THE INTERACTION OF WEEDS AND DRY BEANS (*PHASEOLUS VULGARIS* L.) UNDER VARIED SOIL FERTILITY CONDITIONS, AND THE ECOLOGY OF WEEDS IN DRY BEAN FIELDS IN UGANDA

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by
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THE INTERACTION OF WEEDS AND DRY BEANS (*PHASEOLUS VULGARIS* L.) UNDER VARIED SOIL FERTILITY CONDITIONS, AND THE ECOLOGY OF WEEDS IN DRY BEAN FIELDS IN UGANDA

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Dry beans (*Phaseolus vulgaris* L.) are major legume crops and an important source of protein in Uganda. Their production is constrained by low soil fertility and weed competition. Field experiment was carried out at Thompson Farm (Freeville Farm), Cornell University in 1995 and 1996, and at Namulonge Agricultural and Animal Production Research Institute (NAARI) in Uganda in the 1997A and B seasons. The goal was to determine the effect of competition between beans and weeds (*Galinsoga parviflora* Cav., *Bidens pilosa* L. and *Solanum nigrum* L.) on bean and weed nutrient uptake and bean yield under low soil fertility. Low levels of nutrients (NPK, OPK, NOK, NPO and OOO) were broadcast applied at 50, 50 and 60 kg N, P and K ha^{-1}, respectively. These were combined with bean-weed treatments in a split-plot design with nutrients as the main plots and bean-weed combinations as the sub-plots. Results indicate that high bean dry matter was recorded under full nutrients and under P and N deficit conditions. High weed dry matter was observed in the presence of N and P. Beans are better accumulators of N and the weeds are better accumulators of P, K, Ca and Mg. Bean yield was high under P deficit condition resulting in high total revenue and net profit. *Galinsoga parviflora* caused 33-42%; *S. nigrum* 29% and *B. pilosa*

46-50% yield reduction in beans. Beans are likely to be competitive with weeds under P deficit condition and weeds are likely to be very competitive with beans in the presence of N and P.

A screenhouse experiment under NPK, NPO and NOK nutrients indicated that high shoot and root relative growth rates, and high root elongation and growth rates of the weeds contribute to their competitiveness especially with adequate N and P. Beans are more competitive with weeds under P deficit conditions due to early emergence, erect growth for a longer time, and more root volume compared to the weeds. This is likely to contribute to better growth and yield of beans under P deficit condition.

A survey was also carried out in Uganda on farmers' fields to determine the relationship between weeds and soil chemical and physical characteristics and cropping system-related factors. Both soil factors and cropping systems affected weed abundance. It was noted that *B. pilosa* abundance was positively related to soil P and N while *G. parviflora* was positively associated with soil Ca and pH. Both weeds were widely distributed and were reported by farmers to cause yield losses to beans of over 30%.

BIOGRAPHICAL SKETCH

The author spent his childhood in Nebbi district in Uganda. He attended primary and secondary schools in the northern part of Uganda. He obtained a Bachelor in Agriculture (crop science as a major) from Makerere University, Kampala, Uganda in June 1985 (an upper second class degree with honors). In 1992, he obtained MS degree with major in vegetable crops and a minor in soil fertility. Since then he has been employed by the National Agricultural Research Organization (NARO) as an agronomist. Currently, he is based at Namulonge Agricultural and Animal Production Research Institute (NAARI) working with the National Beans Program (NBP).

The author returned to the United States in June 1995 to pursue a Doctor of Philosophy degree in vegetable crops with minors in soil science and international agriculture and rural development (IARD).

This work is dedicated to my lovely wife Phoebe Akiiki Ugen and my lovely kids – my daughter Jennifer Pimer Abwoli and my son Kevin Eugene Upyem Jr.

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CHAPTER ONE
GENERAL INTRODUCTION

Common or dry beans (*Phaseolus vulgaris* L.) are the most important food legume in the developing tropical countries, Uganda included (Pachico, 1989). Beans are mostly produced under diverse farming systems by small-scale farmers. Production of beans in the tropics accounts for over 70% of the world bean production (Pachico, 1989). Bean production is constrained by a number of factors including (a) low availability of soil nutrients, especially N, P and K, and toxicity complex of aluminum (Al) and manganese (Mn), (b) weed competition, (c) lack of improved varieties, (d) damage caused by insect pests and diseases, (e) moisture stress, and (f) poor agronomic practices (Wortmann and Allen, 1994). Bean yield in Uganda has continued to decline due to the above named constraints. According to FAO (1998) statistics, bean yield in Uganda declined from 787 kg ha^{-1} in 1989 to 590 kg ha^{-1} in 1997 yet land acreage increased from 495,000 ha in 1989 to 630,000 ha in 1997. Total bean production in Uganda also declined from 389,000 metric tons in 1989 to 372,000 metric tons in 1997.

The wide variability in production environments in the tropics also results in a wealth of diversity in cropping systems as well as agronomic constraints to bean production in the tropics. These problems in the tropics, therefore, necessitate the use of cultivars which are more efficient in the use of available resources where these stressful environmental conditions occur. For example, cultivars which are efficient in the uptake and use of available nutrients have been identified (Wortmann et al.,

1995). Crop cultivars tolerant of moisture stress are also continuously being identified which can improve their productivity under marginal moisture conditions. Another possibility to having good crop yield under environmental stresses is the manipulation of these environmental conditions to the benefit of the crops (beans) in a crop-weed situation.

The environmental stresses mentioned constrain the growth of beans as well as other crops. They restrict the crop's potential growth, productivity and reproduction in an ecosystem (Stoller et al., 1987; Elmore et al., 1994). The restrictions imposed by the stresses lead to competition among crops, or between crops and weeds. Stressful levels of environmental factors such as light, temperature, water (moisture), oxygen and nutrients influence crop/crop or crop/weed interaction. This may lead to yield reduction of the less competitive crop in the interaction.

Weeds have been acknowledged to be a major constraint in the production of crops in farmers' fields in Uganda. Both annual and perennial weeds are widely distributed presenting a major problem in crop production (Ivens, 1971; Terry and Michieka, 1987). Usually peak labor demand for farmers in Uganda coincides with weeding times in most crops (Kisakye et al., 1987). This leads to inadequate weed control and yield reduction in the less competitive crops especially annual crops like beans. Migration of young and able people to towns has continued to aggravate labor problems in the rural areas.

This research is aimed at understanding the association between dry beans and weeds (*Bidens pilosa* L., *Galinsoga parviflora* Cav. and *Solanum nigrum* L.) as affected by low soil nutrient supply. It also seeks to identify the factors which are involved in the association and how

these factors are affected by soil fertility levels. Lastly, the research aims to understand the distribution of weeds in Uganda as affected by environmental conditions with particular reference to bidens, galinsoga and black nightshade. A thorough knowledge of the association between bean cultivars and weeds can help in the formulation of effective weed management strategies. The factors involved in the association may be manipulated to the advantage of beans with improved competitiveness of beans against weeds, and eventually improved yield. Therefore, understanding this association is important to help improve weed management for the resource poor farmers practicing low-input agriculture in Uganda.

CHAPTER TWO

DRY BEAN - ANNUAL WEED COMPETITION AS AFFECTED BY SOIL NUTRIENTS

INTRODUCTION

Beans are the most important food legume, and a major source of protein and calories, in eastern Africa (Pachico, 1989). Their production is constrained by low availability of soil nutrients (N, especially for poorly nodulating cultivars, P and K mostly) and the toxicity complexes of aluminum (Al) and manganese (Mn) (Wortmann and Allen, 1994). Poor soils deficient in P and N are common in eastern Africa and other parts of the world (Singh et al., 1989).

