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EFFECT OF VARYING CONCENTRATIONS OF NITROGEN AND PHOSPHORUS SUPPLY ON THE GROWTH OF ENSET (*Ensete ventricosum* (Welw.) Cheesman) SUCKERS

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EFFECT OF VARYING CONCENTRATIONS OF NITROGEN AND PHOSPHORUS SUPPLY ON THE GROWTH OF ENSET (*Ensete ventricosum* (Welw.) Cheesman) SUCKERS

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ABSTRACT

The effect of a range of factorially combined concentrations of nitrogen and phosphorus on the growth of enset suckers (*Ensete ventricosum* (Welw.) Cheesman) was studied in a greenhouse using Randomized Complete Block Design with seven replications. The experiment was conducted on soil samples collected from Sidamo, Agereselam as growing medium. To these soils, four concentrations of nitrogen (0, 10, 50 and 250 mgl^{-1}, designated as N_1, N_2, N_3 and N_4, respectively); and four concentrations of phosphorus (0, 9, 27 and 81 mgl^{-1}, designated as P_1, P_2, P_3 and P_4, respectively) were factorially combined and added to investigate sixteen treatments. The appropriate nutrient solutions were applied to the plants at a rate of 200 ml twice in a week.

Enset suckers responded to an increase in concentrations of nitrogen and phosphorus in solution through increases in pseudostem girth, leaf area, total biomass and tissue nitrogen and phosphorus contents. Increasing concentrations of nitrogen and phosphorus in solution resulted in significant increase ($P < 0.001$) in pseudostem girth and total dry weight. The interaction between the two nutrients were also highly significant ($P < 0.001$). Plants that received nitrogen (250 mgl^{-1}) and phosphorus (81 mgl^{-1}) produced the highest dry matter compared to other treatments and the control. Reduction in the supply of the two nutrients resulted in higher root : shoot ratio and nitrogen and phosphorus stress levels. In comparison with nitrogen, higher levels of phosphorus resulted in higher root : shoot ratio. Total leaf area was also significantly ($P < 0.001$) affected by increasing concentrations of nitrogen and phosphorus in

solution, although the effect of phosphorus on total leaf area was shown only at higher levels of nitrogen combined with higher levels of phosphorus (i.e. at N_3P_3, N_3P_4, N_4P_3 and N_4P_4). Of the parameters of growth studied, leaf area increase/week was found to be a sensitive measure of nutrient stress in enset suckers. Nitrogen and phosphorus concentrations less than 50 mgl^{-1} and 27 mgl^{-1}, respectively resulted in more than 40 percent nutrient stress.

The concentration of nitrogen in the shoot ranged from 0.61 $\pm$ 0.06 percent (at N_1P_1) to 1.04 $\pm$ 0.05 percent (at N_4P_4). Root nitrogen ranged from 0.19 $\pm$ 0.03 (at N_1P_1) to 0.47 $\pm$ 0.06 percent (at N_4P_4). There was a significant increase in shoot and root nitrogen following increased concentrations of nitrogen in solution, but was not significantly affected by phosphorus levels. Phosphorus concentrations in the shoot ranged from 0.11 $\pm$ 0.02 percent (at P_1N_1) to 0.48 $\pm$ 0.05 percent (at P_4N_4). Phosphorus concentration in the root ranged from 0.03 $\pm$ 0.02 (at P_1N_1) to 0.21 $\pm$ 0.01 (at P_4N_4). Phosphorus concentration in the tissue increased following increased concentration of phosphorus in solution, which was also significantly affected at higher nitrogen concentration (250 mg^{-1}) in solution. Of the two nutrients studied nitrogen was found to be more limiting to the growth of enset suckers.

1. INTRODUCTION

1.1. Scope of the problem

Enset (*Ensete ventricosum* (Welw.) Cheesman) is a large monocot plant that belongs to the order *Scistaminae*, family *Musaceae* and genus *Ensete* (Pursglove, 1972). Among eight species, which are widely distributed in Africa and Asia (Brandt *et al.*, 1997), the species *Ensete ventricosum* (Welw.) Cheesman has been predominantly cultivated in the south and southwestern parts of Ethiopia for food and fiber for thousands of years (Taye Bezuneh, 1972). It has been estimated that 10-12 million people depend on enset as a staple and co-staple food (Bezuayehu Haile, 1995). The area coverage of enset in Ethiopia is estimated to be 140,200 hectares (CSA, 1994).

Enset has a wide range of use in Ethiopia. The corm, the inner bark of the pseudostem and the inflorescence stalk provide several food products. Besides food value, the fiber obtained as a secondary product is used industrially as a raw material for making sacks, strings, ropes, mats, bags and many other items. The outer bark of the pseudostem is used for house construction and also as a source of fuel. During the dry season, enset is a good source of fodder. Some varieties of enset have medicinal value (Shack, 1966; Olmstead, 1974; Shigeta, 1990; Worku Nida, 1996). In addition to these, enset provides a wide spread vegetative cover to the soil against rain and hence reduces erosion. Responding to the food demand of the rapidly increasing population, even under risky and variable ecological condition, enset has proven useful to a sustainable intensification of agriculture (Shiferaw Tesfaye, 1996). It has been noted that the populations dependent on enset have never suffered from famine even during the 1970's and 1980's

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tragic drought and famine decades of Ethiopia (Pankhurst, 1986).

Enset is the most frequently grown crop in the home-gardens of south and southwestern Ethiopia (Zemede Asfaw and Ayele Nigatu, 1995). Among other reasons, this is partly due to the fact that enset gives a higher and more dependable yield than any other crop. Seifu Gebremariam (1996) estimated that one million tonnes of food and 34, 000 tonnes of fiber are produced annually from enset plantations. It has also been estimated that about 600 tonnes of enset fiber per year are sent to factories (Brandt *et al.*, 1997). Average fiber yield of enset is about 543 kg/hectare (Shiferaw Tesfaye, 1996). On a hectare basis the productivity of enset crop can reach as high as 10 tonnes/hectare/year (Shiferaw Tesfaye, 1996). When this is compared with that of other crops having a similar moisture content (sweet potato, 4.0 tonnes/hectare/year; and Irish potato, 5.2 tonnes/hectare/year) it has a good performance even with the assumption that the annual crops are produced twice in a year. Information obtained from IAR (1983) indicated that in Imdibir and Sidamo, 50-60 plants; in Kambata, 30-40 plants; are sufficient for a family of 4-5 persons for one year. Yet the number of enset plants harvested in one's farm on a yearly basis is usually in excess of the number required for annual consumption. Regarding space needed for production, it has the advantage that a large sized family can be supported by enset plants grown on a limited area of land. It can withstand moisture stress, as well as, heavy rains and flooding which can devastate other crops. The food can be stored for long time without spoilage and it is easy to grow with a minimum care in a mixed farming system (Yohannes Uloro and Mengel, 1994).

Despite its importance, historically very little attention has been paid to enset crop by researchers as most of their efforts have been concentrated on cash crops and more familiar grains (Yohannes Uloro and Mengel, 1994). The majority of extension, development and research on Ethiopian agriculture has been focused upon the cereal based systems of the highlands of northern, central and eastern Ethiopia, and to a lesser extent upon the shifting cultivation economies of subtropical and lowland western Ethiopia (Brandt *et al.*, 1997). There has been considerably less research on enset agricultural system of the highlands of southern and southwestern Ethiopia (Yohannes Uloro and Mengel, 1994; Brandt *et al.*, 1997). As a result very little has been done concerning the physiological, ecological and nutritional requirements of the enset crop. Information concerning mineral nutrition requirement of enset in general and the optimum amount of nutrients required for best growth in particular are scanty.

It is clear that besides other factors, nutrition of a crop plays an important role in the improvement of crop yield, as it is through optimum balance of nutrients that the maximum production of photosynthates can be achieved (Mengel, 1991). Maintenance of an adequate supply of available and optimum quantity of plant nutrients to meet the needs of crop plants is a highly important problem in agriculture (Bear, 1965). An adequate level of soil fertility is a crucial requisite to the economic production of crops (Olson, 1982). Nutrients supplied by the soil for plant growth influence not only the quantity of production but can have substantial impact on quality.

Observations in areas that have been planted with enset for many years suggest that native soils have been altered positively by the long term application of manures (Brandt

et al., 1997). Farmers maintain the fertility of the enset land largely by applying cow dung. As a result, the production of enset is always combined with cattle rearing (Smeds, 1955). Because enset production improves soils, particularly with adequate manuring, many enset fields have been in continuous production for decades, if not centuries.

However, now-adays, because of significant increase in human population and decrease in livestock, low soil fertility is one of the major constraints of enset production. Farmers are unable to obtain the expected amount of yield out of the crop using traditional systems (Yohannes Uloro and Mengel, 1994; Shiferaw Tesfaye, 1996; Brandt *et al.*, 1997). Brandt *et al.* (1997) noted that because of low productivity and high rates of mortality, the livestock production in enset growing region is under significant stress. Current data indicate that the most severe constraint is lack of adequate forage for livestock. A decrease in the amount of land allocated for grazing per village, and transformation of some common grazing land to crop production have contributed to this decline in forage resources. The cycle of increasing impoverishment of the livestock component in this mixed enset/livestock system is a serious cause for concern. With an increasing population in an already populated area, it is likely that the declining trend in livestock population will continue, with potentially severe impact on enset production. As a result, in future it would be difficult to depend totally on the traditional farming system. Thus new methods need to be devised, for instance, where optimum inorganic mineral rates/levels also play a role in the enset production system.

It is generally agreed that most agricultural soils of Ethiopia are nitrogen and

phosphorus deficient (Desta Beyene, 1982). In particular the soils of the highlands of Ethiopia are known to be poor in nitrogen and phosphorus. Nitrogen and phosphorus are the two major plant nutrients that affect maximum crop production (Fageria, 1992; Marschener, 1995). The relatively slow growth rate and decline in the yield of enset crop could, thus, be attributed (among other things) to nutrient shortage, primarily to combined nitrogen and phosphorus stress. Nevertheless, although preliminary studies have been conducted by Yohannes Uloro and Mengel (1994) on the influence of NPK fertilizers on yield of enset, the effect of a factorial combination of different stress levels of nitrogen and phosphorus on the growth of enset never have been studied. Nor have there been particular studies to address the growth and physiological response of enset to these mineral deficiencies. The present study stems from this understanding. The study was conducted to address the following objectives.

1.2. Objectives of the study

1.2.1. General objectives:

- To investigate the effect of a supply of varying concentrations of nitrogen and phosphorus on the growth and physiology of enset suckers.

1.2.2. Specific objectives:

- To study the effect of nitrogen and phosphorus stress on the growth, total biomass production and carbon allocation patterns of enset suckers.

- To establish nutrient stress levels for growing enset suckers under varying levels of nitrogen and phosphorus supply.

- To identify recommendable (critical) levels of tissue nitrogen and phosphorus concentration for optimal growth.

2. LITERATURE REVIEW

2.1. Taxonomy, morphological features, ecology, propagation techniques and uses of enset in Ethiopia.

2.1.1. Some historical backgrounds

Agricultural systems of Ethiopia are grouped into four major categories: The seed farming complex of the northern, eastern and central plateau, the shifting cultivation economies of the western and southwestern Ethiopia, the pastoral complex represented by nomadic populations in the low-lying plains and the enset planting complex of the south and southwestern Ethiopia (Westphal, 1975).

On cultural grounds, the enset culture complex area distinguishes itself from the plough culture practiced in the north, central and eastern Ethiopia. The term "enset culture complex" has been suggested by Shack (1963) to demarcate the area in the horn of Africa where enset is cultivated.

Given the restricted geographic distribution of domesticated enset and the degree of complexity and variability in contemporary enset agricultural systems, agronomists and biogeographers have long considered the Ethiopian highlands to be the primary center for the origin of enset agriculture (Brandt *et al.*, 1997). Although evidence is lacking to locate the exact place of origin, Smeds (1955) speculated that the highlands along the western edge of the Rift Valley, particularly the present Wolaita, Kambata and Gurage

regions, could be the original centers of enset cultivation. Anthropologists, archaeologists, historians and other scholars have also developed theories and models that argue for the domestication of enset in Ethiopia to have begun as early as 10,000 years ago (Brandt, 1996; Brandt *et al.*, 1997).

Stiehler (1948), as cited in Brandt *et al.* (1997), one of the first scholars to consider the origin of enset, believed that the indigenous hunter/gatherers of southern Ethiopia were the first to cultivate enset. He also proposed that enset agriculture was later introduced to northern Ethiopian highlands by cushitic speaking peoples, only to be replaced by crops such as wheat (*Triticum sativum*), barley (*Hordeum vulgare*) and tef (*Eragrostis tef*).

2.1.2. **Taxonomy and some morphological features of enset**

Ensete ventricosum (Welw.) Cheesman (Syn. *Musa ensete* Gmel (1791); *Musa ventricosa* Welw. (1859); *Ensete edule* Horan. (1862)) is a monocot that belongs to order *Scistaminae* and family *Musaceae* (Lye and Edwards, 1997). There is some confusion as to the number of species in the genus *Ensete*. For instance, Cheesman (1947) listed 24 species which are distributed in Africa and Asia. However, Simmonds (1962) recognized only six species and Pursglove (1972) recognized seven species and of these, *Ensete ventricosum* (Welw.) Cheesman is the only species found in Ethiopia.

Enset is a leafy herb 6 - 12 meters long. It consists of three kinds of stems: The false stem (pseudostem), which is made up of overlapping leaf sheaths; an underground stem

(corm) and true stem, which remains short at the base of the central shoot, from which inflorescence is initiated. The roots of enset are shallow, only 2 - 3 meters long (Kefale Alemu and Sandford, 1991). Leaves are large, oblong up to 7 meters long and 1 meter wide; bright to dark green in color; mid rib, petiole and margin sometimes pale to dark purple; rarely the lower side reddish. Inflorescence of enset is drooping, with strongly sweet flowers. Fruit, the small yellow clusters look like normal bananas. The fruits are not eaten normally. Each leathery fruit contains 1-10 blackish hard seeds. The whole plant dies after fruiting (Taye Bezuneh, 1984; Lye and Edwards, 1997).

2.1.3. **Ecology of enset**

Domesticated enset is planted at altitudes ranging from 1,200 to 3,100 meters above sea level in most regions of southern and southwestern Ethiopia (Brandt *et al.*, 1997). However, the main cultivation zones lie between 1800 and 2450 meters above sea level (Taye Bezuneh, 1984) with an annual rainfall of 1100 to 1500 mm (Westphal, 1975; Brandt *et al.*, 1997), the majority of which falls between March and September. The mean daily minimum and the mean daily maximum temperature of enset growing areas average 8 and 27°C, respectively and the relative humidity ranges between 63 and 80 % (Asnakech Woldetensaye, 1997). Eventhough widely cultivated, wild plants grow in montane and reverine forest, often in clearings, gullies and near streams; (500-)1000-2400 meters above sea level in Tigray, Gonder, Gojjam, Wollega, Illubabor, Keffa; widelyspread in upland regions of tropical Africa south to Angola (Lye and Edwards, 1997). Unlike bananas and coffee, enset can withstand frost and can be planted in valley bottoms (Asnakech Woldetensaye, 1997).

