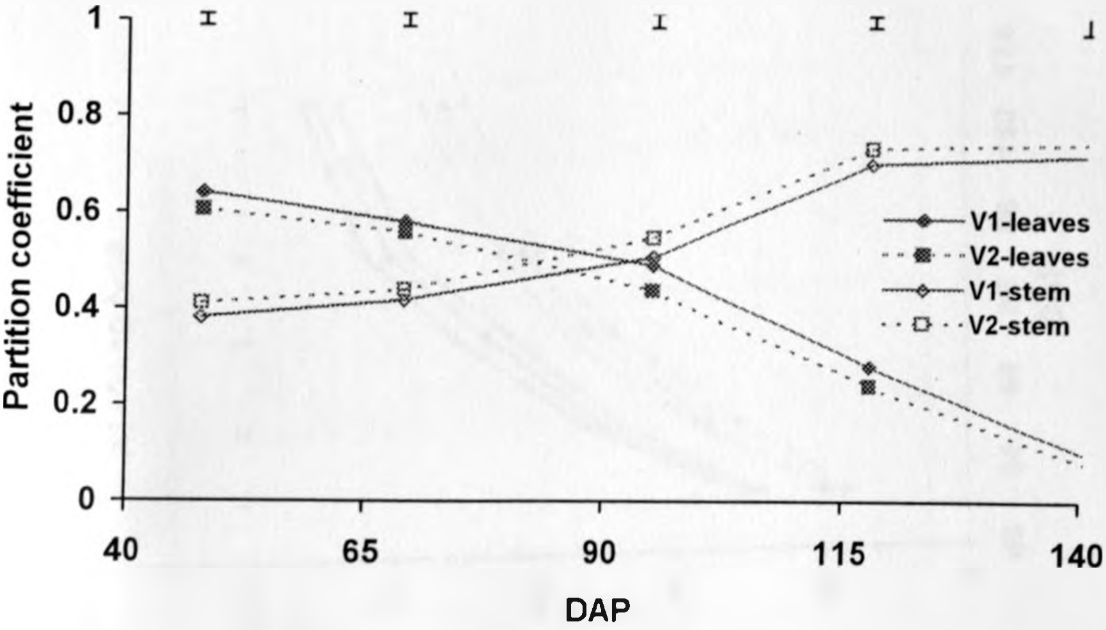
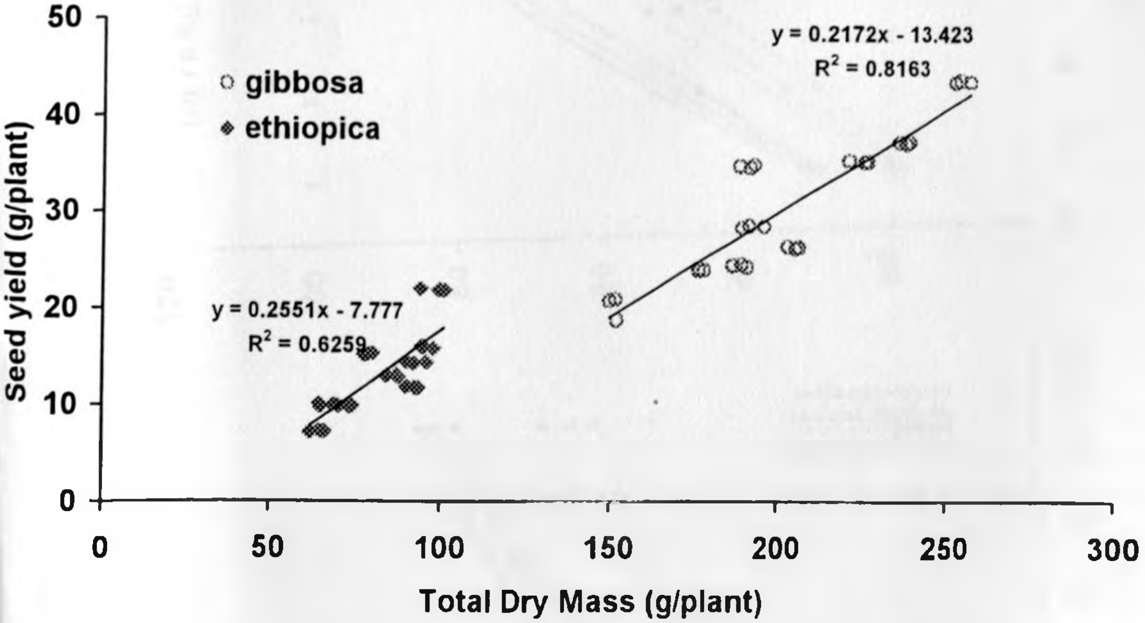


Figure 6a: Dry matter partitioning over time among leaves and stems in two vernonia varieties (V_1 =gibbosa and V_2=ethiopica) grown in Kabete. Nitrogen and phosphorus data pooled for the two experiments. Bars represent LSD values (p=0.05).



igure 6b: The relationship between seed yield and total dry mass (TDM) of wo vernonia varieties (gibbosa and ethiopica) grown in Kabete.Nitrogen and phosphorus ata pooled for the two experiments.