In Uganda, beans are grown mainly as subsistence crops by small-scale farmers who rarely apply fertilizers or pesticides. The use of bean cultivars which are more tolerant to adverse soil conditions was a focus of research in Uganda to help farmers increase bean production. In countries where inputs of fertilizers are used, nutrient efficient cultivars could help reduce the use of these inputs, thus reduce the cost of production. At the same time, cultivars which are more efficient in the use of limited resources may be of benefit when in competition with weeds.

Weeds cause low crop yield, harvesting difficulties and contaminated crop products. The need for better understanding of how environmental stress influences competition between weeds and crops has been emphasized (Patterson, 1995). Weeds and crops usually compete for water, light and nutrients.

Competition with weeds may cause changes in several physiological and morphological characteristics of the crops which may be important in the utilization of resources possibly with negative effects on crop performance. Identification of such physiological and morphological changes may help in the manipulation of resources to benefit crops rather than the weeds.

In Uganda, annual and perennial weeds have been acknowledged as very important in crop production. These weeds are widely distributed and are major hindrances to crop production. The presence of these weeds coupled with high labor demand and low soil fertility have led to reduced bean yields in Uganda (Wortmann, 1993; Wortmann and Allen, 1994). This, therefore, makes the study of crop-weed interaction in Uganda very important as not much has been carried out in this area. The interaction between beans and annual weeds (*Bidens pilosa, Galinsoga parviflora* and *Solanum nigrum*) under varied soil fertility levels of Uganda is especially in need of study. It may be that weeds competing for the major nutrients with beans could have striking effects on crop performance.

LITERATURE REVIEW

General review

Weeds are known to cause direct and indirect losses to crops through weed interference. This interference encompasses the overall effects of neighboring plants on the crop's growth including competition, allelochemical interference, parasitic interference and indirect interference where a weed harbors pests (Zimdahl, 1980; Aldrich, 1984; Ogg and Rogers, 1989; Stoller et al., 1987). The direct losses are those

that reduce the value of the crops including reduction in crop yield and quality. The indirect losses do not represent a reduction in value but a loss to society due to harboring of insect pests and diseases of other crops. Other indirect losses include creation of health and safety hazards, reduction in property value and increased cost of crop production. These losses are due to interference out of which competition exerted by the weeds on crops is the most important. Donald (1963) stated that "competition occurs when each of two or more organisms seeks the measure it wants of any particular factor or thing and when the immediate supply of the factor or thing is below the combined demand of the organisms."

Factors responsible for competition in a crop-weed system can be divided into two categories namely physical and biotic factors (Donald, 1963; McLaughlin, 1978; Radosevich, 1987; Silvertown and Doust, 1993). Physical factors which influence competition between crops and weeds include soil nutrients, soil moisture, oxygen, and light (shading effect). Biotic factors include allelopathic influences, physiological influences (emergence characteristics, growth rates, root length, distribution of root systems and duration of growth of both crops and weeds) and other components of plant size and function.

All the above factors which affect crop-weed competition are modified by physical environment and environmental stresses (Patterson, 1995). Therefore, competitiveness or competitive ability of a weed or group of weeds may differ greatly due to interactive effects of factors affecting the outcome of competition with the crops.

Bean and weed response to nutrients

It has been established that differences exist in nutritional requirements between species of plants, as well as within species (Gerloff, 1963). Wortmann et al. (1995) identified a number of bean cultivars which were more efficient in the uptake and use of available nutrients. Some of the cultivars included RAO 55, K 131, XAN 76, BAT 25, OBA 1, Carioca, Ikinimba, Black Dessie and BAT 85. These cultivars have shown relatively good performance under a number of edaphic stresses of soil nutrients including low P, low N, high Al and high Mn.

In Colombia and Brazil, CIAT (Centro Internacional de Agricultura Tropical) scientists have found that the critical nutrient levels required for bean growth in the soils were: P in the range of 11 - 15 ppm (Colombia) and 11 - 20 ppm (Brazil), and K at 0.15 meq per 100 gm of soil (15 ppm) (Colombia) and 31 - 60 ppm (Brazil) (Flor and Thung, 1989). The critical levels of calcium and Mg have been estimated at 4.5 and 2.0 meq per 100 gm of soil, respectively, in Colombia.

A number of factors are responsible for bean cultivar response to nutrients. Bean response to nutrients also depends on the original nutrient status of the soil. Lynch and White (1992) observed that rate and duration of N acquisition (through N-fixation as well as soil N uptake) and efficiency of use in vegetative growth determined bean cultivar N efficiency use. Other factors they noted affecting N use included rate and duration of N accumulation in seeds and efficiency of N use in seed formation. Bean response to N fertilization varied from no response to increased seed yield and yield components to levels as high as 250 kg N ha^{-1} (Edje et al., 1975; Srinivas and Rao, 1984; Ssali and Keya, 1986;

Buttery et al., 1987). Nitrogen fertilizers have been reported to increase bean LAI, canopy height, canopy width and plant height (Edje et al., 1975). Edje et al. (1975) reported maximum bean yield at 120 kg N ha^{-1}. Buttery et al. (1987) and Srinivas and Rao (1984) reported maximum yield at 112 and 80 kg N ha^{-1}, respectively. Ssali and Keya (1986) observed no difference in Kenya between 10 and 100 kg N ha^{-1} for bean seed yield. They also noted that excessive application reduced yield due to excess vegetative growth at the expense of the reproductive growth and this delayed maturity. Significant reduction in nodulation and N-fixation have also been observed with increasing application of N fertilizer (Ssali and Keya, 1986).

Significant differences among bean cultivars and lines in response to P stress have been noted. Several morphological (root and shoot dry weight, and root architecture) and physiological (P acquisition and utilization) characters have been identified as important for P utilization under P stress (Whiteaker et al., 1976; Fawole et al., 1982; Lynch and van Beem, 1993). Whiteaker et al. (1976) noted that under P stress, net photosynthesis per unit of P was higher in an efficient bean line than in an inefficient line with increased root dry weight. Similarly, Fawole et al. (1982) found that efficient bean lines provided vigorous roots both at stress and at adequate levels of P.

Phosphorus can result in improved N-fixation and dry matter, and increased yield and yield components of beans (Machado et al., 1979; Srinivas and Rao, 1984; Ssali and Keya, 1986; Buttery et al., 1987; Fageria, 1989). Phosphorus is vital in root development by increasing root dry weight and uptake of N, P, K, Ca, Mg and Fe (Fageria, 1989;

Lynch et al., 1991; Fageria et al., 1995; Fageria and Carvalho, 1996). The amount of applied P required for optimum growth depends on the cultivar and varies from place to place depending on edaphic and other environmental factors. Bean responded to 200 kg P_2O_5 ha^{-1} in Brazil with over 100% yield increase (Machado et al., 1979).

The efficient use of K by beans seems to be largely influenced by the K_c gene, the occurrence of which in commonly used bean germplasm is not known (Shea et al., 1968). Bean response to K has been less documented than to N and P. Evanylo and Zehnder (1989) noted that increasing K level from 34 to 68 kg K_2O ha^{-1} increased snap bean pod yield and nutrient accumulation (K, Ca and Mg). Abd-Alla and Wahab (1995) observed that application of 150 mg K kg^{-1} soil increased faba bean resistance to water stress, and therefore, survival. Similarly, Sangakkara et al. (1996) noted that application of 3.0 mM K improved nodulation and N-fixation in snap beans. This reduced the impact of high temperature and enhanced vegetative growth.