Enset grows well in most soil types, if they are sufficiently fertile and well drained. Although enset is grown on diverse soil types, the soils in its major production areas are acidic in reaction and have extremely low available phosphorus. The soils contain on the average 2 to 3 % organic matter (Kelsa Kena, 1996).

2.1.4. **Clones (varieties) of enset**

In Ethiopia many different clones are recognized by local farmers (Kefale Alemu and Sandford, 1991). However, an exhaustive inventory of clones at various location is not available (Teketel Makiso, 1996). Neither is the number of available clones that can be used for food and their potential is known (Seifu Gebremariam, 1996). Still, more than 50 different types of clones are known to exist (Shigeta, 1990; Kefale Alemu and Sandford, 1991; Zippel and Kefale Alemu, 1995).

2.1.5. **Propagation techniques**

Enset is generally propagated vegetatively (Seifu Gebremariam, 1984; Kefale Alemu and Sandford, 1991). However, in some areas (highland part of Gardula) propagation is done both vegetatively and by seed (Taye Bezuneh, 1984). Taye Bezuneh (1996) notes that the seed germination of enset is erratic, generally low and may take several weeks. However, he further suggested that, mechanical scarification or cracking of the seed is known to improve the imbibition of water. In establishing an enset farm, farmers use vegetatively propagated seedlings. This is understandable considering the fact that they have a large number of enset clones and vegetative propagation is the

easiest and quickest method available to farmers at present. Vegetative propagation is done by use of suckers that sprout from the corm of the plant after it has been buried. To initiate suckering, mother plants of four to six years old are dug out and pseudostems cut some 20 to 30 cm above the corm. The apical meristem (situated at the top of the corm) is destroyed to eliminate the apical dominance. Then, the corm which is cut half way or into quarter, is planted into a shallow hole dug at a fertile spot. After four to eight weeks, shoots emanating from the buried corm begin to emerge more or less in rings, forming a cluster of sprouts (Teketel Makiso, 1996). The age of suckers before separation from the mother corm and transplantation to another site depend on the altitude. In altitudes between 1600 and 3000 meters it takes one to one and half years; above 3000 meters two or more years (Westphal, 1975). Although the fundamental reason for repeated transplantation is not adequately known, depending on cultural practices, the suckers are transplanted twice or three times (Seifu Gebremariam, 1996), before they are transplanted to the main field. The optimum harvesting time is when it produces an inflorescence at maturity. At this stage it has maximum storage of food in the pseudostem (Kefale Alemu and Sandford, 1991). However, in some cases enset is harvested in its pre-mature stage especially when there is lack of food and during Meskel festivals. The effect of pre-mature harvest have been reported by Kelbessa Urega *et al.* (1996). According to their studies, enset harvested too young will have a reduced starch content.

2.1.6. **The role of enset in agricultural diversification**

Due to poor protein content and taste of the fermented enset product, Kocho is not

consumed on its own, except during periods of extreme famine or by poor house holds who don't have the means to vary their diet (Pankhurst, 1996). Enset food is, thus, mostly consumed together with other crops such as cabbage, beans, etc, and animal products such as milk, meat, yoghurt etc (Taye Bezuneh, 1996).

Sometimes the enset flour is mixed with other cereals before the bread is baked (Asnakech Woldetensay, 1992; Pankhurst, 1996). Because of these basic reasons, enset is always grown alongside with other crops and livestock. One can argue, thus, that the enset production provides, the opportunity and the need for diversification of agricultural production and promotes a more balanced agricultural system than either the cereal or the pastoral economies, elements of both of which it combines (Pankhurst, 1996)

2.1.7. **Ecological importance of enset**

One contribution of enset in the context of sustainabilty is its role in conservation, which is related not only to reducing the intensity of soil losses but also to preserving and increasing the capacity of the soil to sustain agricultural production. Given its good morphological nature and appearance suited to intercept heavy rainfall showers, enset prevents erosion by providing wide spread cover against rain (Shiferaw Tesfaye, 1996; Asnakech Woldetensaye, 1997). In enset farming systems, there is no specific time during which the enset field is open to the negative impact of high temperature and heavy rainfall. Because the time of planting and harvesting often overlaps, the quantity of the productive soil is maintained; the effect of rainfall erosivity and soil erodibilty

is also diminished. It is therefore possible to meet both the conservation role of enset in maintaining the land capacity to support production and the development end of growth in production (Shiferaw Tesfaye, 1996).

Another merit of enset is related to its capacity to reduce degradation of resource from overgrazing as cattle can be fed with enset leaves through cut-and-carry system. Enset leaves are important for cattle feed especially in the dry season when grasses are scarce. Dereje Fekadu (1996) found that enset has a good potential as feed for ruminants. The stall feeding also helps to avoid wastage of manures and thus renders efficient use of resources.

2.1.8. **Economic importance of enset**

Enset is a multipurpose crop. All parts of the plant are economically important. The crop is an integral aspect of the daily and ritual life of the people. Farmers say "enset is our food, our cloths, our beds, our houses, our cattle feed, our plates, our medicine". The corm, the pseudostem and the stalk of the inflorescence of enset are the most important sources of food. Enset is used as food in three forms: "Kocho", "Bulla" and "Amicho". Kocho is a fermented product obtained from the corm, the pseudostem and inflorescence stalk; Bulla is made by dehydrating the juice collected during the decortication of the pseudostem and grating of the corm. Amicho is a boiled enset corm (Liyuwork Zewdie, 1996).

Besides its food value, enset provides fiber as by product. Enset fiber has an excellent

structure and its strength is only next to abaca (*Musa textilis*), a world class fiber crop (Kefale Alemu and Sandford, 1991). In rural areas and in industries the fiber is used as a raw material to make sacks, bags, mats, sieves and construction materials (such as tying materials that can be used in place of nails) (Lye and Edwards, 1997).

Fresh enset leaves are used as bread and food wrappers, serving plates and pit liners to store kocho for fermentation and future use. During enset harvesting enset leaves are also used to line the ground, where processing takes place (Smeds, 1955; Shack, 1966; Olmstead, 1974; Brandt *et al.*, 1997).

Particular clones (or varieties) of enset are also used medicinally for both humans and livestock to cure bone fractures, broken bones, child birth problems (i.e, assisting to discharge the placenta), diarrhoea, birth control (as an abortifacient), jaundice, back-ache or sprain and heart diseases (Worku Nida, 1996; Brandt *et al.*, 1997). In addition to these vital roles, the leaf sheath, the dried petioles and mid ribs of enset are used as a source of fuel and to make mats.

2.2. **Essential plant nutrients**

The essential role of inorganic elements for plant growth has been a subject of a series of studies for a long time. Such studies have shown the specific roles of several inorganic elements in plant growth processes. Such elements include N, P, K, Ca, Mg, S, Fe, Zn, Mn, Cu, B, Mo and Co for all plants. Essentially all absorption of these elements by plants occurs through the roots from the soil solution or soil colloid surface

in ionic form. The most commonly absorbed ionic forms are: nitrogen as NO_{3-} and NH_{4+}, phosphorus as H_2PO_4- and HPO_4^{2-}, potassium as K^+, calcium as Ca^{2+}, Mg as Mg^{2+}, S as $SO4^{2-}$, Fe as Fe^{2+} and Fe^{3+}, Cu as Cu^{2+}, Mn as Mn^{2+}, Zn as Zn^{2+}, B as $B_4O_7^{2-}$, Co as Co^{2-} and Mo as MoO_4^{2-}.

Among those essential nutrient elements nitrogen and phosphorus are the most extensively deficient on a worldwide basis for efficient production (Hirose, 1984; Fageria, 1992).

2.2.1. **Role of nitrogen in plants.**

Nitrogen is a major nutrient required for the growth of plants. In natural environments when supplies of water are adequate, nitrogen is most commonly a key limiting factor for crop production (Hirose, 1984). Efficient nitrogen use may enhance fitness of plants through increasing amount of resources available for growth and reproduction. Several research results have shown the correlation between nitrogen supply and plant productivity. Thus, on the average, considerably more nitrogen than any other element is supplied to crops as fertilizer (Olson, 1982). Depending upon the plant species, nitrogen content required for optimal growth varies between 0.5 % and 5 %, of the plant dry weight (Cocks, 1980). Nitrogen plays a central role in plant biochemistry as an essential constituent of cell walls, cytoplasmic proteins, nucleic acids, chlorophyll and a vast array of other cell components (Hay and Walker, 1989). Consequently, a deficiency in the supply of nitrogen has a profound influence upon crop growth and can lead to a total loss of yield in extreme cases. Thus, in many experiments where the

control plots receive no fertilizer the yield responses associated with the first increment of nitrogen are often simply the result of relief of severe nitrogen deficiency. Increased nitrogen supply, through its effects on leaf size and longevity and upon tiller formation and survival, results in increase in the size and duration of the crop canopy. In turn this increase results in higher rates of crop dry matter production (Hay and Walker, 1989; Nair and Chatterjee, 1992).

2.2.2. **Role of phosphorus in plants.**

Phosphorus is also an essential macronutrient. The phosphorus requirement of plants for optimal growth is in the range of 0.3 to 0.5% of the plant dry weight during the vegetative stage of growth. Phosphorus has many essential functions, the most important one is its role in energy storage and transfer. Besides this vital metabolic role, phosphorus is also an important structural component of a wide variety of biochemicals including nucleic acids, co-enzymes, nucleotides, phosphoproteins, phospholipids and sugar phosphates (Dell *et al.*, 1995).

Several other gross quantitative effects on plant growth are also attributed to phosphorus, such as photosynthesis, nitrogen fixation, crop maturation, flowering and fruiting including seed formation, root development, particularly the fibrous and lateral roots. Phosphorus gives strength of straw in cereal crops, thus helping to prevent lodging and improves crop quality, especially of forage and vegetables (Brady, 1990).

It has been reported that, phosphorus deficiency limits crop growth by reducing the size

of the leaf area of the plant and consequently limiting light interception (Cromer *et al.*, 1993). Phosphorus deficiency is also known to reduce the photosynthetic capacity of leaves (Jacob and Lawlor, 1991). Because of the function of phosphorus in the growth and metabolism of plants, deficiency leads to a general reduction of most metabolic processes, including cell division and expansion, respiration and photosynthesis (Marschner, 1995). The regulatory function of inorganic phosphorus in photosynthesis and carbohydrate metabolism of leaves can be considered to be one of the major factors limiting growth, particularly during the reproductive stage.

3. MATERIALS AND METHODS

3.1. Collection of soil samples and enset suckers

Soil samples used for this particular experiment were collected from Agereselam, Sidamo (See Fig 1 for map of location of Agereselam). Soil samples were collected from ten enset farms, from new plots where suckers have been transplanted recently (less than a year) and that have not been treated with manure or inorganic fertilizer. From each field 25 individual cores were taken from a depth of 0-60 cm and bulked together to give a single soil sample. These cores were taken at every ten steps by walking in the field in a W pattern following the method described in Archer (1988).

For comparison purposes, soil samples were also taken from fields which have been under enset cultivation, for 2-5 years, for 10-15 years and for more than 30 years based on the information obtained from the farmers. Each sample collected were packed and brought to Addis Ababa University, air dried, sieved to pass 2 mm and 0.5 mm and each sample thoroughly mixed with each other and analyzed for texture, pH, organic carbon, organic matter, total nitrogen and available phosphorus.

The extra-portions of soils collected from recently cultivated fields were also air dried, sieved to pass 2 mm, thoroughly mixed with each other and with pre-leached sand (in a ratio 2 soil to 1 sand). Nine kilogram portions of the soil were then filled in polythene bags, of 40 cm diameter and 50 cm depth. The polythene bags were perforated during the experiment.

One year old enset suckers were also brought from Agereselam from a variety locally called "Ganticha". Suckers of equal size were selected by measuring the pseudostem girth, pseudostem height and by measuring fresh weight using analytical balance. After the suckers were brought to Addis Ababa University, from randomly selected suckers, third leaves were cut and used for analysis of nitrogen and phosphorus contents inorder to know the amount of nitrogen and phosphorus brought by the transplanted material (sucker), prior to planting. The procedures followed in the analyses of nitrogen and phosphorus are described in section 3.5. The results of analysis indicated that the amount of nitrogen and phosphorus that the suckers had were 0.73 $\pm$ 0.05 and 0.1 $\pm$ 0.03 percent, respectively. All the suckers were then cut at a height of 30 cm from the base to remove the leaves and the upper part of the pseudostem (following farmers practice) to facilitate establishment and to minimize any variation in size or in height or leaf number that might be created during establishment.

3.2. **Growing condition**

The suckers were planted in the greenhouse on 13/09/90 E.C. and the experiment ran for six months and harvested at 8/04/91 E.C. During the experimental period the environmental conditions were not controlled. However, the daily maximum and minimum temperature was recorded. The results showed that the daily mean maximum temperature inside the greenhouse was 34.6°C and the daily mean minimum was 10°C. At days whenever the temperature was high the greenhouse was flooded with water in order to reduce the temperature and to raise the relative humidity.