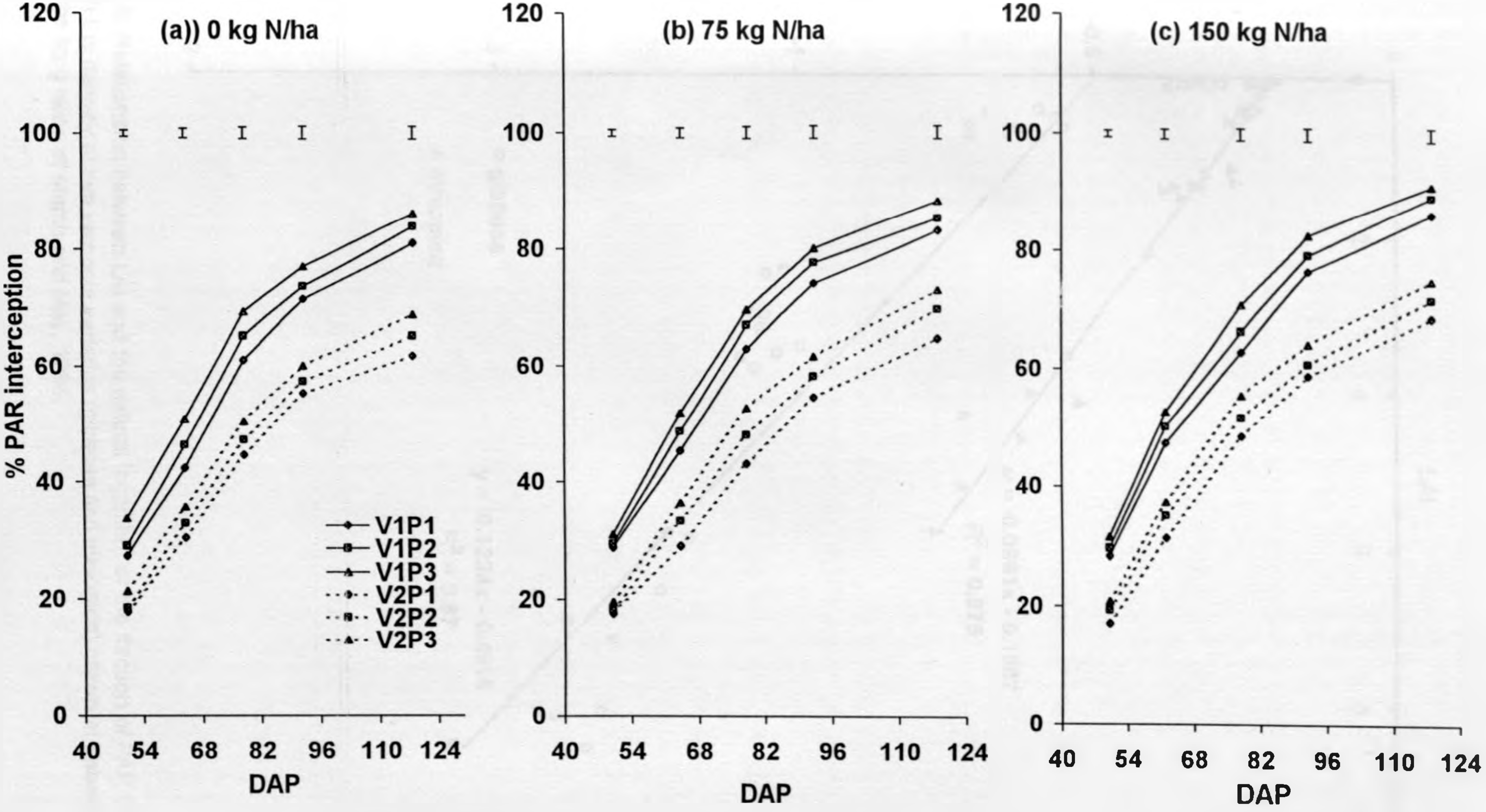


Figure7: Effect of nitrogen and phosphorus (P_1=0, P_2=45 and P_3=90 kg P_2O_5) on solar radiation (PAR) interception of two vernonia varieties (V_1=gibbosa and V_2=ethiopica) grown in Kabete during the long rains of March to May 1998. The bars represent LSD values (p=0.05).