Weeds have been reported to respond greatly to nutrients and their responses are also affected by a number of environmental factors. Everaarts (1992) noted that when 50, 50 and 40 kg ha^{-1} N, P and K, respectively, were applied to weeds, N and P stimulated growth of the weeds (ground cover and height). Potassium had no affect on weed weight but increased weed number and survival. Ivany (1971) and Ivany and Sweet (1973) noted that N, P and K deficiencies reduced growth of *Galinsoga parviflora* although there was no effect on the final height. They noted that lack of N resulted in greater reduction of galinsoga growth than lack of P.

Galinsoga quadriradiata and *G. parviflora* responded to N application up to 20.62 gm per 4 kg of homogeneous air-dry sandy loam soil (soil N increased from 0.18% to 0.36% N) in the greenhouse (Rai and Trapathi, 1986). Both weeds exhibited density-dependent mortality at higher N level as weed density increased from 4 to 108 plants per pot (4, 12, 36 and 108 plants per pot). Total plant biomass increased with increasing plant density and N levels but per plant biomass decreased as N level increased. Similar result was reported by Shontz and Shontz (1972) for ecotypes of *G. ciliata* when given variable levels of "rapid gro" soluble fertilizer.

In a sand culture, eastern black nightshade responded linearly to N application with 5 to 6 times greater dry weight in the highest N treatment than at low N level (levels used were 2.1, 21 and 210 ppm) (Croster and Masiunas, 1998). Nitrogen content of nightshade was 0.76% at 2.1 ppm and 3.22% at 210 ppm N. Khan et al. (1995) also observed that N, P and K in black nightshade was greatest at 1.80 gm N per 3.5 kg soil (N applied at the rate of 0, 0.45, 0.90, 1.35, 1.80 and 2.25 gm N per pot of 3.5 kg soil). Weed growth increased with increasing N level.

Nutritional requirements of *Bidens pilosa* have not been well documented although responses to some fertilizers have been noted. *Bidens pilosa* responded to 30, 100 and 30 kg ha^{-1} of N, P_2O_5 and K_2O, respectively, under field conditions (Carvalho, 1980). Felippe and Dale (1990) observed better response of *B. gardneri* when supplied with 6 mg P per plant under greenhouse condition and higher values than this led to reduced growth of the weed. Chivinge (1996) noted that application of fertilizer, compound D (8% N, 14% P_2O_5, 7% K_2O and 6.5% S) at 3 and

6 gm per pot increased *B. pilosa* growth, height, branching, number of heads and seeds per plant but had no effect on seeds per head.

Research over the years has shown that both beans and weeds respond to increased soil fertility. The extent of response depends on the genotype, nutrients and soil fertility levels. Nutrient efficient cultivars respond better to applied nutrients at low soil fertility levels compared to non-efficient cultivars.

Crop-weed competition

Crop-weed competition for soil nutrients and soil moisture may be more pronounced than for other factors (Wiese and Vandiver, 1970). Soil nutrients and moisture availability can greatly affect the competitive abilities of weeds and crops. Hoveland et al. (1975) reported a wide variation in the responses of weeds and crops to soil nutrients. Studies have shown that crop competitiveness and yields are improved following application of N, P and K nutrients (Di Tomaso, 1995). Although crops benefit from fertilizers, studies have also indicated that weeds benefit more from the nutrients than the crops. Hakansson (1986) noted that weeds are favored by fertilizer application especially if they germinate before the crop does. Weeds often accumulate more nutrients than crops thus gaining a competitive advantage for other resources particularly light (Di Tomaso, 1995).

At low weed density, addition of nutrients to the soil favors crop growth while at high weed density, added nutrients favor weed growth, thereby providing little benefit to crop yield (Di Tomaso, 1995). Addition of N to a wheat/green foxtail mixture increased green foxtail biomass by 41-75% (Peterson and Nalewaja, 1992). This reduced wheat biomass by

29% when seeded on the same day and by 13% when seeded 4 days after wheat. The increase in weed competition at high N rates has been suggested to be due to increased nutrient accumulation rate and nutrient use efficiency by the weeds (Di Timaso, 1995; Qasem, 1992; Sibuga and Bandeen, 1980).

In a replacement series experiment, the growth of *Senecio madagascarienis* Poir. (fireweed) grown together with oats increased significantly with increasing levels of N and P but was less affected by K levels (Sindel and Michael, 1992). Relative competitive advantage of the weed increased at higher N and P levels hence increasing both vegetative and reproductive yield of the weed. They concluded that the use of N- and P-based fertilizer to improve soil fertility was unlikely to increase the competitive ability of oats but rather benefit *S. madagascariensis*. Everaarts (1992) reported a similar finding where N and P stimulated weed growth and K increased the number of weeds. Weeds responded to fertilizer application, but the response varied according to the weed vegetation type and nutrient applied. Similarly, Bhaskar and Vyas (1988) noted that increasing rate of P fertilizer in a wheat (*Triticum aestivum* L)-fathen (*Chenopodium album* L.) mixture increased the competitive ability of fathen against wheat and to a lesser extent N application. The increased interference by the weed led to significant reduction in the number of grains per plant and per ear, grain weight per plant and mean weight per 100 grains. This was more pronounced at high weed density.

In another study, Qasem (1992) showed that N, P and K concentrations in the shoots of most weed species (*Beta vulgaris, Centaurea iberica, Chenopodium murale, Cichorium pumilum, Portulaca*

oleracea, Sinapis alba, Sonchus oleraceus, Solanum nigrum and *Rumex obtusifolius*) were higher than those of the bean crop. On the other hand, weed species had substantially lower amounts of N, K, P, calcium (Ca) and magnesium (Mg) in the roots except for *Rumex* species. Qasem (1992) concluded that competition between bean and weeds may be important for P and to some extent N. He suggested that higher accumulation of nutrients by the weeds is due to greater nutrient uptake and better translocation from the roots to the shoots by weeds than the crops. He also suggested that the difference between weeds and crop plants in P accumulation could have been due to differences in root growth habit and morphology. Weeds may have more, thinner and massive roots than the crops which give them greater root surface area enabling them to take up immobile elements such as P.

Blackshaw (1991) observed that hairy nightshade (*Solanum sarrachoides*) was capable of causing large reductions in bean yields. As few as 2 hairy nightshade plants m^{-1} of bean row reduced bean yields by 13%. Increasing the density of hairy nightshade to 100 m^{-1} resulted in 77% bean yield loss and a similar trend was observed for bean biomass. Fennimore et al. (1984) noted that black nightshade and barnyard grass caused 30 - 40% yield reduction in beans when competing in the first 4 to 5 weeks of the growing season in California. In another experiment, Agamalian (1983) noted that black nightshade population of 3 and 8 plants m^{-2} reduced broccoli yield (*Brassica oleracea* (L) var. *Italica* (Plank) by 33 and 50%, respectively. Four and 28 black nightshade plants m^{-2} reduced tomato (*Lycopersicon esculentum* Mill) yields by 22 and 78%, respectively (Maillet and Abdel-Fatah, 1983).

Ponce et al. (1996) investigated competition between black nightshade and tomato and pepper under greenhouse condition. They found that N, P and K uptake by tomato was reduced if nightshade height exceeded that of tomato especially if it was before tomato flowering. They noted that tomato fruit yield was reduced by 36.5% when tomato and nightshade emerged simultaneously. Pepper yield was reduced by 29, 44 and 62% when black nightshade emerged at six, four and two-leaf stages of the crop, respectively (Ponce et al., 1996). Simultaneous emergence of black nightshade and pepper reduced pepper yield by 93%.