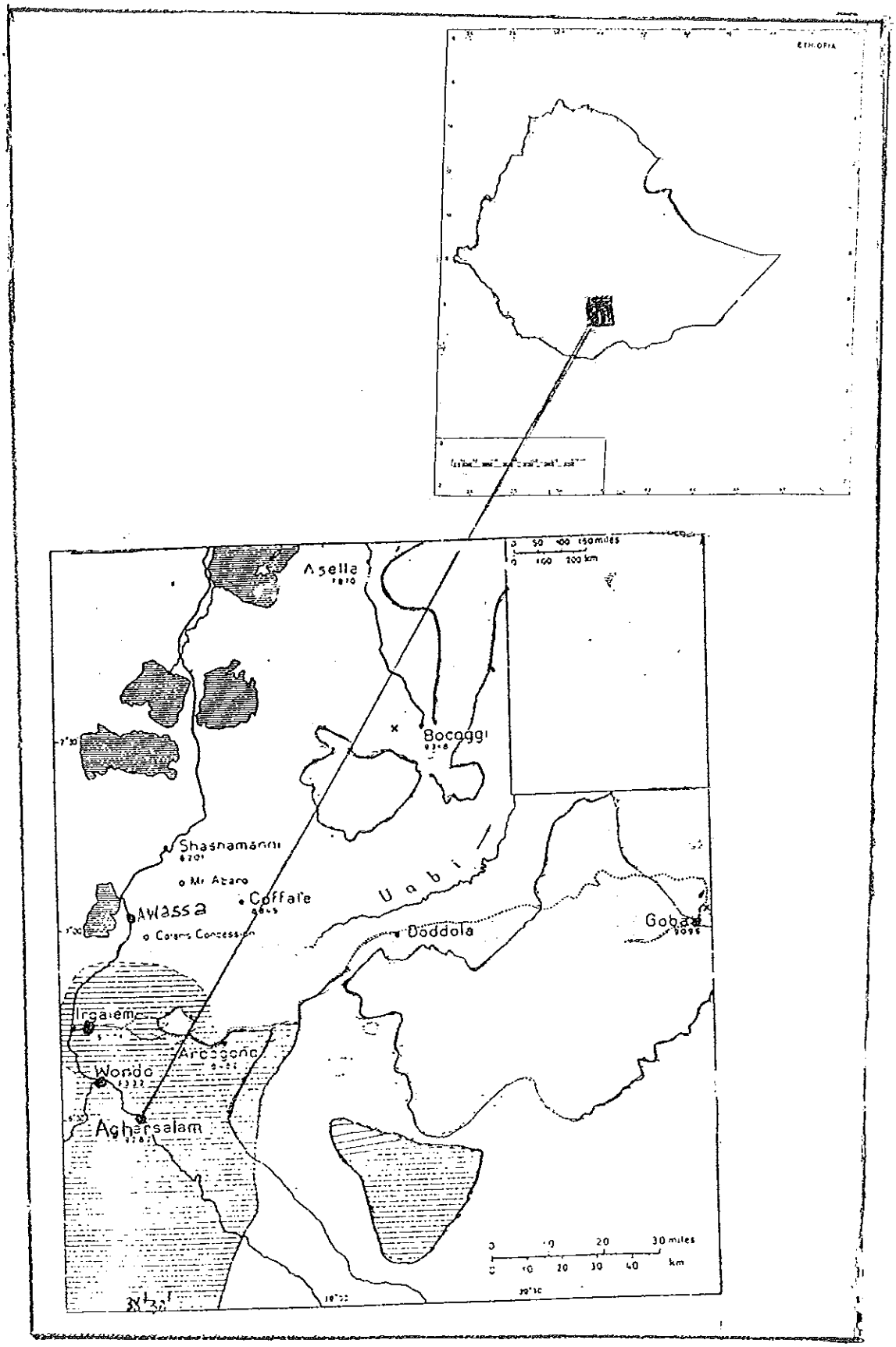


Fig 1. Map showing location of Agereselam

3.3. **Experimental design and treatment**

A 4 x 4 factorial experiment in a randomized complete block design with seven replications was conducted. Four levels of nitrogen, at a rate of 0, 10, 50, and 250 mg $(litre)^{-1}$ and designated as N_1, N_2, N_3 and N_4 , respectively and four levels of phosphorus, at a rate of 0, 9, 27 and 81 mg $(litre)^{-1}$ and designated as P_1, P_2, P_3 and P_4, respectively were combined factorially to investigate a total of 16 treatments. The nutrient solution was based on Long Ashton as described in Hewitt and Smith (1974) and all solutions were prepared from analytical grade chemicals. Throughout the experiment all pots received equal amounts of other macro and micro nutrients (except for nitrogen and phosphorus) on the basis of recommended appropriate concentrations as described in Hewitt and Smith (1974) (Table 1-a). Distilled water was used for the preparation of the nutrient solution throughout the experiment. The pH of the nutrient solution was adjusted between 6.0 - 6.5 as described in Epistin (1972).

The different nitrogen levels were obtained by varying the concentrations of ammonium nitrate (NH_4NO_3) (Table 1-b) and the different phosphorus levels were maintained by varying the concentration of di-sodium phosphate (Na_2HPO_4. $7H_2O$) (Table 1-c).

The appropriate nutrient solution was applied to the plants at a rate of 200 ml twice in a week. Once every two weeks each pot was leached with water to prevent excess accumulation of nutrients.

Table 1-a. Macronutrient and micronutrient composition of nutrient solution used to water plants; stock solution and amounts of stock solution used to make a liter of a complete nutrient medium.

salt	mgl^{-1}	mgl^{-1}	stock solution (gl^{-1})	mll^{-1}
K_2SO_4	348.00	K= 156.00 S= 64.00	21.75	16.0
$CaCl_2$. $6H_2O$	876.00	Ca= 160.00	60.00	14.6
$MgSO_4.7H_2O$	368.00	Mg= 36.00 S= 48.00	46.00	8.0
Fe-citrate $.5H_2O$	33.50	Fe= 5.60	6.70	5.0
$MnSO_4.4H_2O$	2.23	Mn= 0.55	2.23	1.0
$ZnSO_4.7H_2O$	0.29	Zn= 0.06	0.29	1.0
$CuSO_4.5H_2O$	0.25	Cu= 0.06	0.25	1.0
H_3BO_3	3.10	B= 0.54	3.10	1.0
$CoSO_4.7H_2O$	0.06	Co= 0.01	0.05	1.0
$Na_2MoO_4.2H_2O$	0.12	Mo= 0.05	0.12	1.0

Table 1-b. Different nitrogen levels used in the experiment (indicating 0, 10, 50 and 250 mgl^{-1} levels)

NH_4NO_3 Treatements	mgl^{-1}	Nitrogen (mgl^{-1})	Stock solution(gl^{-1}) 28.57	mll^{-1}
N_1	0	0		0
N_2	28.57	10		1
N_3	142.86	50		5
N_4	714.29	250		25

Table 1-c. Different Phosphorus levels used in the experiment (indicating 0, 9, 27 and 81 mgl^{-1} levels)

$Na_2HPO_4.7H_2O$ Treatements	mgl^{-1}	Phosphorus (mgl^{-1})	Stock solution (gl^{-1}) 23.34	mll^{-1}
P_1	0	0		0
P_2	77.80	9		3.3
P_3	233.40	27		10.0
P_4	700.20	81		30.0

3.4 Soil analysis

3.4.1. Determination of soil pH

For soil pH measurement a 1:1 soil water ratio was used (Juo, 1978). Twenty grams of soil was mixed with 20 ml distilled water in 50 ml beaker. The suspension was stirred occasionally and then the pH was determined after 30 minutes using Beckman pH meter (Model CA 92634 - 3100, U.S.A) standardized by buffer solutions of pH 4 and 7.

3.4.2. Determination of soil texture

The texture of the soil was determined following hydrometer method of mechanical analysis (Juo, 1978; Tamirie Hawando *et al.*, 1986). Fifty gram of 2 mm sieved samples were added to 50 ml of sodium hexametaphosphate along with 100 ml of distilled water to remove the humus of the soil. After stirring, the suspension was allowed to stand for 30 minutes. The suspension was then stirred for 15 minutes using multi-mix machine and transferred to a measuring cylinder. The cylinder was filled to the mark and the first hydrometer and temperature readings were taken after 40 seconds. The second hydrometer and temperature readings were taken 3 hours later. The percentages of the various soil separates were determined following the standared formulae (Juo, 1978).

3.4.3. **Determination of organic carbon**

Organic carbon was determined following Walklay and Black's wet oxidation method (Juo, 1978). Initially 0.5 gm soil samples were digested with 10 ml 1 N potassium dichromate and 10 ml of concentrated sulfuric acid in Erlenmeyer flasks. After 30 minutes 10 ml of 85% phosphoric acid was added to complex the Fe^{+3} ions liberated together with 1 ml diphenylamine indicator and the resulting solutions were titrated with hydrated ferrous sulphate. The per cent carbon was calculated using the following formula (Chopra and Kanwar, 1976):

$$\text{Percent carbon} = \frac{(X-Y) \times 0.003 \times 100}{W}$$

Where W= weight of sample in gram,

X= volume of 1 N ferrous sulphate used for reducing 10 ml potassium dichromate (blank) and

Y= volume of 1 N ferrous sulphate used for reducing the excess potassium dichromate in the sample.

3.4.4. **Determination of total nitrogen**

Total nitrogen was determined following the macro kjeldahl method. The kjeldahl method for nitrogen determination involves three processes: digestion, distillation and titration. During digestion, organic nitrogen is converted to ammonium - nitrogen with the help of potassium sulphate (K_2SO_4) to raise the temperatures and cupric sulphate ($CuSO_4$. $5H_2O$) is used as catalyst.

$$\text{Organic nitrogen} + H_2SO_4 \xrightarrow[CuSO_4.5H_2O]{K_2SO_4} (NH_4)2SO_4 + H_2O.$$

Then the amount of nitrogen is estimated from the amount of ammonia liberated by distilling the digest with alkali (NaOH)

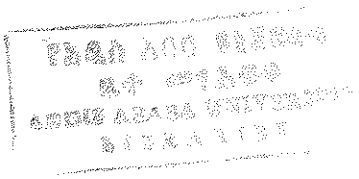
$2(NH_4)SO_4 + 4NaOH \rightarrow 2Na_2SO_4 + 4NH_3 + 4H_2O.$

The ammonia liberated is trapped by boric acid and titrated using HCl.

$NH_3 + H_3BO_3 \rightarrow NH_4H_2BO_3.$

$NH_4H_2BO_3 + HCl \rightarrow NH_4Cl + H_3BO_3.$

To one gram soil sample, passed through a 0.5 mm sieve, 7 g of potassium sulphate and 0.8 g of cupric sulphate was added into macro kjeldahl tube. The mixture was digested at 420°c for about two hours until a clear green solution developed. After cooling, 75 ml of distilled water was added and let to stand overnight. Then the digest was distilled by dispersing 50 ml of 40% sodium hydroxide. The distillate was received in 25 ml of 4% boric acid mixed indicators and titrated with 0.1N hydrochloric acid until the green color of the distillate changed to neutral grey. Similarly the blank was



also passed through all the steps like that of the samples to compensate for any contributions from the reagents used. Then the percent (%) of nitrogen present in the soil samples was calculated as follows:

$$\%N = \frac{(T-B) \times N \times 14.007 \times 100}{\text{Weight of sample in mg}}$$

Where T - titration volume of the sample

B - titration volume from the blank

N - normality of the acid

3.4.5. **Determination of soil available phosphorus**

Available phosphorus in the soil was determined following Bray no.1. method as described in Juo (1978). To one gram of soil sample, passed through 2 mm sieve, 7 ml of extracting solution was added. This was shaken for 2 minutes. Then 2 ml of the clear supernatant was pipetted into 20 ml test tubes. Into 2 ml supernatant 5 ml distilled water and 2 ml of ammonium molybdate solution was added and the content mixed. Then one ml of diluted stannous chloride ($SnCl_2.2H_2O$) was added and after 5 minutes the transmittance of the resulting complex was determined using spectrophotometer (Spectronic 1001) at 660 nm. The concentration of available phosphorus in the soil was calculated from the standard curve obtained with known concentrations of phosphorus. The concentration of dilute fluoride - diluted acid extractable p in the soil was

calculated as follows:

$$\text{ppm of P in soil} = \text{ppm of P in soil sol.} \times \frac{\text{Volume of the mixture}}{\text{Volume of the extract}} \times \frac{\text{Volume of extracting solu.}}{\text{Weight of sample}}$$

ppm of phosphorus in soil = ppm of phosphorus in soil solution x 10/2 x 7/1 = ppm of phosphorus in solution x 35

3.5. **Measurement of growth parameters**

The effects of addition of varying concentration of nitrogen and phosphorus on plant pseudostem girth, leaf area development, leaf number, total leaf area total dry matter production, root : shoot ratio, tissue nitrogen and phosphorus contents, chlorophyll content, percent nutrient stress were determined as follows:

Pseudostem girth

The rate of pseudostem increase of suckers was studied by measuring the pseudostem girth every two weeks. Measurements were taken from the thickest point of the pseudostem. The rate of increase in pseudostem girth in a given period of time was obtained by subtracting the final value from the initial.

Number of leaves

The number of leaves of each plant under each treatment was counted throughout the experiment at two weeks interval.

Leaf area increase

The area expansion of leaves was estimated by measuring the maximum width (W) and length (L) (along the midrib from the leaf base to the tip) of the first fully expanded leaves using measuring tape. Measurement was taken in a weekly interval and individual leaf area (A, cm^2) was calculated as a product of leaf width, leaf length and a shape factor (0.682). The value of the shape factor was calculated by finding the relationship between the actual leaf area and estimated leaf area. Actual leaf area was obtained by projection of the leaf shape of randomly selected leaves on a millimetre paper and calculating the area of inscribed squares. The value of estimated leaf area was calculated by multiplying length (L) with width (W) of the leaves.

Estimation of level of nutrient stress

Stress is expressed as the proportion by which the growth rate of the crop falls short of the maximum rate attained with a non-limiting supply of the nutrient(s). The percent stress in enset was estimated following the method described in Greenwood (1976). Greenwood (1976) proposed five plant parameters for estimating nitrogen stress. These are, leaf nitrogen, dry weight, leaf elongation, leaf area and carbon dioxide exchange

rate. In the present experiment leaf area increment was used to estimate nitrogen stress. Since the techniques described below for estimating nitrogen stress can also be adopted for other nutrients, in this experiment the technique was also used for estimating phosphorus stress. Thus, at a particular nutrient level, intensity of nutrient stress (nitrogen, phosphorus or both) was estimated using the formula:

$S = 100\ (A_{max}-A)/A_{max}$

in which **S** is stress, **A** is the change in leaf area of the deficient plant over a given time interval, A_{max}, is the corresponding change in leaf area for a plant given a non-limiting dose of nutrient.

Dry matter and root (under-ground parts) : shoot (above-ground parts) ratio.

Prior to treatment, at the end of the third and sixth months of growth period, plants were randomly selected and separated into leaves, stems, corm and roots, washed in tap water to remove soil and debris, dried at 105°C and weighed until constant weight was attained. The data were expressed dry weight per plant and the ratio of root (under-ground parts) and shoot (above-ground parts).

Total leaf area

The leaf disc method as described by Adjei-Twum and Splittstorsser (1976) was used for the determination of total leaf area. All leaves were removed from five randomly selected plants per treatment and 2.8 cm^2 disc was cut from a random sample of 18 leaves. After drying the discs and the remaining leaves, the total area was estimated

from the known area of the discs, the dry weight of the discs and the total dry weight of the leaves.

Determination of total chlorophyll in the leaves

The method described by Arnon (1949) was used for the determination of chlorophyll. Third leaf of three randomly selected plants from each levels of nitrogen (0, 10, 50 and 250 mg/liter) with 0 mg/liter levels of phosphorus were removed and composited into one sample. 5 g of fresh leaves from each treatment were taken and blended with 50 ml of 80% acetone (v/v) in a mortar. The slurry was twice strained with four layer cheese cloth, filtered and the filtrate centrifuged for 30 minutes. The pellet was suspended in 10 ml 50% acetone (v/v) and the second supernatant combined with the first and the same process repeated for the third time and the three supernatant combined together and the volume was registered. Then 1 ml of the extract was added to 9 ml of 80% acetone and the optical density was read at 645 and 663 nm with 80% acetone as a blank. Then the amount of total chlorophyll was estimated using the following equation.

Total chlorophyll (μg/ml) = $20.2\ A_{645} + 8.02\ A_{663}$.

Determination of nitrogen and phosphorus in plant tissues

For analyses of nitrogen and phosphorus in plant tissues, the upper recently matured leaves were sampled. Immediately after sampling, samples were placed in plastic bags,

brought to the laboratory and washed thoroughly with distilled water to remove any contamination. Samples were then placed in clean paper bags and dried at 65°C for 48 hours. Subsequently, the leaves were ground with a mortar to pass a 0.5 mm sieve and stored in vials till analysis. The roots were also similarly treated. For the determination of the concentrations of nitrogen and phosphorus in plant tissues a similar process of digestion was used. The materials were digested with concentrated sulphuric acid and hydrogen peroxide at elevated temperature under the influence of selenium as a catalyst (Yerima, 1992). Digestion was initiated by transferring 0.3 g of plant material and 2.5 ml of the digestion mixture (sulphuric acid - selenium - salicylic acid) to a digestion tube and allowed to stand for two hours including the blank digest. Then the tubes were placed in the heating digestion block and heated at 100°C for two hours. After heating, the tubes were removed from the block and allowed to cool. Then 1 ml of hydrogen peroxide was added three times successively by mixing thoroughly after each addition. Again the tubes were placed in the preheated block at 330°C until the digest turned to colourless or light yellow. After cooling 50 ml of distilled water was added and the contents were mixed. This was allowed to stand overnight. Then the digests were filtered into 100 ml volumetric flasks and filled up to the mark with distilled water. The digest was used to determine total nitrogen and phosphorus.