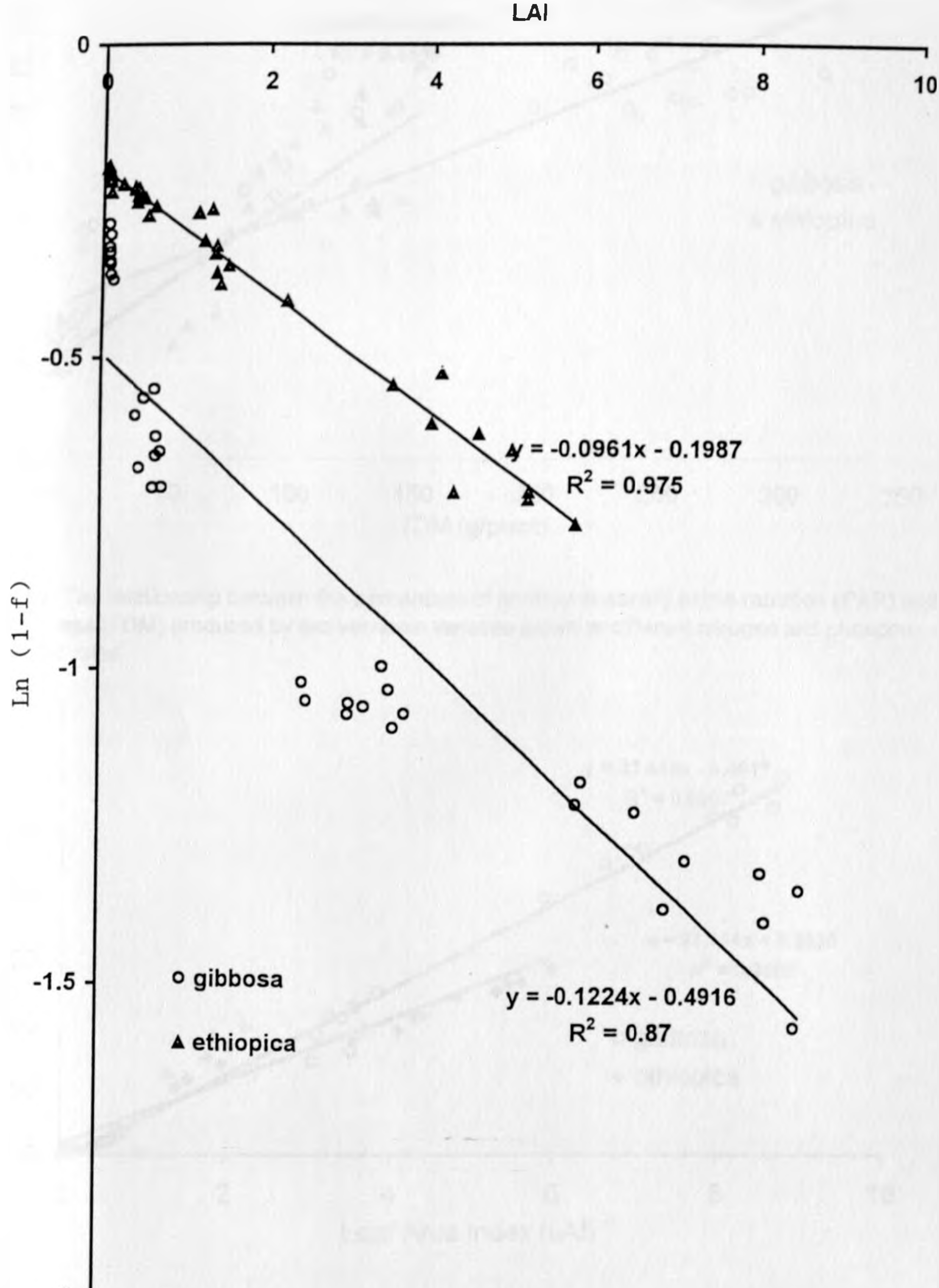


Figure 8: Relationship between LAI and the natural logarithm of the fraction of PAR transmitted through the canopy of two vernonia varieties (gibbosa and ethiopica) grown at Kabete, during the long rains of March and May, 1998.

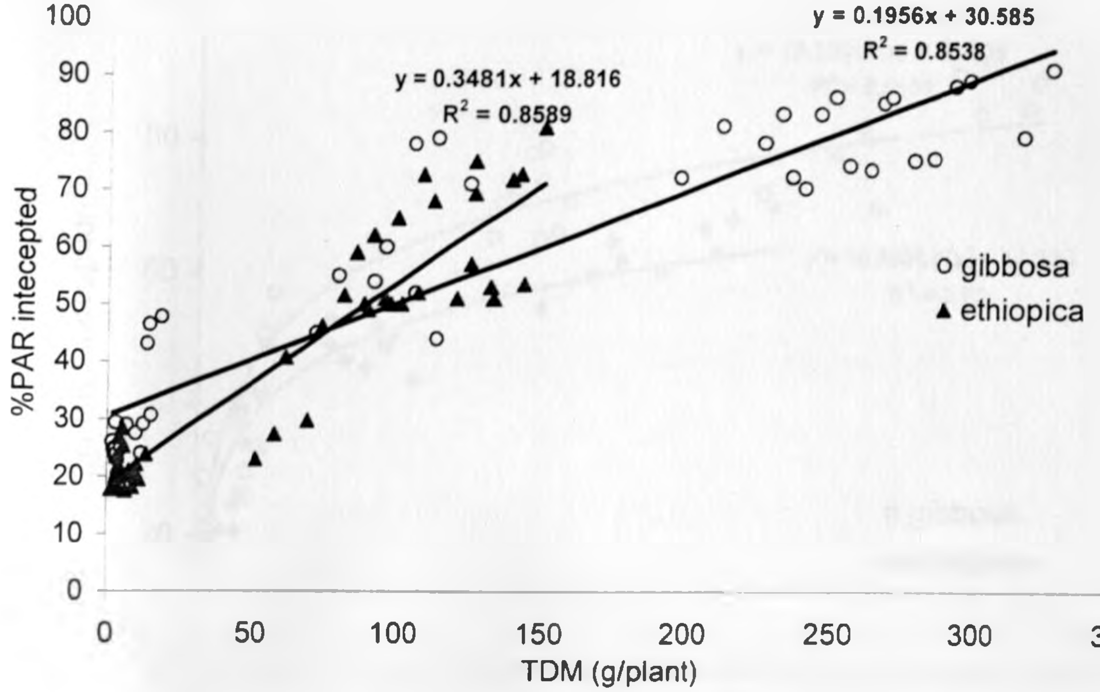


Figure 9a: The relationship between the percentage of photosynthetically active radiation (PAR) and total dry mass (TDM) produced by two vernonia varieties grown at different nitrogen and phosphorus fertilizer rates.

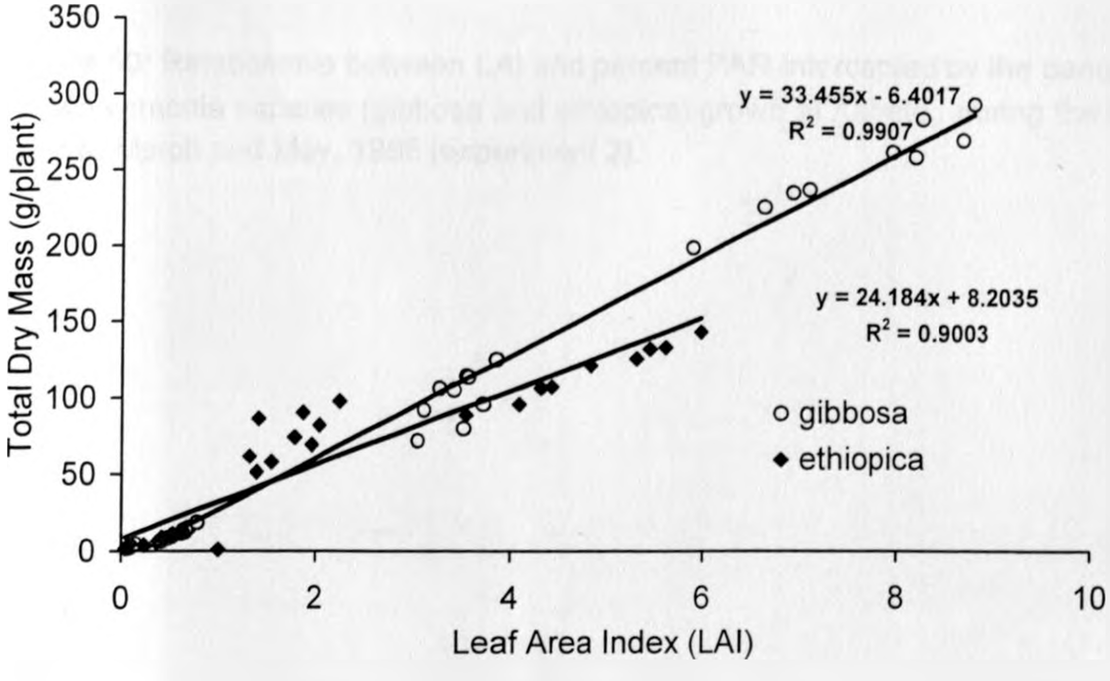


Figure 9b: The relationship between leaf area index (LAI) and total dry mass (TDM) produced by two vernonia varieties grown at different nitrogen and phosphorus fertilizer rates.