In a study to find the effects of different densities of black spanish needle (*Bidens pilosa*) and marmalade grass (*Brachiaria plantaginea* (Link) Hitch.) on beans, Carvalho (1980, 1981) found that the shade cast by the weeds was the most important competition factor affecting the above ground dry matter and grain yield of beans. He noted that spanish needle population of 82 plants m^{-2} had no effect on bean yield. The highest population of spanish needle of 222 plants m^{-2} reduced bean yield by 33% while marmalade grass population of 42 plants m^{-2} reduced bean yield by 37%. Cerna and Valdez (1987) noted bean yield reduction in 18.75% of the 6 sites where *Bidens pilosa* was growing with beans at a population of 18,509 bidens plants per hectare. They found the reductions were higher as the number of weeds per unit area increased.

Average population of 96 and 88 perennial sowthistle (*Sonchus arvensis*) m^{-2} in competition with soybean and bean, respectively resulted in yield reduction of 87 and 83%, respectively (Zollinger and Kells, 1992). Perennial sowthistle reduced seed weight, germination percentage and seedling growth rates of both crops.

In a field trial involving interaction of white bean (*P. vulgaris*) with annual weeds, Malik et al. (1993) found that uncontrolled population of weeds reduced white bean yield by 70%. They noted that for each kg ha^{-1} increase in weed biomass the corresponding white bean yield loss averaged 0.38 kg ha^{-1}. Season-long competition significantly reduced total number of bean pods per plant, number of seeds per pod and seed weight. They noted that late maturing varieties were more adapted to competition against weeds than the early maturing varieties. Earlier on, McWhorter and Hartwig (1972) noted that late maturing soybean cultivars were more competitive against johnson grass and cocklebur than the early maturing determinate cultivars. This was because early determinate cultivars ceased vegetative growth at flowering when weeds were still actively growing.

Proso millet (*Panicum miliaceum*) at a density of 30 plants m^{-2} growing together with beans resulted in bean yield loss of 29-58% over a two-year period (Wilson, 1993). Common ragweed (*Ambrosia artemisiifolia*) emergence together with beans at low population of 1.5 ragweed seedlings m^{-1} of bean row caused 10-22% seed yield loss in white bean over a two-year study (Chikoye et al., 1995). Ragweed mostly affected bean LAI, above ground biomass and pods m^{-2}. Bean density, number of seeds per pod and seed weight were unaffected by the interference.

Vengris et al. (1953) reported that the yield of maize was higher at low than at high P when grown together with weeds because of reduced weed growth at low P. On the other hand, the yield of maize was more reduced at low N than at high N levels when grown in association with

yellow foxtail (*Setaria lutescens*) and green foxtail (*Setaria viridis*). Maize yield reductions with applications of 0, 78 and 157 kg N ha^{-1} were 20, 10 and 5%, respectively (Staniforth, 1961) and 28, 14, and 10%, respectively (Nieto and Staniforth, 1961) when compared to weed-free yields of maize. Increasing the rate of N application in downy brome (*Bromus tectorum*) and winter wheat growing together linearly increased the growth of both species (Rasmussen, 1995). Nitrogen application stimulated downy brome density but continued N application to over 150 kg N ha^{-1} increased wheat height drastically, improving wheat competition against the weed.

Stoller and Myers (1989) noted that weeds (broad leaved weeds) successfully competed with soybeans because of their adaptation to low light intensity. They noted that under reduced greenhouse irradiance, tumble weed (*Amaranthus albus* L.), common lambsquarters (*Chenopodium album* L.), velvetleaf (*Abutilon theophrasti* Medic.), eastern black nightshade (*Solanum ptycanthum* Dun.) decreased their light-saturated photosynthesis, leaf respiration rates, root:shoot ratios, and leaf densities while increasing leaf area ratios (LAR). Of the species they studied including soybeans, eastern black nightshade had the lowest respiration rate, the highest LAR, and the lowest support:leaf ratio for optimum adaptation to shaded environments. They concluded that these characteristics make the weeds more adapted to shading and therefore, more competitive with crops.

Root and shoot competition

Wilson (1988) reviewed 23 studies involving the effects of shoot and root competition in additive and replacement techniques. He

concluded that root competition was more intense and usually affected the balance between components more than shoot competition (68% of the cases). Root competition also had a greater adverse effect on growth than shoot competition. Studies at a range of densities also indicated that effects of root competition intensified more rapidly as density increased than the effects of shoot competition. Snaydon and Howe (1986) studying competition between rye grass (*Lolium perenne* L.) and *Poa annua* and *Festuca rubra* noted that ryegrass competed with the other grasses through root competition. Application of N fertilizer (400 kg N ha^{-1} $year^{-1}$) alleviated the effects of root competition. Shoot competition with ryegrass plants had little effect on seedlings of other grasses regardless of N fertilizer.

Wilson (1988) also noted that although positive interaction between shoot and root competition has always been considered a basic feature of competition, such interactions occurred rarely. In the case of intensity of competition, the interaction was negative. Out of the review, he concluded that there was little evidence to justify the common assumption that adding environmental resources reduces competitive effects; competitive imbalance was often greater at higher resource levels.

Designs for crop-weed interaction studies

Several approaches have been used to study interactions between plants. Most of the methods consider plant density, spatial arrangement and proportions as they affect the interactions (Fischer and Miles, 1973; Radosevich, 1987; Rejmanek et al., 1989; Silvertown and Doust, 1993). The most popularly used techniques or designs to study competition

among plants are additive or partial additive and substitutive or replacement experimental designs.

In a partial additive design a constant density of one species such as the crop is combined with a range of densities of the second species, the weeds or other crops (Radosevich, 1987; Rejmanek et al., 1989; Silvertown and Doust, 1993). Partial additive designs are useful in determining the effect of weeds on a crop or the effects of neighbors on a target plant (Goldberg, 1987; Miller and Werner, 1987; Silvertown and Doust, 1993). They are also useful in determining economic losses of crops from weeds and in separating the effects of root and shoot competition. However, these designs result in simultaneous changes of proportion and total density of the plants making interpretation of the outcome of competition difficult (Radosevich, 1987; Rejmanek et al., 1989; Silvertown and Doust, 1993). Spatial arrangement is assumed to be uniform with the assumption that intraspecific crop competition is constant but usually is not (Radosevich, 1987). Density is not as important as size, emergence time and spatial arrangement of the two species as is assumed by these designs (Silvertown and Doust, 1993). Only interspecific competition components can be estimated by the design.

Some of the drawbacks encountered in partial additive designs may be overcome by use of substitutive or replacement series designs. In these designs, the total plant density per unit area is held constant and the proportions of the mixtures are varied (Harper, 1977; Silvertown and Doust, 1993). Monocultures of each species are also included in the experiment. In these designs, both intra- and interspecific competition are

studied at a single total density (Firbank and Watkinson, 1985). Since total density is held constant while species proportions vary, the two experimental variables are not confounded during the experiment and spatial arrangement among individual plants is nonrandom (Radosevich, 1987). Over a period of time, prediction of shifts in species composition is possible (Conard and Radosevich, 1979) and relative aggressiveness among the species is readily calculated from the yield ratios (Harper, 1977).

Limitations to replacement series designs include their artificial nature for field research because constant crop density is used rather than a variable one to grow most crops (Radosevich, 1987). The actual and expected monoculture yields may vary according to plant density (Jolliffe et al., 1984; Radosevich, 1987). This makes the outcome of the trial depend upon the total plant density selected for the study. This, therefore, suggests the need for several monoculture densities to be included in an experiment and makes use of relative yield responses to alleviate the problem. Lastly, the design is cumbersome for the studies of mixtures of species of different life strategies or growth forms (Radosevich, 1987). This may demand for expression of the proportions based on biomass rather than density. The appropriate design depends on the objectives of the study.