Total nitrogen

Total nitrogen from plant samples was determined by distillation of the aliquot (50 ml) from the digest with 40% sodium hydroxide which was received in 25 ml of boric acid and then titrated with 0.1N HCl to the end point of mixed indicators. The distillation,

titration as well as calculation of % nitrogen from plant sample was done in the same way as for the soil.

Phosphorus

The amount of phosphorus in the digest was determined colorimetrically by using molybdate and metavandate for color development. Five ml of sample from the sample digest was pipetted into 100 ml volumetric flask and 20 ml of molybdate and metavandate solution was added. Then the flasks were filled with distilled water up to the mark. After 10 minutes absorbance was determined at 400 nm wave length. The concentration of phosphorus in the sample digest was calculated from the standard curve of known concentration of phosphorus (Yerima, 1992).

$$P.ppm = \frac{(a-b) \times V_1 \times V_2}{S \times A}$$

Where a = Phosphorus concentration in the sample digest obtained from the standard curve, ppm.

b= Concentration of the blank digest in ppm P read from the curve.

V_1 = Volume of the digest (100 m1)

V_2 = Volume of the dilution (100 ml)

S = Weight of the plant material digested (0.3g).

A = Aliquot (5 ml)

3.6. **Statistical analysis**

All collected data were subjected to statistical analysis using the MINITAB statistical package version 10. One way and two way analysis of variance tests were used to identify the significant effects of nitrogen and phosphorus treatments as well as to determine the interaction of the two nutrients. Variance analysis (one way ANOVA) using Tukey's Family Error Rate was used to test for significant differences among treatments for all data sets.

4. RESULTS

4.1. Results of soil analysis

Results of soil analysis for texture, pH, organic carbon, organic matter, total nitrogen and available phosphorus are presented in Table 2. The texture of the soil was loamy sand. The pH was acidic and it increased with increasing years of cultivation. The value ranged from 4.8 (at recently transplanted site) to 6.3 (at a farm that have been under enset cultivation for more than 30 years) in the upper 0-30 cm layer. The organic carbon content also increased with increasing years of cultivation. It ranged from 1.6 (at recently transplanted site) to 3.3 (at the farm which was cultivated for more than 30 years) in the upper 0-30 cm depth. The total nitrogen of the soil also increased with increasing years of enset cultivation. The value for total nitrogen ranged from 0.28 percent (at newly transplanted site) to 0.69 percent (at the old site) in the upper 0-30 cm depth. The available phosphorus also progressively increased as years of enset cultivation increased. The value ranges from 8.7 ppm (at recently transplanted site) to 148 ppm (at the old farm site) in the upper 0-30 cm depth.

4.2. Pseudostem girth measurements

Effect of varying concentrations of nitrogen and phosphorus supply on the pseudostem girth of enset suckers is shown in Fig 2 and Appendix 1. The results indicated that the pseudostem girth of enset suckers was significantly influenced by nitrogen and phosphorus supply. The interaction between the two nutrients was also highly significant

Table 2. Some physical and chemical properties of soils on which enset had been cultivated for years.

Years of cultivation	Depth in (cm)	Particle size distribution			pH	O.C	OM	Total nitrogen	Available phosphorus
		Sand	Clay %	Silt		%	%	%	ppm
Recent (less than a year)	0-30	78	9	13	4.8	1.6	2.8	0.28	8.7
	30-60	79	6	15	4.5	1.1	1.9	0.25	7.4
2-5 Years	0-30	77	8	15	5.1	1.7	2.9	0.38	15.0
	30-60	83	5	12	4.7	1.4	2.4	0.24	10
10-15 Years	0-30	84	3	13	5.8	1.9	3.3	0.56	130
	30-60	76	7	17	5.2	1.1	1.9	0.21	7.4
More than 30 Years	0-30	91	7	2	6.3	3.3	5.6	0.69	148
	30-60	84	2	14	5.4	2.1	3.6	0.37	11.7

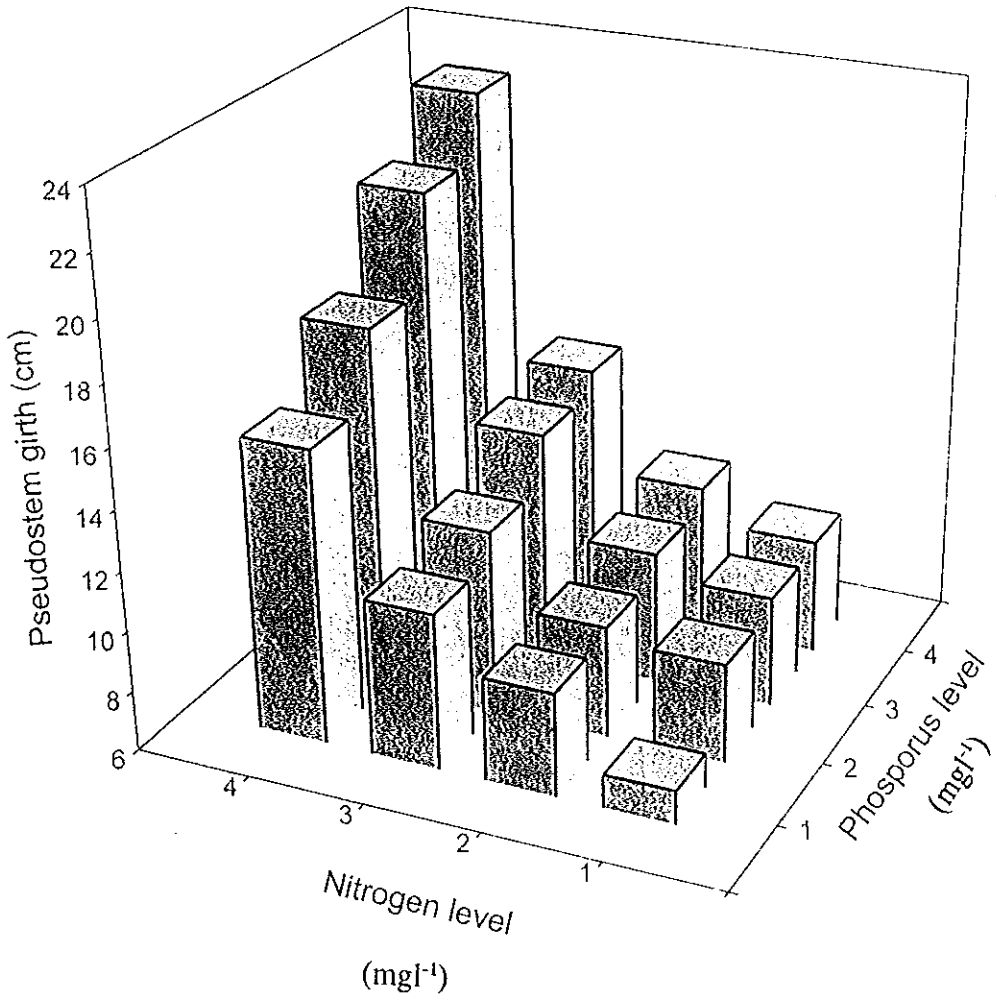


Fig. 2. Relationship between varying concentrations of nitrogen and phosphorus in solution and pseudostem girth of enset suckers

($P < 0.001$) (Table 5). As shown in Fig 2 and Appendix 1, nitrogen at its lowest treatment (10 mgl^{-1}) had no significant effect on pseudostem girth over the controls. However, nitrogen concentration of 50 mgl^{-1} and above resulted in significant increase in pseudostem girth. The effects of phosphorus on pseudostem girth of enset suckers were pronounced more when nitrogen concentration in the solution was 50 mgl^{-1} or above. The highest increase in pseudostem girth was recorded from plants treated with 250 mgl^{-1} nitrogen and 81 mgl^{-1} phosphorus and the lowest value was obtained from the controls. It ranged from 7.12 ± 1.82 (at N_1P_1) to 23.11 ± 1.79 (at N_4P_4). The plants response in pseudostem girth increase was higher with increasing nitrogen than with increasing phosphorus.

4.3. **Dry matter production and root : shoot ratio**

Dry matter production of suckers as affected by varying concentration of nitrogen and phosphorus in solution is shown in Fig 3 and Appendix 2. Dry matter production was significantly influenced both by nitrogen and phosphorus supply. Interaction between the two nutrients was also highly significant ($P < 0.001$). Nitrogen treatment 10 mgl^{-1} had no significant effect on biomass production compared with the controls (N_1P_1). The change in biomass of enset suckers due to increasing concentrations of phosphorus was very small as compared with biomass increase due to increasing concentrations of nitrogen. Significant change in biomass due to changes in phosphorus concentration was observed only at its higher levels (81 mgl^{-1}). The highest biomass, 202.64 ± 30.52 $g(plant)^{-1}$ was obtained from plants treated with 250 mgl^{-1} nitrogen and 81 mgl^{-1} phosphorus, a value almost four times higher than that recorded for the controls (N_1P_1).

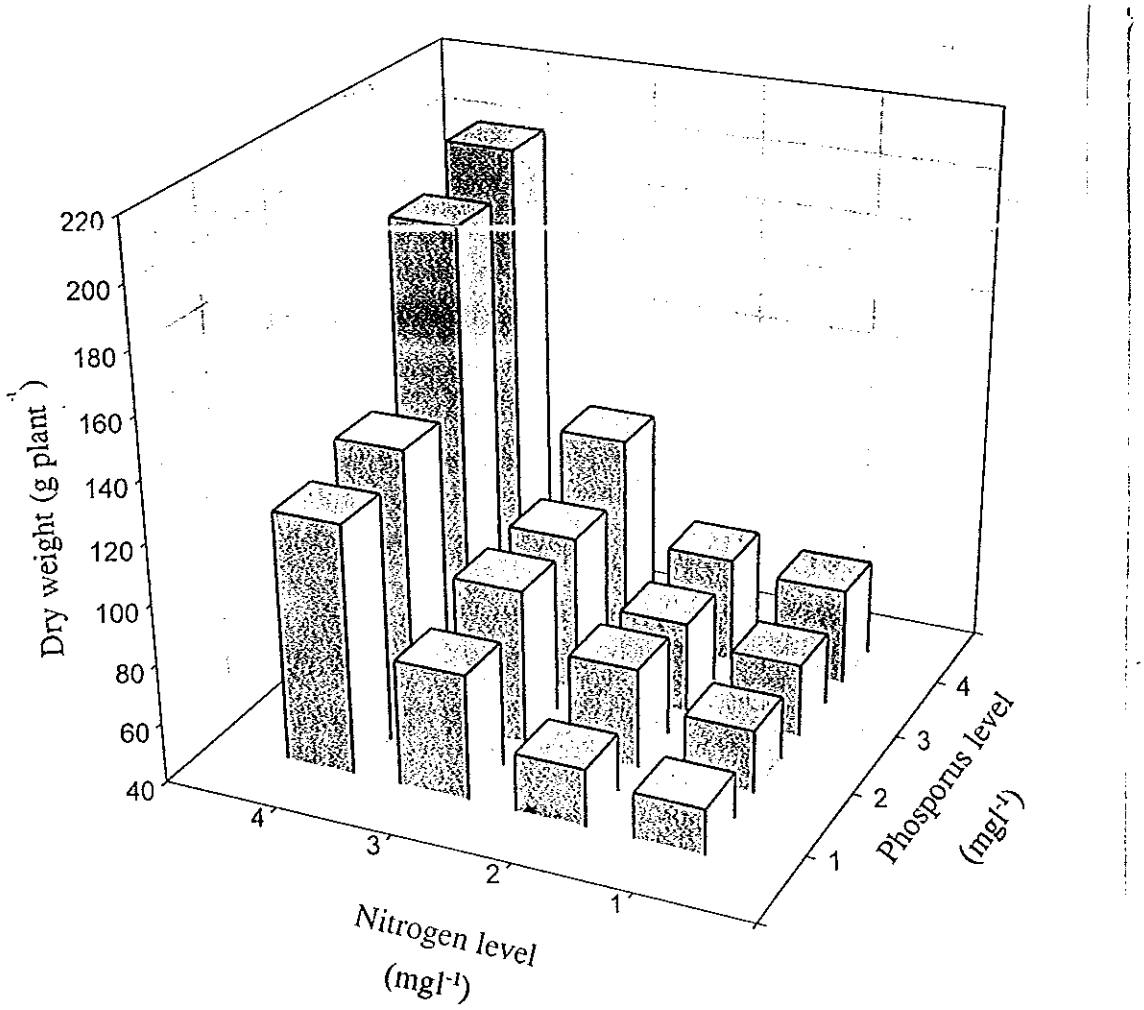


Fig. 3. The effect of addition of different concentrations of nitrogen and phosphorus in solution on dry weight of enset suckers.

Root : shoot ratio (shown in Table 3) decreased with increasing levels of nitrogen and phosphorus. It ranged from 1.07 $\pm$ 0.17 (at N_1P_1) to 0.47 $\pm$ 0.20 (at N_4P_4). The root : shoot ratio at N_4P_1 was 0.49 $\pm$ 0.07 and at N_1P_4 it was 0.85 $\pm$ 0.24. This showed that in comparison with higher levels of nitrogen higher levels of phosphorus resulted in higher root : shoot ratio.

4.4 Leaf number

Mean increase in leaf number of enset suckers is shown in Fig 4 and Appendix 3. Results of statistical analysis showed that the leaf number of enset suckers was significantly enhanced by increasing concentrations of nitrogen and phosphorus. The interaction between the two nutrients was also highly significant ($P < 0.001$). Nitrogen at its lowest treatment (i.e., 10 mgl^{-1}) did not bring any significant effect irrespective of the phosphorus concentration in solution. Phosphorus concentration also resulted in significant increase in leaf number although leaf number due to addition of 9 mgl^{-1} and 27 mgl^{-1} phosphorus was not significantly different at low nitrogen levels. The highest increase in leaf number was recorded from suckers treated with 250 mgl^{-1} and 81 mgl^{-1} nitrogen and phosphorus, respectively and the lowest value of leaf number was recorded from the control treatment.

Table 3. Relationship between varying concentrations of nitrogen and phosphorus in solution and the ratio of root (under-ground parts) and shoot (above-ground parts) (n=8, Mean ± sd).

	P_1	P_2	P_3	P_4
N_1	1.072 ± 0.172^{aA}	1.033 ± 0.097^{abA}	0.933 ± 0.091^{abA}	0.851 ± 0.236^{bA}
N_2	0.927 ± 0.259^{aA}	0.884 ± 0.166^{aA}	0.841 ± 0.156^{aA}	0.702 ± 0.127^{aA}
N_3	0.741 ± 0.221^{aB}	0.672 ± 0.159^{aB}	0.592 ± 0.105^{aB}	0.588 ± 0.085^{aB}
N_4	0.490 ± 0.075^{aB}	0.506 ± 0.079^{aB}	0.537 ± 0.089^{aB}	0.466 ± 0.199^{aB}

Means followed by the same lower case letter in rows and means followed by the same upper case letter in columns are not significantly different at $P<0.05$ as determined by Tukey's, Family Error Rate.