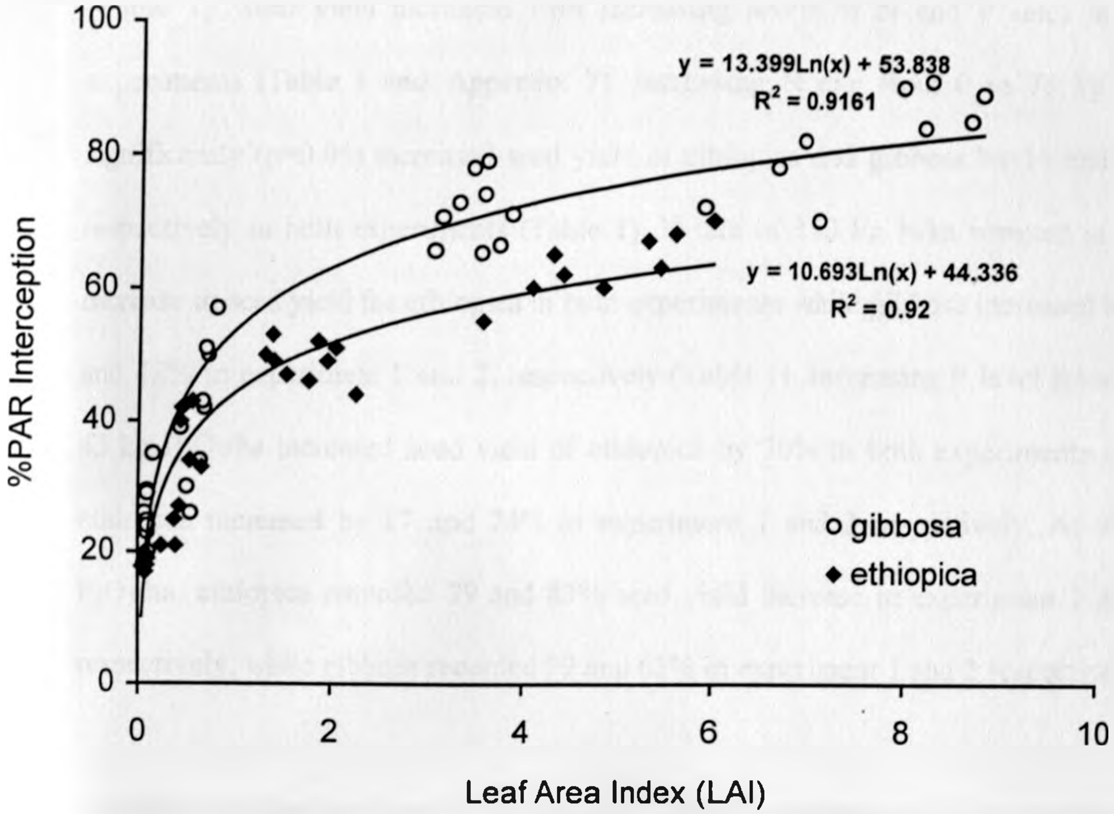


Figure 10: Relationship between LAI and percent PAR intercepted by the canopy of two vernonia varieties (gibbosa and ethiopica) grown at Kabete, during the long rains of March and May, 1998 (experiment 2).

4.6 Seed yield

Gibbosa had higher seed yield (2.3 times) in both experiments compared to ethiopica (Table 1). Seed yield increased with increasing levels of N and P rates in both experiments (Table 1 and Appendix 7). Increasing N rate from 0 to 75 kg N/ha significantly (p=0.05) increased seed yield of ethiopica and gibbosa by 15 and 20% respectively in both experiments (Table 1). N rate of 150 kg N/ha resulted in 36% increase in seed yield for ethiopica in both experiments while gibbosa increased by 44 and 48% in experiment 1 and 2, respectively (Table 1). Increasing P level from 0 to 45 kg P_2O_5/ha increased seed yield of ethiopica by 30% in both experiments while ethiopica increased by 17 and 24% in experiment 1 and 2 respectively. At 90 kg P_2O_5/ha, ethiopica recorded 79 and 83% seed yield increase in experiment 1 and 2 respectively, while gibbosa recorded 59 and 63% in experiment 1 and 2 respectively.

The capsules/plant produced by each variety in both experiments varied significantly (Appendix 7). Gibbosa produced approximately twice the number of capsules/plant (137) as ethiopica (74) in both seasons (p=0.001). Nitrogen and phosphorus fertilizer application had no significant influence on the number of capsules/plant. The 1000-seed mass of gibbosa was higher and about twice that of ethiopica (Table 2). Both nitrogen and phosphorus application significantly increased 1000 seed mass (Table 2 and Appendix 7). There was a general increase in 1000 seed mass with increase in rates of both fertilizers (Table 2). N at 75 kg N/ha increased 1000 seed mass of gibbosa by 34% and 37% in experiment 1 and 2 respectively, while ethiopica the increase was 26% and 15% in experiment 1 and 2 respectively compared to the control. N at 150 kg/ha increased 1000 seed mass of gibbosa by 59 and 68% in experiment 1 and 2 respectively, while that of ethiopica increased by 76 and 71% in experiment 1 and 2 respectively. P at 45 kg P_2O_5/ha increased 1000 seed mass of gibbosa by 10 and 15% in experiment 1 and 2, respectively, while ethiopica increased by 15% in both experiments compared to the control. P at 90 kg P_2O_5/ha increased 1000 seed mass of gibbosa by 17 and 28% respectively in experiment 1 and 2 respectively while ethiopica increased by 20 and 29% in experiment 1 and 2 respectively.