Bean cultivars differ in response to soil nutrients. This study was partly carried out to determine the response of bean cultivars namely K 131, RAO 55 and BAT 25 to N, P and K nutrients and their factorial combinations. The idea was to select a cultivar with good characteristics

that may contribute to competitiveness against weeds in a bean-weed interaction study under varied soil fertility regimes.

Due to the difficulty of weed control and its importance in maintaining bean yield, analysis of weed interference with bean under varied soil nutrients is important. The information will enable determination of crop losses due to weeds under varied soil nutrient levels. It will also enable economic analysis of alternative control practices and eventual selection of suitable control options. Increased knowledge of competition between crops and weeds is desirable for improved use of competitive effects of crops as an integral part of weed control systems. Not much work has been carried out on competition between beans and weeds under varied soil fertility levels, especially in Uganda.

The broad objective of the study was to analyze competition between beans (*P. vulgaris*) and annual weeds (*B. pilosa*, *G. parviflora* and *S. nigrum*) under low soil fertility regimes.

The specific objectives of the study were: (a) to determine the response of bean cultivars and weeds to N, P and K and their factorial combinations; (b) to determine competition between beans and galinsoga, nightshade and blackjack or beggarticks (bidens) as affected by the NPK, OPK, NOK, NPO and OOO nutrients; (c) to determine the effect of nutrients on bean and weed nutrient uptake; and (d) to determine yield and financial losses to beans caused by these weeds under the varied soil nutrients.

MATERIALS AND METHODS

Field site and soil analysis

Research was carried out during the summer of 1995 and 1996 (June - October) at the Thompson Research Farm in Freeville, Cornell University, Ithaca, New York on a Howard Gravelly Loam soil (loamy-skeletal, mixed mesic, Glossoboric Hapludalf). The same research was repeated in Uganda at Namulonge Agricultural and Animal Production Research Institute (NAARI) during the first and second seasons of 1997. The soil type in Uganda was the red ferrallitic sandy clay soil (Harrop, 1970; FAO, 1993). The field at Cornell University was of low inherent soil fertility, and has been managed as plots to which N, P and K or their factorial combinations had been added since 1984. The plots had fertilizers applied since 1984 at the rates of 97.8 kg P ha^{-1}, 186.1 kg K ha^{-1} and 112.1 kg N ha^{-1} every year up to 1994.

In early June of 1995 and 1996, soil samples were taken from each nutrient plot before fertilizer treatments were applied. A soil borer was used to sample the top 10-15 cm from 5 places to form a composite soil sample for each plot. Composites of thoroughly mixed soil samples in a bucket were then placed in marked-pint size paper cans for analysis. A similar procedure was followed at NAARI (Uganda) in early March and August of 1997. The analysis results for 1995 and 1996 (Cornell University) and 1997 (NAARI) are shown in Tables 2.1, 2.2 and 2.3. The fields used at NAARI were identified through soil tests and long histories of the fields to be low in most essential nutrients.

Table 2.1 Soil chemical properties of the plots at Freeville Farm used for field trial in the 1995 season

Available[a] nutrients	NPK	NPO	OPK	NOK	OPO	NOO	OOK	OOO
P	10.80	15.45	17.35	0.35	19.80	0.35	0.85	1.45
K	213.50	31.00	236.00	210.50	33.00	29.50	239.00	32.50
Mg	90.65	101.95	149.70	125.45	151.00	91.25	140.65	181.85
Ca	1211.50	1341.00	1519.50	1238.50	1652.50	1022.50	1405.00	1511.50
Fe	1.85	1.25	0.85	1.15	1.35	1.70	1.05	1.55
Al	30.65	23.60	16.50	19.70	17.10	31.40	18.65	13.30
Mn	5.00	6.55	4.20	5.30	4.05	4.10	2.45	4.30
Zn	1.37	1.87	1.49	1.27	1.02	1.70	0.69	0.58
Cu	0.35	0.50	0.30	0.75	0.55	0.05	0.65	0.95
pH[b]	6.59	6.62	7.12	6.72	7.04	6.62	7.15	7.20
OM%	5.23	4.65	5.05	5.09	5.06	4.28	5.05	4.63

[a] P, K, Mg, Ca, Fe, Al, Mn, Zn and Cu are available nutrients expressed as mg kg^{-1}, and OM% (organic matter)

[b] pH in water

Table 2.2 Soil chemical properties of the plots at Freeville Farm used for field trial in the 1996 season

Available[a] nutrients	NPK	NPO	OPK	NOK	OPO	NOO	OOK	OOO
P	17.75	22.20	26.35	0.00	20.85	0.00	0.00	0.20
K	203.50	22.50	196.50	218.00	27.50	28.50	190.50	26.50
Mg	91.05	100.60	138.50	124.35	148.55	92.65	128.65	155.40
Ca	1206.50	1296.50	1534.50	1204.00	1665.00	1006.50	1380.50	1358.50
Fe	2.25	1.20	1.70	1.25	1.90	1.85	1.30	2.30
Al	36.50	24.05	21.55	20.45	21.10	34.45	21.30	16.35
Mn	5.40	6.60	5.30	6.95	5.20	4.45	2.75	5.65
Zn	0.20	0.17	0.22	0.21	0.16	0.13	0.06	0.14
Cu	1.20	1.35	1.80	1.10	1.90	0.85	1.10	1.10
pH[b]	6.19	6.45	6.73	6.49	6.83	6.43	6.98	6.91
OM%	4.90	4.32	4.80	4.70	4.76	3.85	4.55	4.22
NO_3	8.59	8.86	10.41	8.87	10.96	8.21	7.54	5.25

[a] P, K, Mg, Ca, Fe, Al, Mn, Zn, Cu and NO_3 are available nutrients expressed as mg kg^{-1}, and OM% (organic matter)

[b] pH in water

Table 2.3 Soil chemical properties of the plots at NAARI used for field trials during the 1997A and B seasons

Available	NAARI[a]	NAARI 1997B season				
nutrients	1997A[b]	NPK	NPO	OPK	NOK	OOO
P, available, mg kg^{-1}	3.79	16.21	17.52	14.45	8.58	5.68
K, " "	99.00	126.10	152.34	134.67	179.65	143.77
Mg, " "	-	359.18	433.53	400.69	469.82	385.12
Ca, " "	367.50	467.10	546.29	531.43	665.10	499.25
pH in water, pH	4.83	4.78	4.84	5.03	5.01	4.95
Organic matter, %	4.35	3.85	3.79	3.89	3.88	3.81
% nitrogen	-	0.23	0.25	0.25	0.24	0.22
% clay	36.67	39.60	40.20	38.90	41.50	40.40
% sand	47.66	48.00	49.60	50.00	47.80	46.40
% silt	15.67	12.40	10.20	11.10	10.70	13.20

[a]NAARI = Namulonge Agricultural and Animal Production Research Institute,
[b]1997A or B season means the first and second rains of 1997, respectively.