4.5. **Total leaf area**

Results of the study of the effects of varying concentrations of nitrogen and phosphorus in total leaf area of enset suckers is shown in Fig 5 and Appendix 4. Nitrogen treatment of 10 mgl^{-1} did not affect the total leaf area significantly. However, increasing concentration of nitrogen above 10 mgl^{-1} resulted in significant increase in total leaf area of suckers. The effect of phosphorus on total leaf area of enset suckers was very small and it was pronounced only at higher levels of nitrogen in solution (i.e., 50 mgl^{-1} and 250 mgl^{-1} nitrogen). The highest total leaf area was obtained from plants treated with 250 mgl^{-1} nitrogen and 81 mgl^{-1} phosphorus and the lowest total leaf area was recorded from the controls.

4.6. **Chlorophyll content**

In this study the effect of increasing concentrations of nitrogen on chlorophyll content of enset suckers were studied at 0 level of phosphorus. The results are shown in Table 4. The results showed that addition of 10 mgl^{-1} nitrogen did not increase chlorophyll content significantly. However, addition of 50 mgl^{-1} and 250 mgl^{-1} nitrogen increased the chlorophyll content of enset suckers significantly.

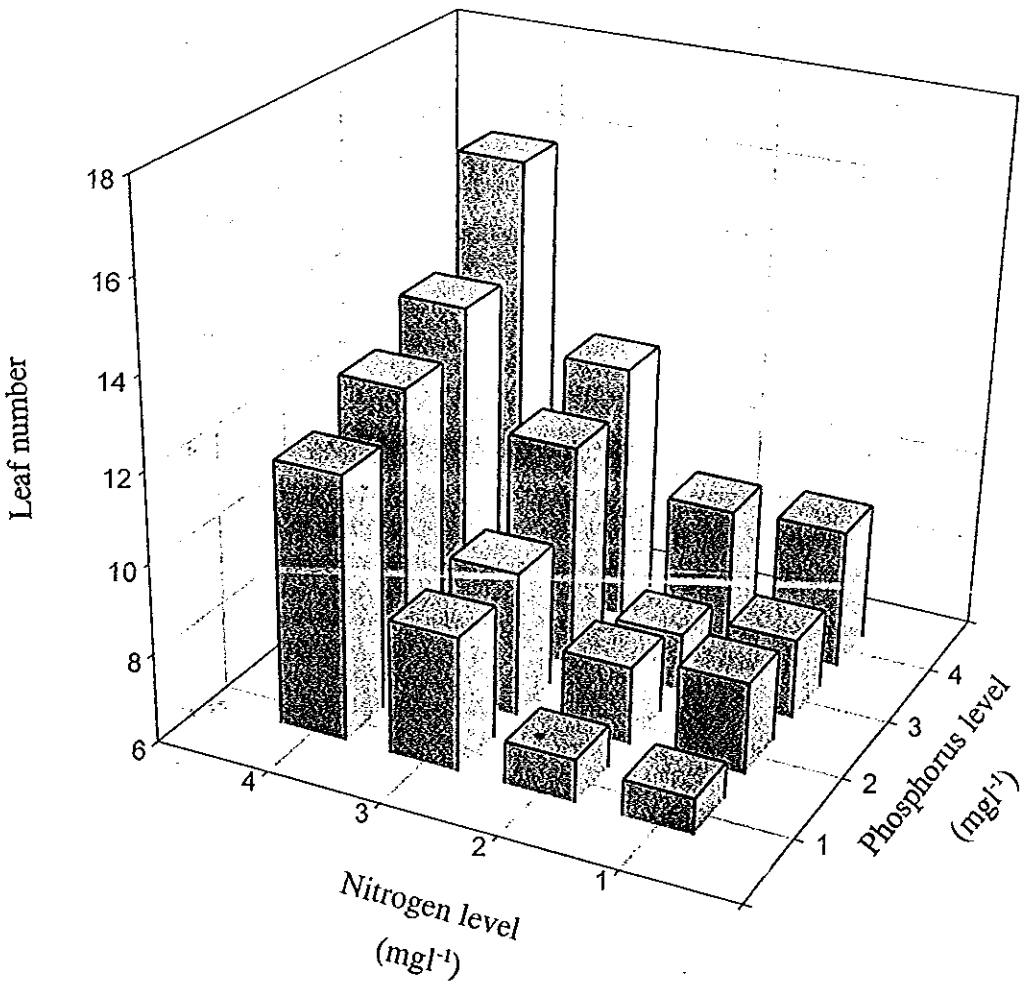


Fig. 4. Influence of varying concentrations of nitrogen and phosphorus in solution on leaf number of enset suckers.

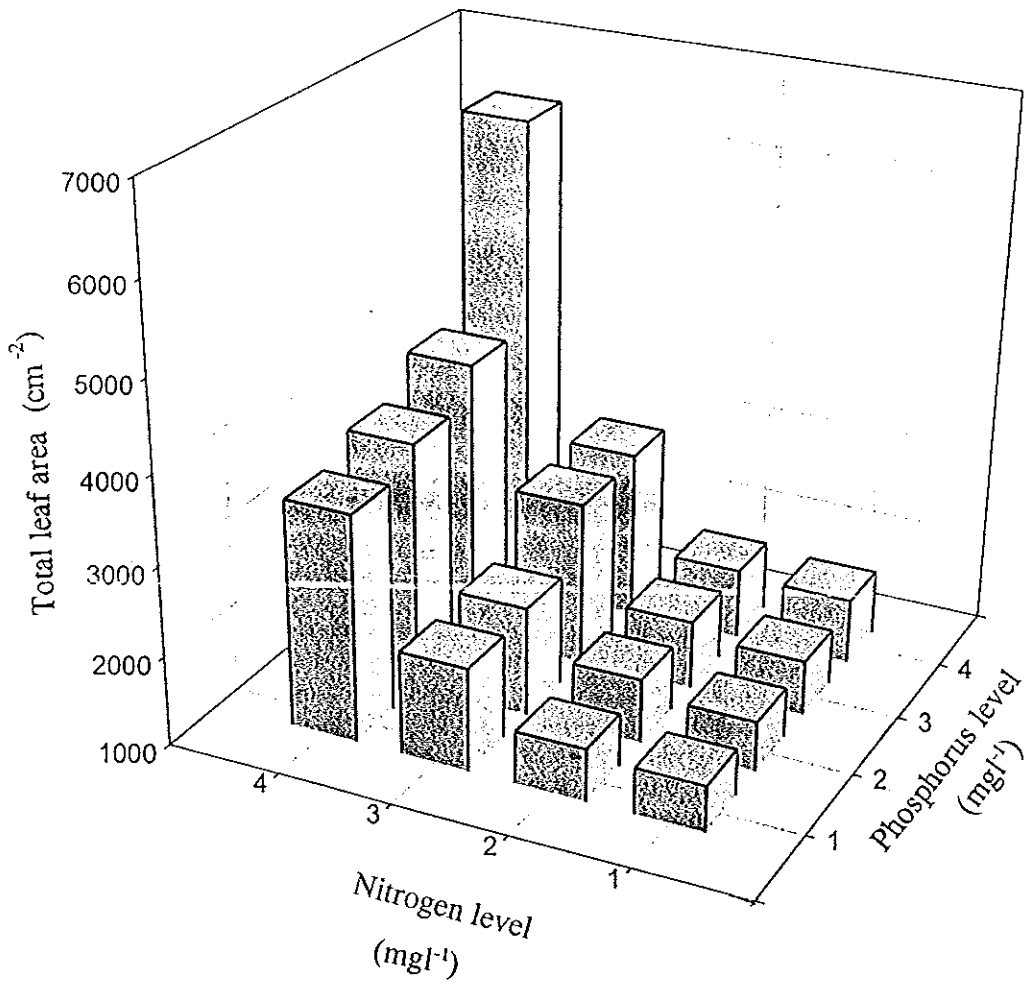


Fig. 5. Effect of added nitrogen and phosphorus in solution on total leaf area of enset suckers.

Table 4. Effect of increasing concentrations of nitrogen in solution on chlorophyll content of enset leaves (μg/ml)

Nitrogen level (mgl^{-1})	Chlorophyll Content (μg/ml)
0	0.379 ± 0.063^{a}
10	0.402 ± 0.062^{a}
50	0.751 ± 0.053^{b}
250	1.499 ± 0.055^{c}

Means followed by the same lower case letter in columns are not significantly different at $P<0.05$ as determined by Tukey's, Family Error Rate.

4.6. **Tissue nitrogen concentration**

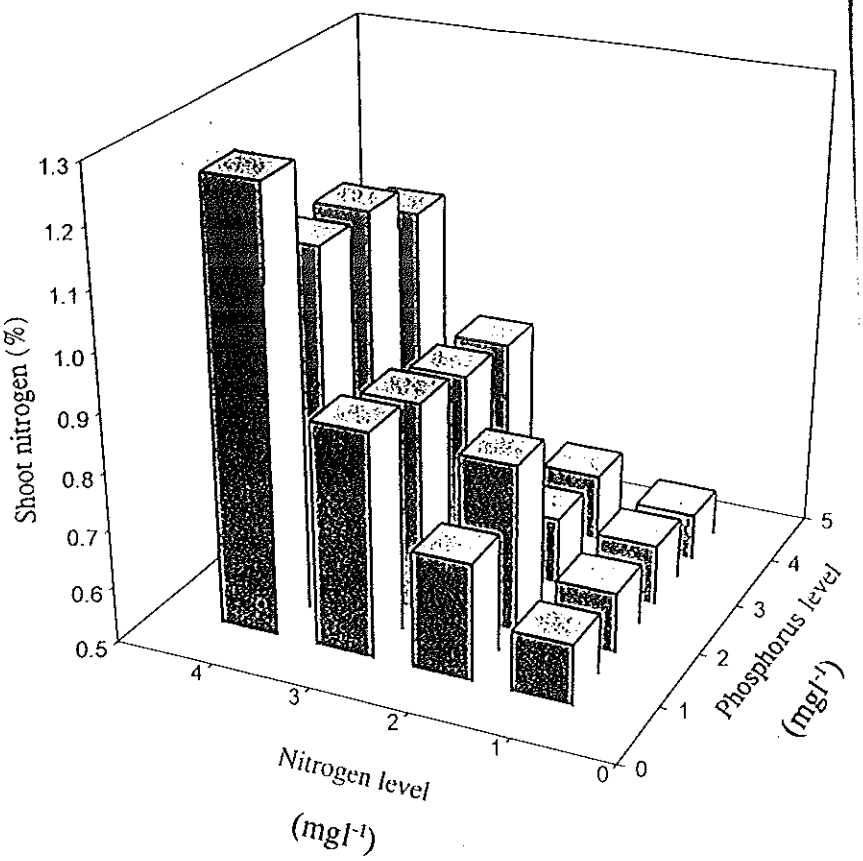
Percent nitrogen in the shoot and root of enset suckers are shown in Fig. 6-a and Fig. 7-a, respectively. The percentage of nitrogen in the shoot ranged from 0.61 ± 0.06 (at N_1P_1) to 1.04 ± 0.05 (at N_4P_4). Root nitrogen ranged from 0.19 ± 0.03 percent (at N_1P_1) to 0.48 ± 0.05 (at N_4P_4). There was a significant increase in percent nitrogen in the shoot with increasing concentration in solution, although there was no difference in shoot nitrogen concentration between suckers that received 10 mgl^{-1} nitrogen and the controls. At a given nitrogen concentration increasing concentrations of phosphorus in solution had no significant effect on shoot nitrogen concentrations. However, at 250 mgl^{-1} nitrogen level, increasing concentration of phosphorus in solution resulted in

reduction of percent shoot nitrogen concentration (although the difference was not significant). Increasing concentration of nitrogen in solution also resulted in significant difference in root nitrogen concentration. In this particular study root nitrogen concentration due to 10 mgl^{-1} did not differ significantly with root nitrogen concentration due to 50 mgl^{-1} nitrogen supply. Similar to the shoot nitrogen concentration, percent root nitrogen concentration was not affected significantly by increasing phosphorus concentration in solution.

4.7. **Tissue phosphorus concentration**

Results of analysis of phosphorus concentration in the shoot and root of enset suckers are shown in Fig 6-b and Fig 7-b, respectively. The percentage of phosphorus in the shoot ranged from 0.11 $\pm$ 0.02 (at N_1P_1) to 0.48 $\pm$ 0.05 (at N_4P_4). The percentage of phosphorus in the root ranged from 0.03 $\pm$ 0.02 (at N_1P_1) to 0.21 $\pm$ 0.01 (at N_4P_4). Both the percentage of phosphorus in the shoot and root were significantly increased ($P < 0.001$) following increased concentration of phosphorus in solution. There was also a significant interaction between the two nutrients ($P < 0.001$) (Table 5). Phosphorus concentration in solution higher than 9 mgl^{-1} resulted in increase in shoot phosphorus concentration (Fig. 6-b). Nitrogen concentration (250 mgl^{-1}) also brought significant difference in shoot phosphorus concentrations. Similarly, phosphorus concentration higher than 9 mgl^{-1} resulted in significant change in root phosphorus concentration (Fig 7-b). Nitrogen concentration 50 mgl^{-1} and 250 mgl^{-1} in solution influenced the root phosphorus concentration significantly.