Table 1. The effect of different rates of nitrogen and phosphorus fertilizer on seed yield (kg/ha) of two *Vernonia* varieties (gibbosa and ethiopica).

		Mean seed yield (kg/ha)							
		Gibbosa				Ethiopica			
Expt.		N levels (kg N/ha)				N levels (kgN/ha)			
	P_2O_5 (kg/ha)	0	75	150	Mean	0	75	150	Mean
	0	949	1093	1205	1082	330	458	524	437
1	45	1015	1241	1534	1263	459	586	662	569
	90	1512	1679	1982	1724	682	735	935	784
	Mean	1159	1338	1574	1357	490.333	593	707	597
	0	942	1142	1232	1105	341	462	553	452
2	45	1121	1331	1651	1368	467	607	672	582
	90	1625	1743	2041	1803	712	745	1025	827
	Mean	1229	1405	1641	1425	506	604	750	620

Season 1: $LSD_{Nitrogen}$ = 4.525
$LSD_{Phosphorus}$ = 4.525
$LSD_{Variety}$ = 3.694
%C.V = 4.8

Season 2: $LSD_{Nitrogen}$ = 9.75
$LSD_{Phosphorus}$ = 9.75
$LSD_{Variety}$ = 7.96
% C.V = 4.5

Table 2: Effect of different rates of nitrogen and phosphorus fertilizer on 1000 seed weight (g) of two Vernonia varieties (gibbosa and ethiopica).

Experiment		Mean 1000 seed weight (g)							
		Gibbosa				Ethiopica			
		N levels (kg N/ha)				N levels (kgN/ha)			
	P_2O_5 (kg/ha)	0	75	150	Mean	0	75	150	Mean
	0	1.97	2.07	2.3	2.11	1.03	1.2	1.37	1.2
1	45	2.63	2.7	2.97	2.77	1.43	1.63	1.93	1.66
	90	3.13	3.16	3.76	3.35	2	2.1	2.17	2.09
	Mean	2.58	2.64	3.01	2.74	1.49	1.64	1.82	1.65
	0	1.9	2.6	3.2	2.57	1.13	1.57	1.93	1.54
2	45	2.17	2.77	3.33	2.76	1.3	1.7	2.07	1.69
	90	2.43	3	3.86	3.1	1.46	1.9	2.12	1.83
	Mean	1.17	2.79	3.46	2.81	1.3	1.72	2.04	1.68

Experiment 1: $LSD_{Nitrogen}$ = 0.122
$LSD_{Phosphorus}$ =0.123
$LSD_{Variety}$ = 0.099
%C.V = 8.2

Experiment $LSD_{Nitrogen}$ = 0.079
$LSD_{Phosphorus}$ = 0.078
$LSD_{Variety}$ = 0.064
%C.V = 5.2

CHAPTER 5

DISCUSSION AND CONCLUSIONS

5.1 Discussion

The two varieties studied showed considerable differences in vigour; gibbosa, which had larger seeds had more vigorous growth compared to ethiopica. Similar results were obtained with soybeans where large seeded cultivars produced taller and heavier plants because of a large supply of nutrient reserve (Singh et al., 1972).

Gibbosa was consistently taller than ethiopica, with average maximum height of 150 cm at 118 DAP while ethiopica measured about 100 cm on average at the same stage (Figure 1). Plant height was not influenced by nitrogen and phosphorus application, indicating a wide genetic variation between the two varieties in height.

Leaf, stem and total dry matter mass of both gibbosa and ethiopica were significantly increased by nitrogen and phosphorus fertilizer application (Figures 2, 3 and 4). The highest total dry matter mass (310 and 148 g per plant for gibbosa and ethiopica, respectively) was obtained at the highest rates of nitrogen and phosphorus application (150 kg N/ha and 90 kg P_2O_5/ha respectively) for both varieties and experiments. The dry matter response to nitrogen and phosphorus application indicates low levels of the same in the soil. The soil total nitrogen concentration ranges from 0.22 to 0.32 percent (Kahuro, 1990; Gachene, 1995) while phosphorus ranges from 0.3 to 0.59 mg kg^{-1} (Gachene, 1995) thus deficient (Olsen and Dean, 1965). Nitrogen at 75 and 150 kg N/ha significantly increased dry mass of both varieties thus suggesting that appreciable increases in dry matter content can be obtained with relatively wide range of both nitrogen and phosphorus fertilizers rates, however, the higher rates of both fertilizers gave the best results. The varietal differences observed could be due to the highly varied genetic make up of the *Vernonia spp.* which is also reflected by adaptation to a wide range of climatic conditions (Thompson *et al.*, 1994). Gibbosa is adapted to cool climatic conditions and occurs along forest margins unlike ethiopica which is adapted to semi-arid conditions (Gilbert, 1986). The rather cool weather in of Kabete may have limited dry matter production in ethiopica but favoured gibbosa.

In this study, nitrogen at 75 and 150 kg N/ha increased maximum total dry matter mass of both varieties by 30 and 34% respectively in both experiments. The rate of increase in total dry matter mass slacked from 118 DAP for both varieties in the two experiments, this coincided with the end of the vegetative phase and marked the on set of seed filling phase. This lag in growth was probably due to limited leaf production and accelerated senescence consequently reducing the photosynthetic area and hence dry matter production. In the early stages of vegetative growth the relative contribution by leaves to the total dry matter mass was high compared to the stems (Figure 6a).

Significant differences in leaf area index between the two varieties were observed as early as 69 DAP (Figure 5), with gibbosa maintaining higher leaf area index than ethiopica at all stages of growth in both experiments. These results suggest that lack of both nitrogen and phosphorus limited development of leaf area index of vernonia. Nitrogen deficiency may have affected leaf area through reduced leaf expansion hence leaf size (Hay and Walker, 1989), because the number of leaves per plant were similar.