Soil pH was determined on a 1:1 (by volume) soil: water or soil: 0.01M $CaCl_2$ suspension. At Kawanda Agricultural Research Institute (KARI), Soil Science Program, it was measured in 1:2.5 soil:water ratio using a pH electrode (Okalebo et al., 1993). Available nutrients including major and minor nutrients were extracted with Morgan's solution, 10% sodium acetate in 3% acetic acid buffered to pH 4.8 using a 1: 5 (by volume) soil: solution ratio at Cornell University (Cornell CALS Nutrient Analysis Laboratories, 804 Bradfield Hall). Potassium (K), Mg, Ca, Mn, iron (Fe), Al and zinc (Zn) were determined by atomic absorption. The same was true for soil samples analyzed from NAARI. Phosphorus (P), nitrate nitrogen (NO_3-N), and ammonia nitrogen (NH_4-N) were determined colorimetrically by stannous chloride reduction, automated hydrazine reduction, and phenate-hypochlorite methods, respectively. At NAARI, P and exchangeable bases were extracted with excess ammonium lactate solution at pH 3.8 (Foster, 1971). Total nitrogen was determined by the micro-Kjeldahl technique and soil texture by the hydrometer method (Gee and Bauder, 1986). For all nutrients, mg/kg = ppm by weight of soil. Organic matter at Cornell University was determined by loss of ignition (LOI). The soil was first heated at 50 °C for one hour, then ignited at 500 °C for two hours. To convert LOI to organic matter: (0.7 x LOI) - 0.23 = OM and this is valid up to 6% OM. At NAARI, organic carbon was determined by Walkey and Black (1934) with chromic acid titration method with the value obtained multiplied by 1.729 to give percentage organic matter.

Treatment application and field activities

Eight nutrient treatments of NPK, OPK, NOK, NPO, OOK, OPO, NOO and OOO were used for experimentation in 1995. This was to determine the responses of three bean cultivars, namely K 131 (indeterminate bush, type IIb growth habit, erect stem with guides and ability to climb) BAT 25 and RAO 55 (determinate bush, type I) (CIAT, 1987) to the different nutrient combinations. In 1995, the trial was planted as a split plot design with the eight nutrient treatments as the main plots and the three bean cultivars as the sub-plots and replicated three times. Fertilizers were broadcast applied and incorporated immediately into the soil a day before planting at the rate of 50 kg P ha^{-1} as superphosphate (20.1% P), 99.6 kg K ha^{-1} as muriate of potash (49.8% K) and 50 kg N ha^{-1} as ammonium nitrate (34% N). The three bean cultivars were machine-planted at spacing of 75 cm x 5 cm, and two rows of 4 m length of each cultivar per plot were used.

For the bean-weed interaction to nutrients in the 1996 (Cornell University), 1997A and B seasons (NAARI), five nutrient treatments were used namely, NPK, OPK, NPO, NOK and OOO. Nutrient applications were: 50 kg N ha^{-1} as ammonium nitrate, 50 kg P ha^{-1} as superphosphate, and 60 kg K ha^{-1} as muriate of potash as broadcasts. The fertilizers were incorporated immediately into the soil. Each nutrient combination treatment had 5 bean-weed treatments namely: (a) beans and galinsoga, (b) beans and black nightshade, (c) weed-free beans (d) sole galinsoga, and (e) sole black nightshade. Weeds and beans were combined in an additive design where weeds were added to a constant density of beans as described by Rejmanek, et al. (1989) and Radosevich

(1987). The same bean-weed teatments used at Cornell University in 1996 were repeated at NAARI (Uganda) during the first and second seasons of 1997 except that nightshade was replaced by bidens. The trial was planted as a split-plot design with nutrient treatments as the main plots and bean-weed treatments as the subplots replicated twice at Cornell University and four times in Uganda. The same plots used in the 1997A season were also used in the 1997B season at NAARI.

Bean cultivar K-131 (which normally matures in 80 to 90 days in Uganda) was machine planted at 75 cm between rows and 5 cm between bean plants at Cornell University. Beans were manually planted at 50 cm between rows and 10 cm between plants in Uganda. Galinsoga and black nightshade were manually planted at 25 cm from the bean rows (two rows of weeds between two bean rows) at high densities but thinned to 120 and 90 plants m^{-2}, respectively, 21 DAP at Cornell University. At NAARI, bidens and galinsoga were planted in a single row 25 cm from the bean rows, that is, between two bean rows.

In addition to the 5 nutrients (NPK, OPK, NOK, NPO and OOO) used in the bean-weed experiment at Cornell University in 1996, data were also collected from the other three nutrient treatments (NOO, OPO and OOK) used in 1995. Nutrients in the three treatments were applied as stated above for N, P and K in 1996. Bean cultivar K 131 was planted in the three nutrient treatments and kept weed-free.

Field activities in the two years are summarized in Table 2.4. First weeding of weed-free beans in 1995, 1996 and 1997 was carried out at 21 DAP and subsequent weeding was by hand pulling. Irrigation was applied as needed in 1995 but only once in 1996 (equivalent of 20 mm)

Table 2.4 Schedule and timing of field activities at Freeville Farm (Cornell University) in the 1996 season and at NAARI in the 1997A and B seasons

	Activity	1995	1996	1997A	1997 B
1.	Fertilizer application	27 June,	12 June,	21 April,	3 October,
2.	Dry beans planted	28 June,	13 June,	21 April,	3 October,
3.	Weeds planted		13 June,	21 April,	3 October,
4.	Weeds thinned		5-12 June,		
5.	First weeding (weed-free plots)	18 June,	5 July,	12 May,	21 October,
6.	Irrigation	when needed	12 July,		
7.	Spraying of insecticides and fungicides:				
	Insecticide (Oxamyl)	3 August,			
	" (Methoxychlor)		17 July,		
	" (Orthene)	3 August,	3 Aug., 4 Sept.,		
	Insecticide (Ambush)			2 June,	
	Fungicide (Benlate)	3 August,	3 Aug., 4 Sept.,		
	Fungicide (Dithane M45)				10, 17, 24 Nov.,
	Fungicide (Antracol)				10, 17, 24 Nov.,
8.	Bean harvested	9 October,	4 and 5 October,	14 July,	29 December,

while no irrigation was applied in Uganda. In the 1995 and 1996 seasons, insecticides Vydate (Oxamyl [methyl N'N'-dimethyi-N-[(methylcarbamoyl)oxy]-1-thiooxamimidate) (24% active ingredient), Methoxychlor (25% a.i.) and Orthene (Acephate (O,S-Dimethyl acetylphosphoramidothioate)) were applied against Mexican bean beetles (*Epilachna varivestis*) and Japanese bean beetles (*Popillia japonica*) (Table 2.4). Fungicide, Benlate (Benomyl [methyl 1-(butylcarbamoyl)-2-benzimidazolecarbamate] (50% a.i.) was sprayed to control fungal diseases including bean white mold or sclerotinia wilt (*Sclerotinia sclerotiorum*) as per the schedule indicated in Table 2.4. In the 1997A and B seasons, insecticide super Ambush (Permethrin (3-Phenoxyphenyl) methyl (+)-cis, trans-3-(2,2-dichloroethenyl)-2,2-dimethylcyclopropanecarboxylate) (25% a.i.) and fungicides Mancozeb (Dithane M45 wettable powder 80%) (Ethylene bisdithiocarbamate) and Antracol, 70 WP (Propineb 700 g/kg) (Zinc propylene-bisdithiocarbamate) were applied as per the schedule in Table 2.4.

Data collection

Field data collected during the studies included planting date and emergence time for beans and weeds. Also measured were plant heights from the soil surface to the last growing points of either beans or weeds on the main stem at 28, 42 and 56 DAP in 1995, 1996 and 1997. Light measurements or measure of photosynthetically active radiation (PAR) were taken using a Sunfleck Ceptometer (Decagon Devices Inc., Pullman, Washington, 99163, USA) with a 1 m-long sensing element in 1995. Photosynthetically active radiation (PAR) was measured by taking reading at the top of the plant canopy (incoming radiation) and the

average of three readings within the plant canopy down to the soil surface. Readings were expressed as a percentage of the incoming radiation for each treatment. Measurements of PAR were taken between 12.00 noon and 2.00 p.m. at 42 and 56 DAP.