a



b

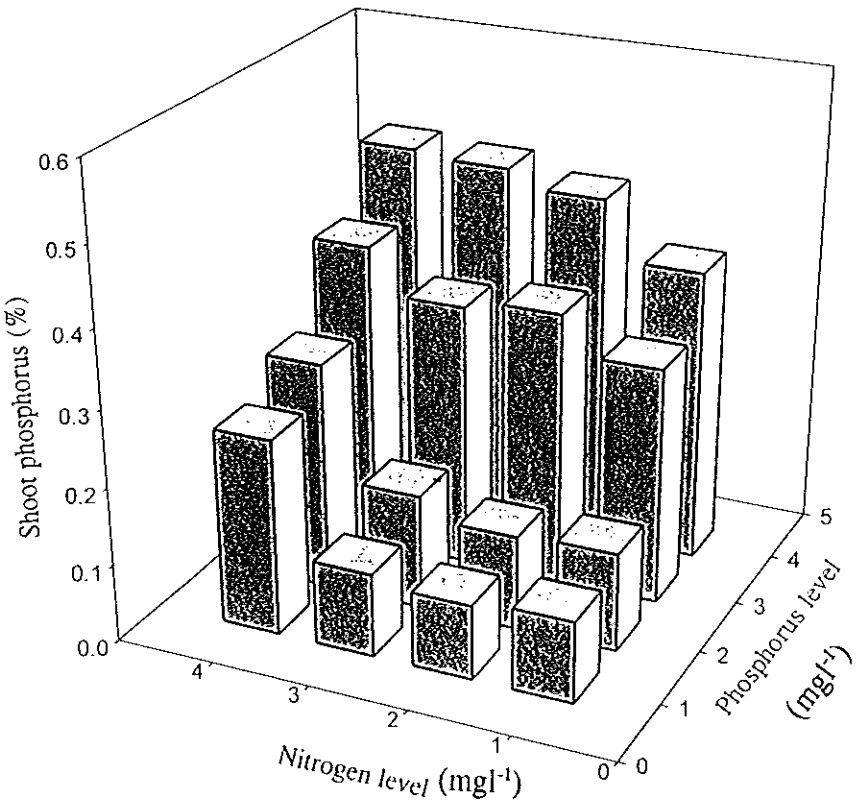
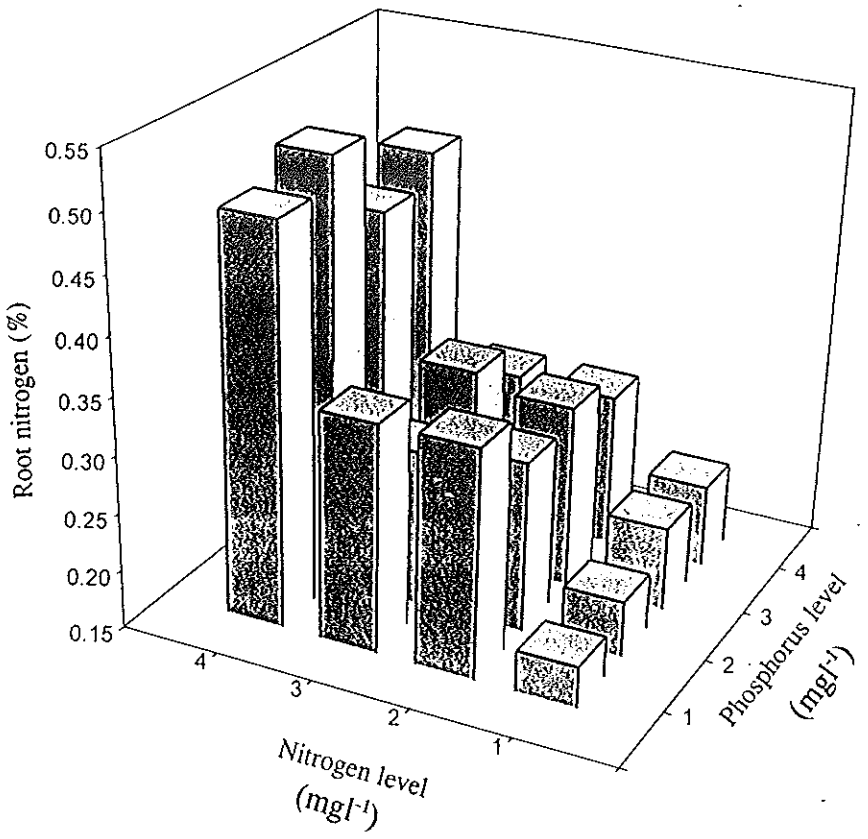


Fig. 6. Relationship between varying concentrations of nitrogen and phosphorus in solution and shoot nitrogen concentration (a) and shoot phosphorus concentration (b) of enset suckers.

a



b

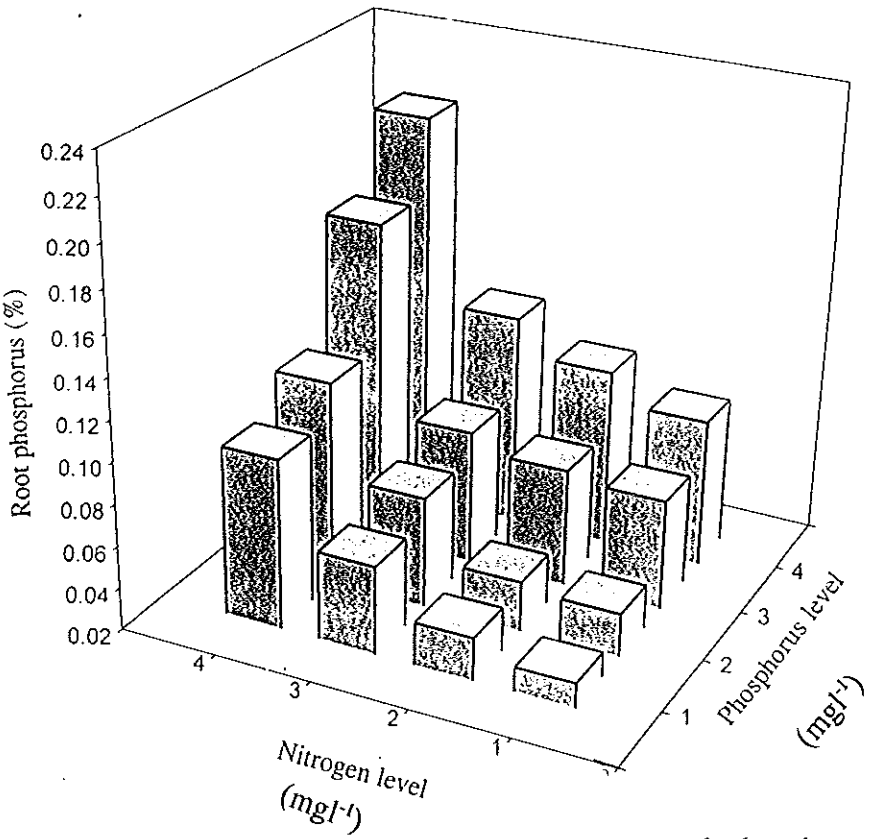


Fig. 7. Relationship between varying concentrations of nitrogen and phosphorus in solution and root nitrogen concentration (a) and root phosphorus concentration (b) of enset suckers

4.9. **Levels of nutrient stress**

Levels of nutrient stress were calculated based on leaf area increase/week taking 250 mgl^{-1} nitrogen and 81 mgl^{-1} phosphorus as non-limiting levels. Results are shown in Fig. 8. The results showed that there was 69.4 percent nutrient stress at N_1P_1 (i.e., at 0 levels of nitrogen and phosphorus supply). There was 22.7 percent nutrient stress at N_4P_1 (i.e., at 250 mgl^{-1} nitrogen and 0 levels of phosphorus supply) where as at N_1P_4 (i.e., at 0 nitrogen and 81 mgl^{-1} levels of phosphorus supply) there was 38.2 % nutrient stress. Percent nutrient stress was much higher when nitrogen was absent from the solution than phosphorus was absent.

4.10. **Levels of nitrogen stress**

Levels of nitrogen stress was calculated based on leaf area increase/week taking 250 mgl^{-1} nitrogen as non-limiting level. Calculated levels of nitrogen stress is shown in Fig. 9. Nitrogen stress at N_1P_1 was 60.3 %. There was 36.27 % stress with 10 mgl^{-1} nitrogen and 0 phosphorus. When nitrogen in solution was raised from 10 mgl^{-1} to 50 mgl^{-1}, percent nitrogen stress was reduced to 30.8 %. The percent nitrogen stress showed a decrease when the nitrogen and phosphorus concentrations in solution increased.

4.11. **Levels of phosphorus stress**

Levels of phosphorus stress were calculated based on leaf area increase/week taking 81 mgl^{-1} phosphorus as non-limiting level. Results are shown in Fig. 10. The results indicated that there was 50.4 % phosphorus stress at P_1N_1. There was 38.5 % phosphorus stress with addition of 9 mgl^{-1} phosphorus and 0 nitrogen. With addition of 27 mgl^{-1} and 0 nitrogen the percent stress was reduced to 14.4 %. In general it was observed that the percent phosphorus stress decreased with increasing concentration of both phosphorus and nitrogen. However, the percent phosphorus stress decreased more in the direction of increasing phosphorus than increasing nitrogen.

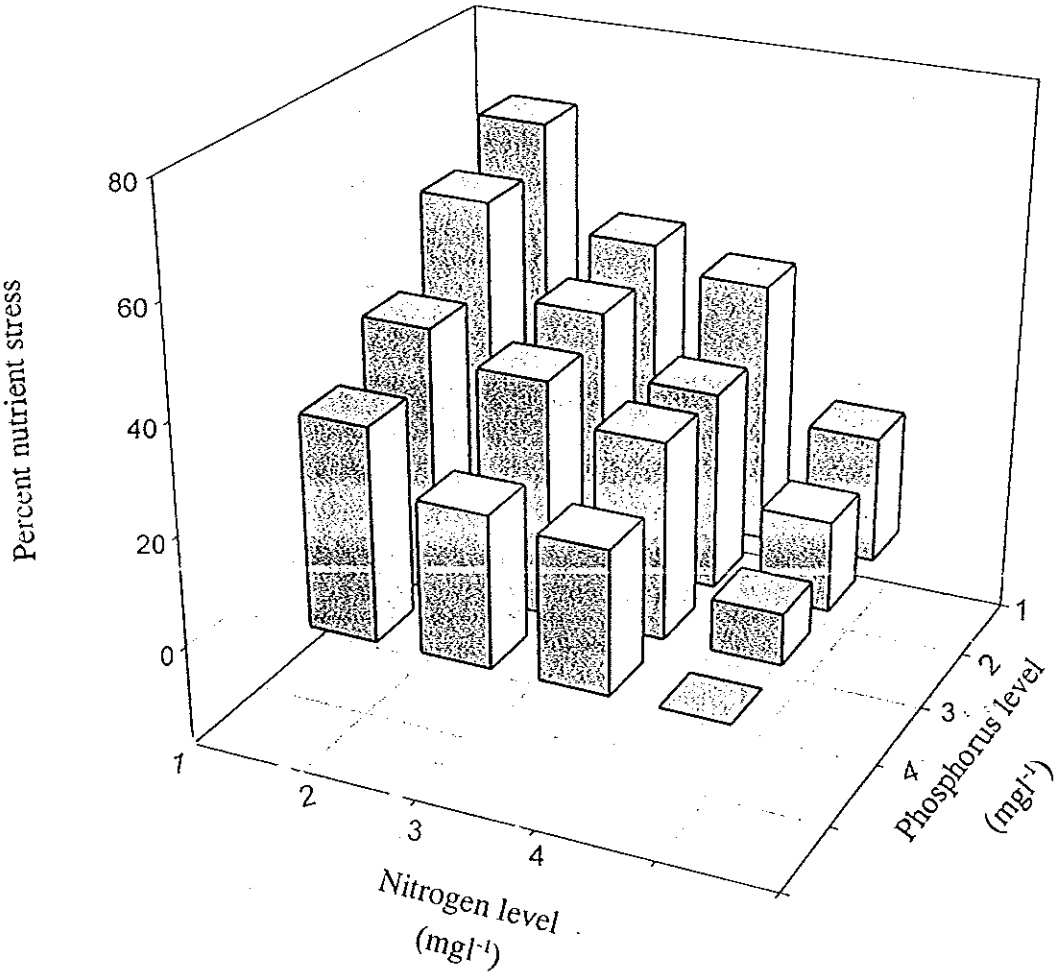


Fig. 8. Effect of varying concentrations of nitrogen and phosphorus in solution on percent nutrient stress of enset suckers.

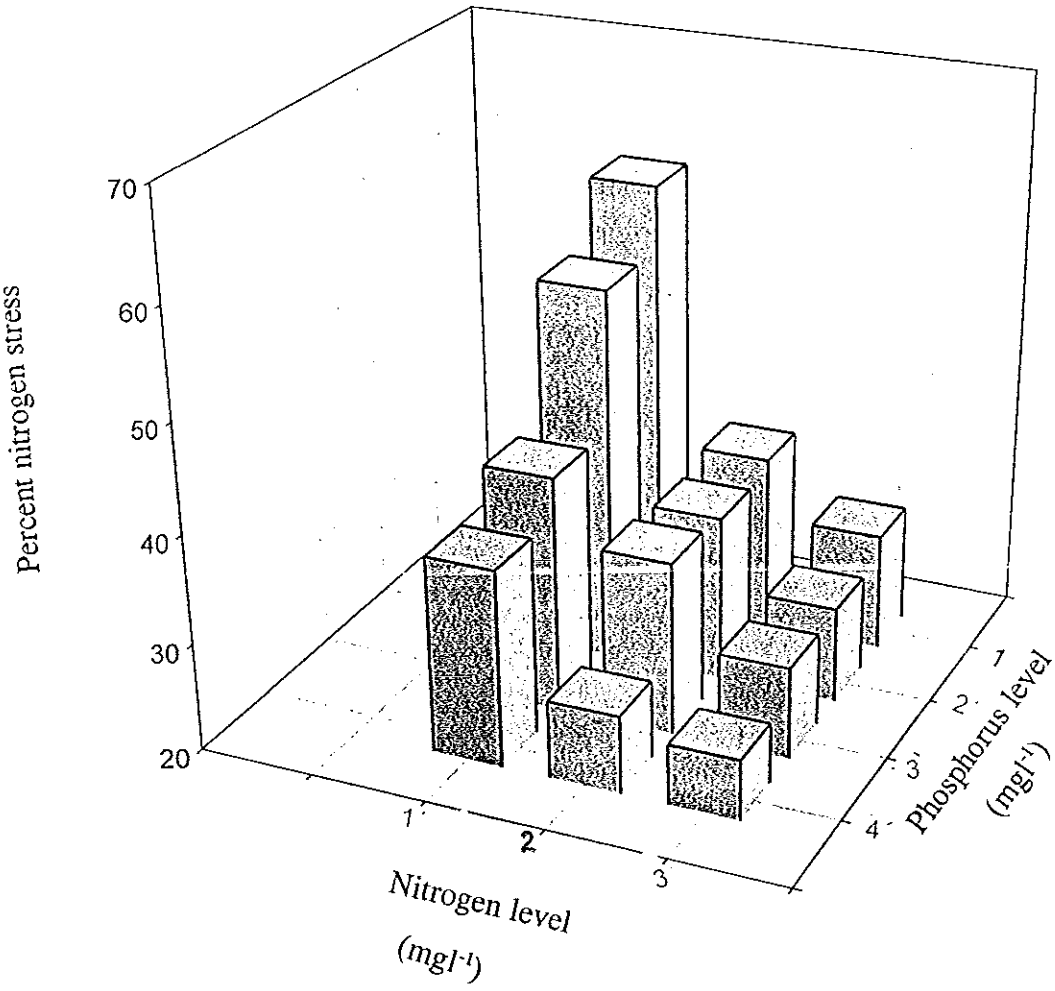


Fig.9. Effect of varying concentrations of nitrogen and phosphorus in solution on percent nitrogen stress