PAR interception by ethiopica during early stages of growth was much smaller than obtained with gibbosa (Figure 7), reflecting the low growth of leaf area index of ethiopica (Figure 5). Towards the end of the growing season the rate of increase in percent PAR intercepted declined due to leaf senescence. Increased nitrogen and phosphorus application rates significantly increased the fraction of PAR intercepted (Figure 7). The light extinction coefficient (k) of both gibbosa (0.12) and ethiopica (0.10) were similar (Figure 8). The k values obtained in this experiment suggest that both varieties have an erectrophilous canopy (Nobel et al., 1993). These results suggest high transmission of light lower in the canopy even at a high LAI hence uniform distribution of incident PAR within the canopy (Squire, 1990). This helped the plant to maintain a large LAI, which was contributed to the high dry matter mass especially in gibbosa. The additional leaf area increased the amount of solar energy intercepted during the growing period, hence increased dry matter.

Seed yield (g/area) can be expressed as a product of unit seed mass (g/1000 seed), number of seeds per capsule, number of capsules per plant and number of plants per area. Seed yield differences between the two vernonia varieties could directly be attributed to differences in unit seed mass (g/1000 seed) and probably to the number of seeds per capsule. Nitrogen significantly increased seed yield and 1000 seed-mass in both varieties (Table 1 and 2) probably due to improved assimilate supply from a larger leaf area during seed filling stage. Similar results have been observed in safflower (El-Nakhlaway, 1991) and beans (Mburu, 1996).

Seed yield is influenced by dry matter produced and the partitioning vegetative and reproductive parts (harvest index). Harvest index was not significantly influenced by nitrogen and phosphorus application in both experiments (Figure 6a and Appendix 6). Ethiopica had a higher harvest index (maximum of 0.26 and 0.23 in experiment 1 and 2, respectively) than gibbosa (maximum of 0.19 in both experiments). Compared to other crops like sorghum (0.34), rice (0.42), groundnut (0.47) (Beadle, 1988), and beans (0.4, Mburu, 1996), harvest index for both gibbosa and ethiopica was relatively low indicating room for genetic improvement.

The high correlation between leaf area index and total dry mass (Figure 9a) and percentage PAR intercepted (Figure 9b) indicates, that dry matter production was directly proportional to leaf area index and the subsequent fractional radiation intercepted. The closely fitting relationship between leaf area index and total dry mass ($R^2 > 0.9$) indicates that over 90% of total dry mass can be accounted for by leaf area index. The lower R^2 values between total dry mass and percent fractional PAR intercepted (Figure 9b) can be accounted for by high spatial percent fractional PAR variability in the field; nevertheless percent fractional PAR interception accounted for 85% of total dry matter production.

If the slope of Figure 9b is considered an indirect indicator of canopy photosynthetic efficiency, then gibbosa is more efficient than ethiopica. It is noteworthy that despite gibbosa developing a very large canopy (LAI > 8) the fractional radiation intercepted by leaf area index between 4 and 8 increased gradually (Figure 10). A probable optimal leaf area index to target in order to obtain reasonable yields would be about 6 in both vernonia varieties which would intercept about 80% of the incident PAR.

Nitrogen had large effects on vegetative growth primarily through increased leaf area index while phosphorus influenced grain yield and 1000-seed mass possibly through higher seed set (Table 1 and 2). Variety ethiopica had 10% higher response (1000 seed mass and seed yield) respectively compared to gibbosa (Table 1 and 2). This may be an indicator of different nitrogen and phosphorus use efficiencies. Tissue nitrogen and phosphorus analysis in the different plant organs of vernonia would be required to verify this hypothesis.

5.2 Conclusions

Nitrogen and phosphorus fertilizer application significantly increased dry mass of both varieties as a result of increased leaf area index, increased PAR interception and consequently seed yield.

(1) There were large differences in seed yield and dry matter mass in the two vernonia varieties. Since plant density was constant across all the treatments and HI was not apparently affected by nitrogen, phosphorus and variety significantly, then, differences in seed yield were probably attributable to differences in dry matter production per plant.

(2) A possible way of increasing dry matter production on unit land especially of ethiopica is increasing planting density.

(3) Differences in the fraction of PAR intercepted between treatments were brought about by leaf area index. Leaf area index was a major factor influencing radiation interception and the largest contributor to differences between treatments in interception hence growth. It can be deduced that f (fraction of PAR intercepted) was significantly increased as a result of increase in leaf area index and hence increased dry matter and seed yield.

5.3 Recommendation

1) There is need to investigate the possibility of increasing yield of vernonia through changes in planting densities.

2) There is need to determine response of vernonia to nitrogen and phosphorus using more levels of both fertilizers under different climatic conditions.

3) There is need to study the rooting patterns of vernonia so as to understand its nutrient uptake patterns.

4) Breeding for higher harvest index varieties is necessary if vernonia has to compete with established cash crops.

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APPENDICES

Appendix 1: Analysis of variance table showing mean sum of squares for the number of branches per plant, number of leaves per plant and maximum crop height at 96 DAP.

		mean sum of squares			
Experiment	Source of Variation	df	number of Branches/plant	number of Leaves/plant	Maximum crop Height
	Blocks	2	980.583	25.912	138.109
	N	2	635.167	21.423	204.973
	P	2	646.103	336.409	181.328
1	V	1	264.892	154.637	940.251***
	N x P	4	596.205	66.288	201.614
	N x V	2	404.812	11.546	66.83
	P x V	2	413.876	69.699	161.394
	N x P x V	4	699.063	60.452	94.417
	Experimental Error	34	621.026	183.366	84.168
	Sampling Error	216	668.597	83.483	36.338
	Total	269			
	Blocks	2	12.479	80.074	40.208
	N	2	14.804	6.013	184.602
	P	2	12.512	268.186	132.427
2	V	1	4.668	173.749	1208.963***
	N x P	4	7.29	11.063	24.195
	N x V	2	5.515	5.546	31.414
	P x V	2	3.723	37.233	86.222
	N x P x V	4	10.404	20.723	151.76
	Experimental Error	34	7.432	100.232	122.635
	Sampling Error	216	8.337	40.85	38.761
	Total	269			

Appendix 2: Analysis of variance table showing mean sum of squares for leaf dry matter weight.