Bean and weed leaf chlorophyll content measurements were taken using a chlorophyll meter (Minolta SPAD-502, silicon photodiode which provides a relative number or index related to the chlorophyll status or 'greenness' of the plant) in 1996. The chlorophyll status measurement of the plants was recorded by inserting a small section of leaf into the measuring head and reading the index. An average of 25 readings per plot was recorded. Canopy measurements were taken at 28, 42 and 56 DAP by use of a 1-m ruler in the 1996, 1997A and B seasons to estimate ground surface coverage by the beans. Leaf area index (LAI) was recorded at 42 and 56 DAP in 1996 and at 28, 42, 56 and 70 DAP in 1997. This was by harvesting all the green leaves on the bean plants and measuring their areas using a Portable Area Meter (LI-COR Model LI-3000, LI-COR Inc., Lincoln, Nebraska, 68504, USA). Total leaf area was divided by the ground area covered by the plants harvested to give LAI.

Bean shoot dry weight per square meter was recorded at 42 and 56 DAP in the 1996 season. Similarly, shoot dry weight records were made at 42 and 56 DAP in the 1997A season and at 28, 42, 56 and 70 DAP in the 1997B season. Weed shoot and root and bean root dry weights were recorded at 56 DAP in the 1996 season. Weed shoot dry weights in the 1997B season were made at 42, 56 and 70 DAP. Beans and weeds were harvested at ground level and the above ground matter dried in the oven at 80 °C for 48 to 72 hours. Dry weight measurements were taken when

the weights were constant. In 1996 and 1997, a portion of the dry shoots (stems and leaves above ground) for both weeds and beans were ground and analyzed for nutrient contents at 56 DAP. Plant analyses were carried out by Fruit and Vegetable Science ICP Analytical Laboratory (Cornell University) and Makerere University, Soil Science Department (Uganda). Root dry matter was determined by digging plant roots in a 0.5 and 0.75 m^2 at Cornell University and at NAARI, respectively, and collecting as many of the roots as possible from that sampling area into a sampling bag. The depth of sampling varied depending on how far the roots penetrated the soil. The roots were then washed, dried at 80 °C for 48 to 72 hours till constant weight was achieved and weighed.

At bean flowering, nodule rating was carried on 5 bean plants per plot on a scale of 1-5 with 1 indicating excellent nodulation (over 80 nodules per plant) and 5 very poor nodulation (less than 10 nodules per plant). White mold disease scores were made at R8 (pod filling stage) and R9 (physiological maturity in beans) development stages of beans according to the CIAT (1987) rating scale for diseases. The scale used for white mold rating was 1-9 where 1 was no disease symptoms and 9 very high disease symptoms.

Other parameters recorded included days to 50% flowering in beans (when nearly 50% of the beans had flowered) and days to physiological maturity (when the bean pods had turned yellow tending towards brown but not fully brown). Also recorded were bean yield parameters including pods per plant (reported as pods m^{-2}), bean seeds per pod, 200 seed weight and bean seed yield per unit area.

Statistical analysis

All data or variables were subjected to analysis of variance (ANOVA) procedures after diagnosis for normality, constant error variance, zero error mean and independent distribution of the errors and outlier observations. Data which deviated from normality were transformed by use of either log or square root transformation. Means of the variables under the different treatments were separated at the 5% level of significance using the multiple mean comparison method of protected least significant difference (LSD). Interaction graphs were used to explain interactions between the treatments where they occurred. Regression analysis was carried out on some of the variables. Regression graphs were used to report relationships between the measured variables.

Economic analyses were also performed for the different treatments. Total revenue was calculated as the product of bean price per kilogram and total bean yield per hectare. Net profit was calculated as total revenue less production costs, marketing and transport costs (Appendix A, Table A1). Total revenue and net profit were subjected to ANOVA to determine the effects of nutrients and weeds on revenue and profit. As in the above case, LSD was used to separate the means of the main effects.

RESULTS

Weather measurements in the 1995, 1996 and 1997 seasons

Weather conditions at Freeville Farm (Cornell University) and NAARI (Uganda) are given in Table 2.5. Rainfall was more and better distributed in the 1996 compared to the 1995 season. In Uganda during the 1997A season, rainfall was poorly distributed and a dry period

Table 2.5 Summary of weather conditions at Freeville farm and NAARI (Uganda) during the 1995, 1996, 1997A and B seasons

Month	1995			1996			1997					
	Temperature		Rainfall	Temperature		Rainfall	Temperature		Rainfall	Relative	Solar	Wind
	Max.	Min.	(mm)	Max.	Min.	(mm)	Max.	Min.	(mm)[a]	humidity	radiation (MJ m^{-2} d^{-1})	speed $m\ s^{-1}$
January							29.2	15.3	69.7 (5)	77.7	16.8	1.8
February							31.5	15.5	13.4 (2)	67.4	19.4	2.0
March							30.6	16.3	133.1 (7)	75.8	17.9	2.2
April							26.7	14.8	269.2 (15)	89.3	16.5	1.9
May							27.4	15.2	187.7 (9)	88.7	16.1	1.7
June	25.8	12.5	76.2	25.3	13.3	107.7	28.1	15.7	41.8 (6)	86.1	16.3	1.8
July	28.5	15.3	72.9	25.7	12.3	107.4	28.0	15.4	77.6 (10)	85.4	14.0	1.5
August	29.3	13.0	48.3	27.5	12.2	108.2	28.5	15.3	92.9 (9)	86.0	15.3	1.1
September	22.0	6.1	69.6	22.2	9.3	96.2	30.7	16.0	35.6 (5)	77.8	18.8	1.0
October							27.6	15.2	272.9 (19)	88.4	16.6	0.9
November							24.7	14.7	295.4 (24)	92.8	14.7	0.6
December							23.7	14.5	309.1 (21)	91.8	15.6	0.7

Note: Growing seasons in Uganda were between March and June, and September and December for first and second rains, respectively. Elevation at NAARI = 1150 m or 3770 ft ASL, Latitude = 01 23°. 185', Longitude = 032° 24. 816',
[a]Figures in parentheses are the number of days it rained during the month

constrained the yield of beans (Figure 2.1). For three weeks after planting, rainfall distribution was about right. After this period for the next 6 to 7 weeks it was dry which coincided with the flowering period in beans (Figure 2.1). This reduced yield greatly. The 1997B was El Nino season with too much rain which led to white mold disease (*Sclerotinia sclerotiorum*) attack on beans (Figure 2.1). Relative humidity was high, with reduced solar radiation and wind speed at NAARI (Table 2.5). This provided good environment for the development of white mold disease on beans. This was similar to the observation made in 1996 where the cool and humid season increased white mold disease on beans.

Bean and weed emergence

Beans emerged on the 5 July, 18 June, 26 April and 7 October in the 1995, 1996, 1997A and B seasons, respectively. Galinsoga and nightshade species emerged between 18 and 22 June in 1996 with more galinsoga emerging early compared to nightshade species. Bidens and galinsoga emergence in Uganda were however, delayed for one and two days, respectively under the NOK treatment. Beans grew vigorously under the NPK nutrient treatment. Slight yellowing of leaves under the OPK treatment was observed probably due to inadequate N. In the NOK nutrient plots, bean leaves were dark green as a sign of lack of P and the weeds were less vigorous. Under the NPO nutrient, weeds were very vigorous while beans showed retarded growth. The same situation was observed under the OOO treatment in which both beans and weeds remained stunted.