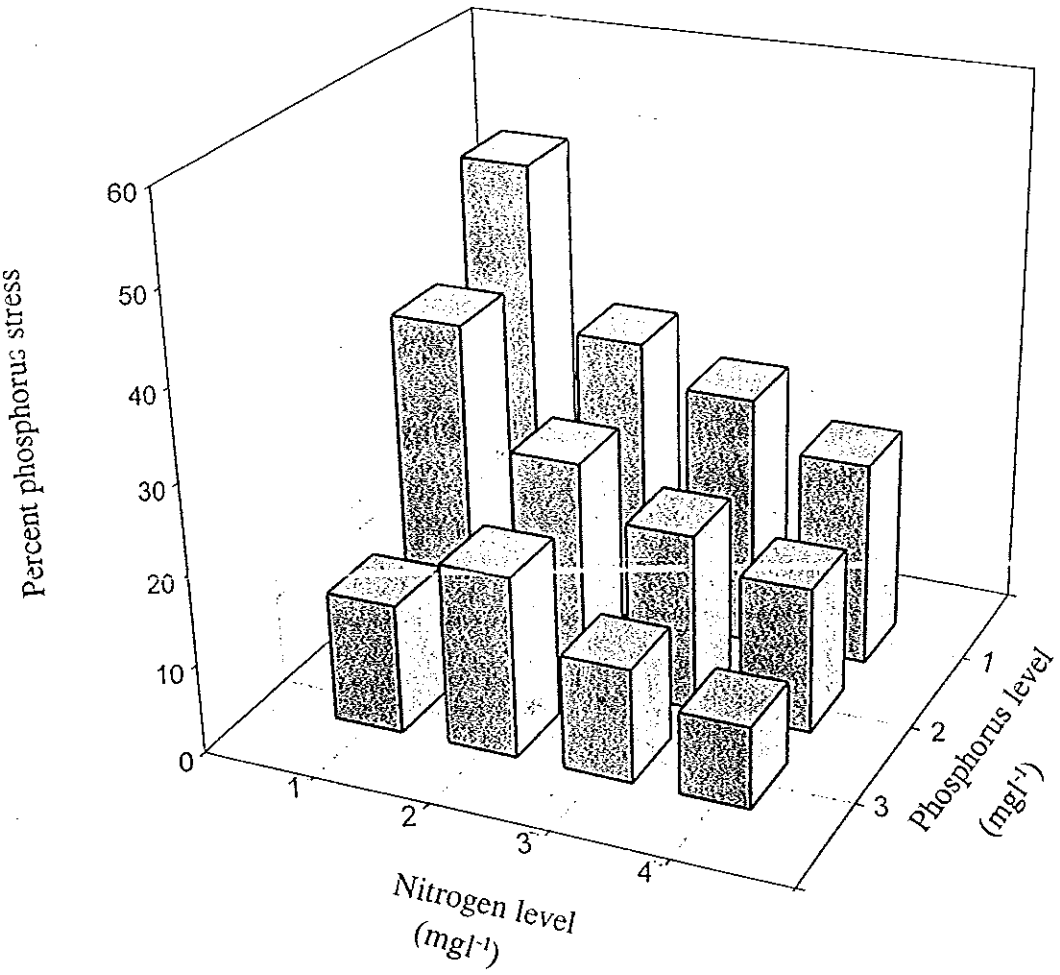


Fig.10. Effect of varying concentrations of nitrogen and phosphorus in solution on percent phosphorus stress of enset suckers.

Table 5. Results of two way ANOVA for test of significance difference between treatments in increase in pseudostem girth, leaf number, total leaf area and total biomass production.

Source	Pseudostem girth				Leaf number				Total Leaf area				Total biomass production			
	DF	MS	F	P	DF	MS	F	P	DF	MS	F	P	DF	MS	F	P
Nitrogen(N)	3	1867.2	705.8	<0.001	3	584.4	789.4	<0.001	3	35479952	515.4	<0.001	3	65043	265.7	<0.001
Phosphorus(P)	3	223.7	84.6	<0.001	3	114.5	154.7	<0.001	3	4100966	59.6	<0.001	3	7806	31.9	<0.001
N*P	9	29.5	11.1	<0.001	9	6.8	9.1	<0.001	9	1864508	27.1	<0.001	9	2351	9.6	<0.001
Error	320	2.7			304	0.7			64	68842			112	245		

5. DISCUSSION

The results of soil analysis of samples collected from areas that differed in total number of years under enset cultivation clearly showed that organic carbon, organic matter, total nitrogen and available phosphorus of soils increased with increasing years of cultivation (Table 2). The pH of the soil tended to increase with increasing years of cultivation. This is probably associated with the influence of ash applied to enset fields along with cow dung and household wastes. The relative increase in organic carbon (organic matter) of the soil with cultivation may be caused by continuous application of cow dung, other household wastes and decomposition of leaves and leaf sheaths of enset. The increase in total nitrogen and available phosphorus with cultivation may be due to increased soil organic matter. Soil organic matter is the most desirable source of nitrogen and phosphorus (Soon, 1983).

In the present study, increasing concentrations of nitrogen and phosphorus supply resulted in significant increase in pseudostem girth. The highest pseudostem girth, 23.11 $\pm$ 1.79 (cm) was obtained from plants that received the highest concentration of nitrogen and phosphorus (250 mgl^{-1} nitrogen and 81 mgl^{-1} phosphorus) and the lowest pseudostem increase was recorded from plants that received the lowest nitrogen and phosphorus treatment (0 mgl^{-1} nitrogen and 0 mgl^{-1} phosphorus) (Fig. 2). The effect of phosphorus on pseudostem girth was more pronounced with increasing nitrogen concentration in solution. The crop's response to increased concentration of nitrogen and phosphorus through increase in pseudostem girth observed in the present study is in agreement with what was reported for banana by Srnivas (1997). Since both nitrogen

and phosphorus are the two major elements involved in the growth of plants, increase in pseudostem girth of enset suckers with increasing supply of these two nutrients obtained in the present study, indicates the crucial role the two nutrients play on the growth of plants. Higher growth change in the direction of increasing nitrogen supply compared with increasing phosphorus supply might indicate the demand of the plants for nitrogen and the greater influence of nitrogen on vegetative growth than does phosphorus.

One of the objectives of the present work was to see the effects of varying concentrations of nitrogen and phosphorus supply on biomass production of enset suckers. As shown in Fig 3 and Appendix 2 the biomass of suckers were significantly influenced by both nitrogen and phosphorus supply. Increasing nitrogen concentrations above 50 mgl^{-1} increased the total biomass of suckers significantly; further improvement occurred with increasing phosphorus concentration in solution. Increase in biomass of enset in response to addition of both nitrogen and phosphorus, as observed in the present study, is consistent with those reported by Yohannes Uloro and Mengel (1994).

It is well known that nitrogen and phosphorus deficiency usually have overriding control of growth and dominate the effects of other elements. Plants deprived of nitrogen and phosphorus show decreased cell division and expansion (Hewitt and Smith, 1974). Since both nitrogen and phosphorus are elements involved in most life processes, it is clear that a deficiency of either element would limit growth of the above and below ground portions of plants (Grunes, 1959; Nielsen and Halvorson, 1991).

Nitrogen and phosphorus are usually found in nature in variable proportions, and the variable proportions may not necessarily be favourable to plant growth (Masresha Fetene and Amha Belay, 1988). Pemadassa (1983) reported reduced dry matter production of some grasses at higher concentrations of nitrogen and phosphorus. Ingestand and Lund (1979) reported that in birch seedlings the required nitrogen concentration in solution for optimum uptake rate was about 25 mgl^{-1} and higher concentrations of nitrogen above 25 mgl^{-1} are tolerated without growth responses up to 270 mgl^{-1} nitrogen. Pemadassa (1981) reported that the dry weight of *Arundinella villosa* at highest level of phosphorus supply showed a significant reduction when nitrate was raised from 25 to 125 mgl^{-1}. In the present study, however, increasing concentration of nitrogen significantly increased the dry weight of suckers with corresponding increase of phosphorus in solution. In this experiment nitrogen and phosphorus were not added corresponding to optimum consumption rates as Ingestand and Lund (1979). Enset suckers had, however significantly higher dry matter at N_4 (250 mgl^{-1}) than at N_3 (50 mgl^{-1}) and than at N_2 (10 mgl^{-1}). However, addition of phosphorus above 27 mgl^{-1} did not bring any significant change in biomass of enset suckers.

Root : shoot ratio (Table 3) of enset suckers decreased with increasing levels of nitrogen and phosphorus. The highest root : shoot ratio was obtained at N_1P_1 and the lowest root : shoot ratio was obtained at N_4P_4. It ranged from 1.07 ± 0.17 (at N_1P_1) to 0.47 ± 0.2 (at N_4P_4). Compared to higher levels of nitrogen higher levels of phosphorus resulted in higher root : shoot ratio. Shamsi and Whitehead (1977) studied the effect of decreasing concentrations of nutrient solution on the root : shoot ratio of *Lythrum salicaria* and they found that the species responded to each reduction in

nutrient concentration by an increase in root : shoot ratio. Ingestand and Lund (1979) also recorded a similar increase in root : shoot ratio of birch seedlings at low nutrient supply. Cassman *et al.* (1980) also studied the relationship between root and shoot of soy bean during nutrient deprivation and they observed that when plants are deficient in nutrient supply they tend to accumulate more dry matter in their roots, thus resulting in an increase in root : shoot ratio. The carbon allocation patterns of plants changes during plant growth depending upon environmental conditions (Hirose, 1986). Many studies have reported that when nutrients are insufficient, the roots become the dominant sink for photosynthates and root growth is favoured over shoot growth resulting in higher root : shoot ratio. (Goldworthy and Fisher, 1984; Squire, 1990; Marschner, 1995). A large root system and a high rate of root replacement, ensuring a high proportion of young roots, are advantageous for water and mineral nutrient uptake, particularly in soils with low mineral supply (Marschner, 1995). The highest root : shoot ratio at lower nitrogen and phosphorus supply observed in the present study might thus be a physiological response for the shortage of these mineral nutrients. The occurrence of higher root : shoot ratio at higher phosphorus supply compared to higher nitrogen supply might indicate the greater influence of phosphorus on the growth of roots as compared to nitrogen.

Results of the present study showed that leaf number and total leaf area of enset suckers were significantly influenced by nitrogen and phosphorus supply. Leaf number and/or leaf area increase in response to nitrogen and phosphorus supply, as observed in the present study (Fig. 4 and Fig. 5, respectively) is consistent with what has been reported for *Trifolium subterannum* (Bouma, 1970a,b), for wheat (Thomas and Thome, 1975;

Jacob and Lawlor, 1991; Rodriguez *et al.*, 1998), on sunflower (Radin and Boyer, 1982; Rodriguez *et al*, 1998), on citrus (Addiscott *et al.*, 1992), and on banana (*Musa paradisiaca* L.) (Srinivas, 1997). However, Uhart and Andrade (1995) reported that nitrogen supply had a much larger effect on the area of individual leaf but it had no effect on number of leaves of maize (*Zea mays* L.). Likewise Petrie *et al.* (1939) as cited in Watson (1952) had reported that increase in phosphorus supply to tobacco increased leaf size but it had very little effect on leaf number. In the present experiment the supply of 50 mgl^{-1} and 250 mgl^{-1} nitrogen resulted in increase in both leaf number and leaf area. This is probably due to its effect on leaf expansion and cell division. Phosphorus had little effect on leaf area of enset suckers except at higher levels combined with higher level of nitrogen (at N_3P_3, N_3P_4, N_4P_3 and N_4P_4). However, phosphorus significantly affected leaf number in enset suckers.

The measurement of leaf area of a plant is an important index of its growth and development (Palit and Bhattacharyya, 1984). It is commonly employed in several agronomic and physiological studies. Since leaf area is important in determining solar radiation intercepted (Sinclair, 1984), it is closely linked to dry matter accumulation and has therefore been used to estimate the photosynthetic capacity and to predict a performance of a crop. Watson (1952) in his studies on the physiological causes of variation in crop yield concluded that variation in leaf area was the main cause of differences in yield. Since the life of the entire plant is dependent upon food products synthesized on the leaf, increase in plant leaf area has an important implication. The higher the photosynthetic area provided by a plant, the better its growth would be. The higher leaf number may be caused either by an increased rate of production of leaves

from each growing point or by increasing the number of growing points. Marschner (1995) discussed that nitrogen supply affects both cell division and cell extension in the leaf. The limitation of cell division and expansion under conditions of nitrogen deficiency are the results of decreased protein and RNA synthesis. Because of this multiplicity of effects, application of nitrogen tends to increase leaf area throughout the whole growth period. Phosphorus is also found to increase the leaf area and number. Rodriguez *et al.* (1998) reported that phosphorus deficiency can either directly or indirectly limit leaf expansion rate of wheat, by limiting the size of individual leaves through the production of fewer cells per leaf and/or limiting cell elongation. Radin and Eidenbock (1984) proposed that direct effect of phosphorus deficiency on leaf expansion could be mediated through the limited hydraulic conductivity in roots and consequently a lack of turgor for cell expansion. However, recent evidences indicated that the expansion properties of the cell wall rather than a lack of turgor for cell expansion are more likely to limit leaf expansion (Pritchard *et al.*, 1990), particularly since nutrients have been observed to have direct effects on these properties.

Chlorophyll content of enset suckers (Table 4) was significantly influenced by increasing nitrogen supply except for nitrogen supply at 10 mgl^{-1} level. The value of the chlorophyll content ranged from 0.40 $\pm$ 0.06 $\mu g\ ml^{-1}$ (at N_1P_1) to 1.50 $\pm$ 0.05 $\mu g\ ml^{-1}$ (at N_4P_1).

It is well known that in addition to its role in the formation of proteins, nitrogen is an integral part of chlorophyll. As chlorophyll is the site of photosynthesis, its concentration in leaves has a direct influence on yield. Thus one way nitrogen

deficiency is manifested in crop yield is through reduction in chlorophyll synthesis (Oelke and Andrew, 1966; Tisdale *et al.*, 1985).

Phosphorus concentration in the shoot of enset suckers in the present study was significantly increased following increased concentration of phosphorus in solution except at 9 mgl^{-1} level (Fig. 6-b). Nitrogen concentration in solution up to 50 mgl^{-1} did not result in any significant increase in shoot phosphorus concentration except at N_3P_4 (i.e. 50 mgl^{-1} nitrogen and 81 mgl^{-1} phosphorus). However nitrogen concentration 250 mgl^{-1} resulted significantly in higher shoot phosphorus concentrations compared to others. Root phosphorus concentration was also significantly affected by increases in phosphorus concentration in solution (Fig. 7-b). Particularly, phosphorus concentration higher than 9 mgl^{-1} resulted in significant increase in root phosphorus concentration. Nitrogen concentration higher than 10 mgl^{-1} also resulted in significant increase in root phosphorus concentration. Maclead (1976) studied effects of nitrogen, phosphorus and potassium and their interactions on kernel weight of barley in hydroponic culture and observed that percent phosphorus in tissue of barley (*Hordeium vulgare*) continued to increase with increasing nitrogen concentration in solution. A similar observation was also made by Chatha *et al.* (1992) and they found that phosphorus uptake by *Kinnow mandarin* was enhanced and the concentration of phosphorus in the tissue increased when it was applied with nitrogen. In contrast to this, Masresha Fetene and Amha Belay (1988) reported that increasing concentration of nitrogen in solution did not affect phosphorus concentration on the tissue of tef (*Eragrostis tef*) significantly.

Jones (1985) tried to explain the effect of nitrogen on the uptake of phosphorus. He

pointed that addition of nitrogen has a marked effect on the absorption of phosphorus. The possible reasons for the stimulatory effects of nitrogen on the uptake of phosphorus are the following: Nitrogen might increase the solubility of soil phosphorus, increase root growth in the fertilized zone, increase metabolic activity in the root or it might increase the phosphorus carriers of plasmalemma. In the present experiment nitrogen supply of 250 mgl^{-1} resulted in significant increase in shoot phosphorus and nitrogen concentration 50 mgl^{-1} and 250 mgl^{-1} also resulted in significant increase in root phosphorus concentration. The increase in phosphorus concentration with increasing nitrogen level might be attributed to stimulatory effects of nitrogen in phosphorus uptake.