			Mean Sum of Squares				
		DAP	48	69	95	118	139
Experiment	Source of Variation	df					
1	Blocks	2	0.018	0.120	0.239	1.013	17.637
	N	2	0.021	0.646	15.041*	18.908*	107.505*
	P	2	0.038	0.261	10.177*	20.211*	105.453*
	V	1	0.029	0.695	34.903***	51.330***	253.628***
	N x P	4	0.026	0.159	6.639	8.886	51.821
	N x V	2	0.021	0.348	2.071	10.584	12.941
	P x V	2	0.014	0.038	0.257	10.06	9.381
	N x P x V	4	0.030	0.900	3.039	11.042	6.951
	Error	34	0.023	0.526	2.846	4.720	21.538
	Total	53					
2	Blocks	2	0.029	0.127	0.344	0.941	10.092
	N	2	0.027	0.512	15.938*	26.706*	51.201*
	P	2	0.074	0.855	11.460*	21.683*	50.658*
	V	1	0.072	0.717	38.992***	49.232***	131.617***
	N x P	4	0.032	0.016	6.771	7.482	19.802
	N x V	2	0.010	0.034	7.695	10.641	20.419
	P x V	2	0.007	0.042	0.769	7.644	1.321
	N x P x V	4	0.050	0.855	2.735	12.922	3.051
	Error	34	0.048	0.526	2.843	5.338	11.431
	Total	53					

* - significant at p = 0.05, *** - significant at p = 0.001

Appendix 3: Analysis of variance table showing mean sum of squares for stem dry matter weight.

			Mean Sum of Squares				
	DAP		48	69	95	118	139
Experiment	Source of Variation	df					
1	Blocks	2	0.006	0.212	17.737	35.776	20.436
	N	2	0.008	1.144	107.905*	271.544*	120.804*
	P	2	0.004	1.744*	107.453*	230.276*	122.893*
	V	1	0.004	2.049	251.628***	609.384***	259.282***
	N x P	4	0.006	0.364	52.821	104.491	50.564
	N x V	2	0.000	0.328	17.941	159.308	63.135
	P x V	2	0.003	0.428	6.381	147.665	66.101
	N x P x V	4	0.004	0.557	46.951	32.214	10.104
	Error	34	0.004	0.805	21.538	60.599	24.012
	Total	53					
2	Blocks	2	0.301	1.260	11.192	8.539	8.284
	N	2	0.274	1.316	53.201*	66.874*	15.025*
	P	2	0.146	1.031	49.658*	64.257*	10.231*
	V	1	0.302	1.302	130.667*	149.640*	27.312***
	N x P	4	0.052	0.729	19.802	5.174	2.357
	N x V	2	0.279	1.335	21.419	4.943	3.362
	P x V	2	0.228	0.303	0.921	3.408	3.022
	N x P x V	4	0.043	0.355	1.070	1.220	0.977
	Error	34	0.109	0.455	10.450	12.704	2.904
	Total	53					

* - significant at $p = 0.05$, *** - significant at $p = 0.001$

Appendix 4: Analysis of variance table showing mean sum of squares for total dry matter weight.

			Mean sum of squares				
		DAP	48	69	95	118	139
Experiment	Source of Variation	df					
1	Blocks	2	0.024	0.637	21.609	25.961	20.236
	N	2	0.039	3.164	117.528*	299.958*	102.267*
	P	2	0.017	2.896	90.547*	277.994*	91.438*
	V	1	0.053	3.533	311.295***	691.964***	279.692***
	N x P	4	0.044	0.534	18.216	24.371	18.064
	N x V	2	0.025	1.293	6.392	40.180	33.135
	P x V	2	0.023	0.327	9.148	24.543	16.101
	N x P x V	4	0.050	2.395	49.506	13.168	5.104
	Error	34	0.027	1.170	25.145	71.080	24.012
	Total	53					
2	Blocks	2	0.230	0.946	36.315	12.295	8.284
	N	2	0.181	2.865	65.024*	80.425*	14.198*
	P	2	0.124	1.276	70.416*	89.062*	12.807*
	V	1	0.278	3.024	212.685***	210.552***	37.311***
	N x P	4	0.125	0.737	25.802	27.688	3.357
	N x V	2	0.108	2.332	36.822	41.788	3.362
	P x V	2	0.250	0.559	1.947	37.367	3.022
	N x P x V	4	0.077	0.847	13.968	14.723	0.977
	Error	34	0.094	0.934	13.826	17.378	2.904
	Total	53					

* - significant at p = 0.05, *** - significant at p = 0.001

Appendix 5: Analysis of variance table showing mean squares for leaf area index (LAI).

			Mean Sum of Squares			
		DAP	48	69	95	118
Experiment	Source of Variation	Df				
1	Blocks	2	0.000	0.003	0.028	0.034
	N	2	0.0001	0.023*	0.135*	0.430*
	P	2	0.0001	0.024*	0.144*	0.504*
	V	1	0.0002	0.049***	0.339***	1.107***
	N x P	4	0.000	0.001	0.029	0.099
	N x V	2	0.000	0.001	0.0143	0.100
	P x V	2	0.000	0.000	0.002	0.240
	N x P x V	4	0.000	0.008	0.686	0.226
	Error	34	0.0001	0.005	0.035	0.112
	Total	53				
2	Blocks	2	0.001	0.000	0.011	0.026
	N	2	0.002	0.021*	0.219*	0.466*
	P	2	0.002	0.018*	0.209*	0.381*
	V	1	0.003	0.049***	0.473***	1.007***
	N x P	4	0.000	0.001	0.051	0.190
	N x V	2	0.000	0.000	0.087	0.111
	P x V	2	0.000	0.000	0.007	0.203
	N x P x V	4	0.001	0.004	0.105	0.173
	Error	34	0.001	0.005	0.041	0.101
	Total	53				

* - significant at p = 0.05, *** - significant at p = 0.001

Appendix 6: Analysis of variance table showing mean sum of squares for the number of capsules per plant, seed yield (kg/ha) and Harvest Index (HI) at harvest.

Experiment	Source of Variation	df	number of capsules	seed yield	Harvest Index (HI)	1000 seed weight
	Blocks	2	168.452	18.506	0.00002	0.00963
	N	2	32.257	185.823*	0.0003	0.15463*
	P	2	131.042	182.704*	0.0008	0.17001*
1	V	1	764.0***	297.781*	0.0127***	0.31574***
	N x P	4	127.957	20.221	0.0001	0.00796
	N x V	2	217.108	35.511	0.0003	0.04241
	P x V	2	80.21	33.612	0.00104	0.04019
	N x P x V	4	206.379	15.5475	0.00074	0.015019
	Error	34	168.438	44.616	0.00044	0.03257
	Total	53				
	Blocks	2	15.548	161.93	0.00008	0.03852
	N	2	45.884	995.782*	0.00092	0.70296*
	P	2	216.586	963.466*	0.00105	0.76963*
2	V	1	54903.7***	1630.290*	0.00114***	2.88903***
	N x P	4	141.49	52.639	0.00284	0.00574
	N x V	2	250.985	96.543	0.00254	0.00356
	P x V	2	108.465	66.973	0.00085	0.00763
	N x P x V	4	213.06	29.358	0.00076	0.00246
	Error	34	313.812	207.355	0.00071	0.01343
	Total	53				

* - significant at p = 0.05, *** - significant at p = 0.001

Appendix 7: Analysis of variance table showing mean squares for leaf dry matter partition coefficient (Leaf dry matter/TDM).

			mean sum of squares				
Experiment	Source of Variation	df	48 DAP	69 DAP	95 DAP	118 DAP	139 DAP
	Blocks	2	0.0098	0.0003	0.0008	0.0001	0.0001
	N	2	0.0001	0.0006	0.0001	0.0001	0.0011
	P	2	0.0002	0.0012	0.0024	0.0005	0.0005
1	V	1	0.0004	0.0018	0.0042	0.0002	0.0004
	N x P	4	0.0013	0.0028	0.0019	0.0001	0.0001
	N x V	2	0.0035	0.0011	0.0028	0.0002	0.0002
	P x V	2	0.0036	0.0035	0.0002	0.0001	0.0001
	N x P x V	4	0.0013	0.0031	0.0026	0.0001	0.0001
	Experimental Error	34	0.0048	0.0049	0.0018	0.0002	0.0002
	Total	53					
	Blocks	2	0.0306	0.0147	0.0025	0.0003	0.0001
	N	2	0.0084	0.0463	0.0059	0.0006	0.0001
	P	2	0.0102	0.0298	0.0013	0.0003	0.0004
2	V	1	0.2048	0.0269	0.0289	0.0002	0.0002
	N x P	4	0.0013	0.0023	0.0021	0.0001	0.0002
	N x V	2	0.0023	0.0005	0.0006	0.0003	0.0001
	P x V	2	0.0002	0.0004	0.0012	0.0005	0.0002
	N x P x V	4	0.0024	0.0041	0.0006	0.0001	0.0003
	Experimental Error	34	0.0041	0.02982	0.0606	0.0003	0.0003
	Total	53					

Appendix 8: Analysis of variance table showing mean squares for % PAR interception.

		Mean sum of squares				
	DAP	50	64	78	92	118
Source of Variation	df					
Blocks	2	6.854	2.284	0.057	8.035	20.601
N	2	30.016*	51.623*	6.946*	84.869*	114.518*
P	2	36.614*	59.677*	5.447*	89.813*	125.547*
V	1	96.102***	9.968***	18.368***	314.29***	211.255***
N x P	4	9.358	15.840	1.656	47.611	15.226
N x V	2	14.427	26.757	1.515	59.514	4.192
P x V	2	0.593	5.195	1.082	45.143	6.144
N x P x V	4	9.959	10.524	1.320	23.103	40.106
Error	34	6.924	11.003	1.322	31.606	24.245
Total	53					

* - significant at $p = 0.05$, *** - significant at $p = 0.001$

Appendix 9: Analysis of variance table showing mean squares for stem dry matter partition coefficient (stem dry matter/TDM).

		Mean	sum of squares				
Experiment	Source of Variation	df	48 DAP	69 DAP	95 DAP	118 DAP	139 DAP
1	Blocks	2	0.0098	0.0003	0.0008	0.0001	0.0001
	N	2	0.0001	0.0006	0.0001	0.0001	0.0011
	P	2	0.0002	0.0012	0.0024	0.0005	0.0005
	V	1	0.0004	0.0018	0.0042	0.0002	0.0004
	N x P	4	0.0013	0.0028	0.0019	0.0001	0.0001
	N x V	2	0.0035	0.0011	0.0028	0.0002	0.0002
	P x V	2	0.0036	0.0035	0.0002	0.0001	0.0001
	N x P x V	4	0.0013	0.0031	0.0026	0.0001	0.0001
	Experimental Error	34	0.0048	0.0049	0.0018	0.0002	0.0002
	Total	53					
2	Blocks	2	0.0006	0.0014	0.0002	0.0001	0.0002
	N	2	0.0084	0.0016	0.0005	0.0003	0.0002
	P	2	0.0123	0.0002	0.0013	0.0001	0.0007
	V	1	0.0048	0.0027	0.0003	0.0001	0.0008
	N x P	4	0.0013	0.0021	0.0002	0.0001	0.0002
	N x V	2	0.0023	0.0005	0.0006	0.0002	0.0001
	P x V	2	0.0002	0.0004	0.0001	0.0001	0.0002
	N x P x V	4	0.0024	0.0041	0.0006	0.0001	0.0001
	Experimental Error	34	0.0041	0.0031	0.0006	0.0003	0.0007
	Total	53					