In the present study, with increasing concentration of nitrogen in solution, the nitrogen concentration in the shoot increased significantly, except at 10 mgl^{-1} nitrogen level (Fig. 6-a). Root nitrogen concentration also increased with an increasing nitrogen concentration in solution (Fig. 7-b). However, shoot and root nitrogen concentrations were not affected by increasing phosphorus levels in solution. Masresha Fetene and Amha Belay (1988) obtained an increase in percent nitrogen in the shoot of tef (*Eragrostis tef*) with increasing phosphorus levels, which was in contradiction with the present result. In this study at higher level of nitrogen (250 mgl^{-1}) increasing concentration of phosphorus in solution (although the difference was not significant) resulted in a decrease in shoot nitrogen concentration (Fig. 6-a). This could probably be due to dilution of nitrogen concentration through increased shoot growth. In general from the results of percent nitrogen and phosphorus in the tissue obtained one could mention that phosphorus had no influence on tissue nitrogen but nitrogen had an

influence on tissue phosphorus of enset suckers.

Increase in nutrient stress (both individual and combined) with decrease in nitrogen and phosphorus concentration in solution, as observed in the present study (Fig 8, 9 and 10), closely resemble those observed in tef (*Eragrostis tef*) by Masresha Fetene and Amha Belay (1988). Nutrient stress is a quantitative estimate of the intensity of current nutrient deficiency in a crop (Greenwood, 1976). It can be evaluated as the proportion by which the growth rate of a crop is limited by the nutrient under prevailing conditions. According to Greenwood, (1976) knowledge of nutrient stress of a crop at least provides a partial answer; that is whether the amount of fertilizer required is zero, little or a lot. Thus, one major objective of investigating the nutrient stress of crops is to be able to relate internal nutrient concentration with some sensitive measure of growth for both diagnostic and predictive purposes (Masresha Fetene and Amha Belay, 1988). Leaf area increment ranks as one of the simplest and most meaningful parameters of growth for estimating nitrogen stress in plants (Greenwood, 1976). This is because of the fact that, for nitrogen, the main effect on growth is through leaf area. Watson (1952) reported, for instance, that 98 percent of the variation in dry weight is accounted for by the regression on leaf area. Thus, leaf area qualifies as a good measure for estimating nutrient stress.

Greenwood, (1976) noted that in grasses and cereals nitrogen deficiency symptoms begin to develop at nitrogen stress level of 40 percent. In the present study typical nitrogen deficiency symptoms were observed at N_1 (0 nitrogen level) and N_2 (10 mgl^{-1} nitrogen level). The calculated percent nitrogen stress levels that correspond to the

above nitrogen concentrations in solution were 60 and 36, respectively. Although the estimated percent nitrogen stress for N_1 agree with what Greenwood (1976) has mentioned for grasses and cereals, the estimated percent nitrogen stress for N_2 was a little less. On the other hand P_1 (0 phosphorus level) and P_2 (9 mgl^{-1} phosphorus level) had percent phosphorus stress of 50 and 38, respectively. The combined nitrogen and phosphorus stress (designated as nutrient stress) also showed an increment at every reduction of nitrogen and phosphorus in solution. There was more increment in percent nutrient stress in the direction of reduced nitrogen, in comparison with reduced phosphorus (Fig. 8). The increase in stress level more in the direction of reduced nitrogen levels in comparison with reduced phosphorus indicated that, of the two nutrients, nitrogen may be the more limiting element in enset. This is supported by the data of the plant N : P ratio. The N : P ratio of plant material is also a good indicator of a primary element limitation. Aerts *et al.* (1992) reported that if the N : P ratio of stressed plants is low (<10) it may point towards nitrogen limited growth and if N : P ratio is high (>14) it may indicate that plant growth is phosphorus limited. In the present experiment the N : P ratio was found to be 5.7 in both shoots and roots of N_1P_1 plants, indicating once again nitrogen may be the more limiting element on the growth of enset suckers.

6. SUMMARY AND CONCLUSION

The study was carried out to investigate the effect of a supply of varying concentration of nitrogen and phosphorus on the growth and physiology of enset suckers. It was also designed to quantify levels of nutrient stress and to identify recommendable levels of nitrogen and phosphorus for optimal growth. The results showed that addition of nitrogen and phosphorus increased the pseudostem girth, leaf number, leaf area, the total biomass and thus, the overall growth of enset suckers significantly. The biomass of enset suckers recorded at the highest nitrogen and phosphorus supply was almost four times higher than the controls. It has also been observed that the growth response was much higher in the direction of increasing nitrogen compared to phosphorus. There was no limitation of growth at higher levels of nitrogen supply. Increasing nitrogen supply linearly increased the biomass of enset suckers and this was further favoured by increasing phosphorus concentration. However, the response of enset suckers to increasing concentration of phosphorus was more governed by the availability of nitrogen. Enset responded to phosphorus better in the presence of nitrogen. In most of the growth parameters studied addition of 10 mgl^{-1} nitrogen and 9 mgl^{-1} phosphorus did not bring significant change over the controls. The results of tissue analysis also showed that nitrogen had an influence on tissue phosphorus but phosphorus had no influence on tissue nitrogen. Calculation of levels of nutrient stress based on leaf area showed an increase in levels of nutrient stress, with decreasing nitrogen and phosphorus concentration in solution. The increase in nutrient stress was more pronounced in the direction of reduced nitrogen levels in comparison with phosphorus, showing that, of the two nutrients, nitrogen is more limiting element in enset.

The ultimate practical goal of research on nutrient supply and plant response is to increase the yield of a crop for feeding a growing population on limited land resources. In the present experiment the growth response of enset suckers to addition of increasing concentration of nitrogen and phosphorus on representative soil suggest that enset requires substantial quantities of nitrogen and phosphorus for best growth and also indicated that enset, demands much larger amounts of nitrogen and phosphorus than are available in the soil.

In the traditional system of production, the crop's nitrogen and phosphorus requirement has been fulfilled with application of farm yard manure, however, as described, now-adays due to significant increase in human population and a decrease in livestock size the amount of manure applied to the enset crop has been reduced, with a negative consequence in enset yield. Thus, inorder to achieve the highest dry matter production, the nitrogen and phosphorus supply to the enset crop should be optimized.

The present experiment showed that enset responded better to application of inorganic fertilizers. This indicates that in the absence of adequate farm yard manure enset's mineral nutrition requirement could be fulfilled through the use of inorganic fertilizers. Thus it is recommended that the nitrogen and phosphorus status of the enset soil should be maintained to achieve the highest yield and to feed the growing population, further research for fertilizer response curves to determine optimum fertilizer rates should be carried out, and intercropping enset with leguminous plants (particularly at their suckering stage) should be practiced.

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8. APPENDIX

Appendix 1. Effect of different levels of added nitrogen and phosphorus on pseudostem girth (cm) of enset suckers (n= 21, Mean ± sd)

	P_1	P_2	P_3	P_4
N_1	7.12 ± 1.82^{aA}	9.27 ± 1.83^{bA}	9.66 ± 1.82^{bA}	9.81 ± 1.46^{bA}
N_2	9.42 ± 1.88^{aB}	9.70 ± 1.23^{aA}	10.37 ± 1.15^{abA}	10.97 ± 1.55^{bA}
N_3	11.17 ± 1.67^{aC}	12.09 ± 1.37^{aB}	13.71 ± 1.49^{bB}	14.37 ± 1.53^{bB}
N_4	15.71 ± 2.15^{aD}	18.06 ± 1.73^{bC}	21.09 ± 1.17^{cC}	23.11 ± 1.79^{dC}

Means followed by the same lower case letter in rows and means followed by the same upper case letter in columns are not significantly different at $P<0.05$ as determined by Tukey's, Family Error Rate.

Appendix 2. Relationship between varying concentrations of added nitrogen and phosphorus in solution and dry weight (g/plant) of enset suckers (n=8, Mean ± sd).

	P_1	P_2	P_3	P_4
N_1	55.26 ± 6.53^{aA}	61.25 ± 7.71^{abA}	64.49 ± 10.54^{abA}	72.43 ± 13.62^{bA}
N_2	59.36 ± 8.20^{aA}	73.47 ± 7.45^{abA}	70.70 ± 12.14^{abA}	75.69 ± 15.88^{bA}
N_3	82.00 ± 20.47^{aB}	91.99 ± 7.23^{aB}	92.71 ± 9.81^{abB}	110.32 ± 11.11^{bB}
N_4	123.64 ± 30.76^{aC}	131.46 ± 15.87^{aC}	190.09 ± 13.24^{bC}	202.64 ± 30.52^{bC}

Means followed by the same lower case letter in rows and means followed by the same upper case letter in columns are not significantly different at $P<0.05$ as determined by Tukey's, Family Error Rate.

Appendix 3. Influence of different levels of nitrogen and phosphorus in solution on leaf number of enset suckers (n= 20, Mean ± sd).

	P_1	P_2	P_3	P_4
N_1	6.80 ± 0.83^{aA}	8.05 ± 1.23^{bA}	7.80 ± 1.01^{bA}	9.15 ± 0.81^{cA}
N_2	6.95 ± 0.76^{aA}	7.75 ± 0.72^{bA}	7.30 ± 0.57^{abA}	9.05 ± 0.76^{cA}
N_3	9.00 ± 0.65^{aB}	9.25 ± 0.64^{aB}	11.00 ± 0.79^{bB}	11.80 ± 0.89^{cB}
N_4	11.90 ± 0.79^{aC}	12.75 ± 1.25^{bC}	13.60 ± 0.94^{cC}	16.00 ± 0.79^{dC}

Means followed by the same lower case letter in rows and means followed by the same upper case letter in columns are not significantly different at $P<0.05$ as determined by Tukey's, Family Error Rate.

Appendix 4. Effect of varying concentrations of nitrogen and phosphorus in solution on total leaf area of enset suckers (n=5, Mean ± sd).

	P_1	P_2	P_3	P_4
N_1	1511.4 ± 133.7^{aA}	1554.3 ± 288.7^{aA}	1614.4 ± 129.2^{aA}	1730.4 ± 150.0^{aA}
N_2	1584.4 ± 134.4^{aA}	1717.5 ± 186.5^{aAB}	1769.0 ± 72.2^{aA}	1790.5 ± 76.8^{aA}
N_3	2151.1 ± 277.2^{aB}	2224.1 ± 585.6^{aB}	2846.7 ± 248.8^{aB}	2894.0 ± 488.7^{aB}
N_4	3542.3 ± 188.4^{aC}	3782.8 ± 141.1^{aC}	4164.9 ± 241.5^{bC}	6436.9 ± 250.7^{cC}

Means followed by the same lower case letter in rows and means followed by the same upper case letter in columns are not significantly different at $P<0.05$ as determined by Tukey's Family Error Rate.

Appendix 6. Relationship between varying concentrations of nitrogen and phosphorus in solution and root nitrogen concentration of enset suckers (n=4, Mean ± sd).

	P_1	P_2	P_3	P4
N_1	0.185 ± 0.025^{aA}	0.198 ± 0.028^{aA}	0.222 ± 0.000^{aA}	0.222 ± 0.041^{aA}
N_2	0.346 ± 0.028^{aB}	0.297 ± 0.049^{aB}	0.309 ± 0.025^{aB}	0.284 ± 0.025^{aB}
N_3	0.346 ± 0.049^{aB}	0.284 ± 0.025^{aB}	0.321 ± 0.040^{aB}	0.284 ± 0.047^{aB}
N_4	0.494 ± 0.049^{aC}	0.519 ± 0.000^{aC}	0.445 ± 0.049^{aC}	0.470 ± 0.057^{aC}

Means followed by the same lower case letter in rows and means followed by the same upper case letter in columns are not significantly different at $P<0.05$ as determined by Tukey's Family Error Rate.

Appendix 7. Effect of varying concentrations of nitrogen and phosphorus in solution on shoot phosphorus concentration of enset suckers (n=5, Mean ± sd).

	P_1	P_2	P_3	P_4
N_1	0.106 ± 0.019^{aA}	0.127 ± 0.018^{aA}	0.306 ± 0.018^{bA}	0.379 ± 0.038^{cA}
N_2	0.097 ± 0.015^{aA}	0.122 ± 0.036^{aA}	0.355 ± 0.003^{bAB}	0.454 ± 0.048^{cAB}
N_3	0.108 ± 0.013^{aA}	0.148 ± 0.012^{aA}	0.342 ± 0.091^{bAB}	0.475 ± 0.027^{cB}
N_4	0.253 ± 0.037^{aB}	0.296 ± 0.057^{aB}	0.399 ± 0.038^{bB}	0.482 ± 0.047^{cB}

Means followed by the same lower case letter in rows and means followed by the same upper case letter in columns are not significantly different at $P<0.05$ as determined by Tukey's Family Error Rate.

Appendix 8. Effect of varying concentrations of nitrogen and phosphorus in solution on root phosphorus concentration of enset suckers (n=5, Mean ± sd).

	P_1	P_2	P_3	P_4
N_1	0.032 ± 0.015^{aA}	0.041 ± 0.007^{aA}	0.073 ± 0.012^{bA}	0.092 ± 0.005^{cA}
N_2	0.041 ± 0.020^{aAB}	0.044 ± 0.009^{aA}	0.077 ± 0.004^{bA}	0.107 ± 0.006^{cAB}
N_3	0.062 ± 0.007^{aB}	0.073 ± 0.010^{abB}	0.085 ± 0.007^{bA}	0.124 ± 0.017^{cB}
N_4	0.101 ± 0.015^{aC}	0.119 ± 0.018^{aC}	0.177 ± 0.012^{bB}	0.213 ± 0.012^{cC}

Means followed by the same lower case letter in rows and means followed by the same upper case letter in columns are not significantly different at $P<0.05$ as determined by Tukey's Family Error Rate.

Appendix 9. Influence of varying concentrations of added nitrogen and phosphorus in solution on percent nutrient stress.

	P_1	P_2	P_3	P_4
N_1	69.4	62.0	47.1	38.2
N_2	50.8	45.8	41.8	27.2
N_3	46.6	35.1	35.1	25.6
N_4	22.7	16.2	9.2	0

Appendix 10. Results of two way ANOVA for test of significant difference between nitrogen and phosphorus treatements in shoot nitrogen, shoot phosphorus, root nitrogen and root phosphorus.

Source	Shoot nitrogen				Shoot phosphorus				Root nitrogen				Root Phosphorus			
	DF	MS	F	P	DF	MS	F	P	DF	MS	F	P	DF	MS	F	P
Nitrogen(N)	3	0.8635	93.0	<0.001	3	0.0611	40.5	<0.001	3	0.2087	146.8	<0.001	3	0.0358	246.8	<0.001
Phosphorus(P)	3	0.0327	3.5	>0.05	3	0.4239	280.5	<0.001	3	0.0023	1.5	>0.05	3	0.0234	160.8	<0.001
N*P	9	0.0116	1.3	>0.05	9	0.0064	4.2	<0.001	9	0.0033	2.3	>0.05	9	0.0008	5.7	<0.001
Error	48	0.0093			64	0.0015			48	0.0014			64	0.0001		