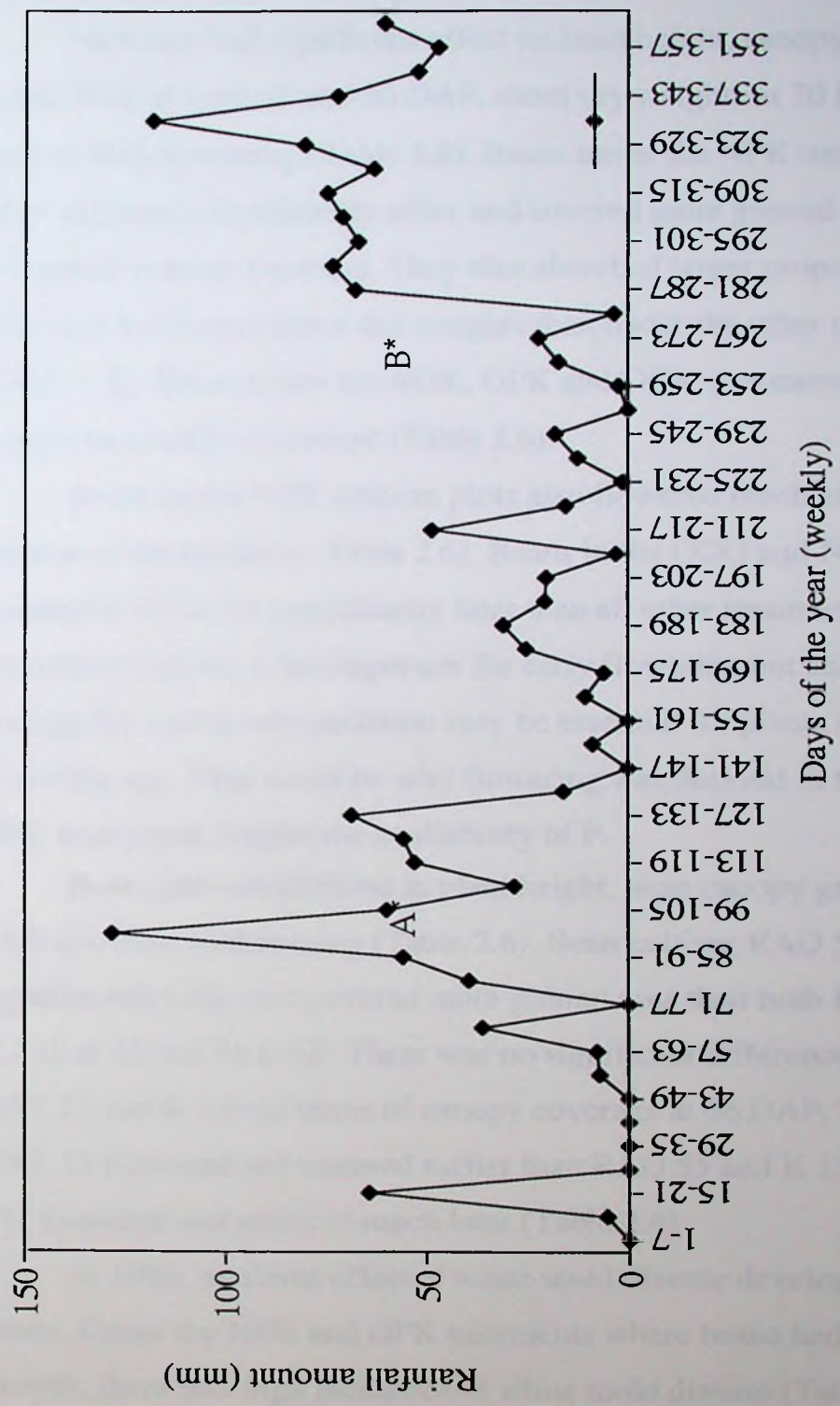


Figure 2.1 Rainfall distribution at Namulonge Agricultural and Animal Production Research Institute (NAARI) during the 1997A and B seasons. Beans during the 1997A season were planted on April 21 (111th day of the year marked A*) and in the 1997B season on October 3 (275th day of the year marked B*) where day 1 corresponds to January 1 and day 365 to December 31, 1997

Effect of nutrients on bean growth in 1995 and 1996

Nutrients had significant effect on bean height, canopy ground cover, PAR at both 42 and 56 DAP, shoot dry weights at 70 DAP and days to 50% flowering (Table 2.6). Beans under the NPK treatment were more vigorous, significantly taller and covered more ground area compared to other nutrients. They also absorbed larger proportions of PAR and had higher shoot dry weights than under the other nutrients (Table 2.6). Beans under the NOK, OPK and OOK treatments grew well compared to OOO treatment (Table 2.6).

Beans in the NPK nutrient plots also flowered much earlier than the rest of the nutrients (Table 2.6). Beans in the OOO and NOO treatments flowered significantly later than all other treatments. Phosphorus seems to be important for early flowering but additionally, enough dry matter accumulation may be essential for plants to reach flowering age. That could be why flowering was delayed in the NPO and OPO treatments despite the availability of P.

Bean cultivars differed in plant height, bean canopy ground cover, PAR and days to flowering (Table 2.6). Bean cultivar RAO 55 was significantly taller and covered more ground area than both BAT 25 and K 131 at 42 and 56 DAP. There was no significant difference between BAT 25 and K 131 in terms of canopy coverage at 56 DAP. Bean cultivar BAT 25 flowered and matured earlier than RAO 55 and K 131 while K 131 flowered and matured much later (Table 2.6).

In 1996, nutrients affected white mold disease development on beans. Under the NPK and OPK treatments where beans had vigorous growth, there was high incidence of white mold disease (Table 2.7). This

Table 2.6 The effect of nutrients and bean cultivar on bean growth at Freeville Farm in the 1995 season

Treatment	Plant height (cm)		Canopy cover (%)		PAR (%)[a]		Shoot dry weight ($g\ m^{-2}$)	Days to 50% flowering
	42 DAP	56 DAP	42 DAP	56 DAP	42 DAP	56 DAP	70 DAP	
Nutrient treatment								
NPK	99.8 e	100.1 d	86.5 e	97.2 f	91.4 d	94.4 c	687.1 d	43.6 a
OPK (minus N)	83.0 cd	84.0 c	62.8 d	82.7 de	63.0 c	89.5 c	535.8 c	46.8 b
NOK (minus P)	73.3 c	74.3 b	56.4 c	78.2 cd	47.3 b	87.9 c	543.3 c	47.9 cd
NPO (minus K)	80.4 cd	82.1 bc	61.4 d	79.4 cd	65.2 c	85.3 bc	374.1 b	48.9 de
OOK (minus N, P)	86.3 d	87.4 c	62.0 d	85.5 e	61.8 c	88.5 c	510.5 c	47.0 bc
OPO (minus N, K)	76.6 cd	78.4 bc	57.0 c	75.1 c	56.6 bc	73.6 b	368.1 b	49.0 e
NOO (minus P, K)	59.4 b	61.4 a	44.8 b	63.5 b	34.3 a	51.9 a	368.1 b	50.1 f
OOO (minus N, P, K)	50.7 a	52.2 a	38.4 a	55.0 a	30.5 a	42.9 a	232.8 a	51.8 g
Bean cultivars								
BAT 25	75.3 b	78.0 b	59.3 b	75.9 a	51.5 a	72.6 a	440.6 b	45.5 a
K 131	63.2 a	65.6 a	53.2 a	73.3 a	47.6 a	70.6 a	395.4 a	51.9 c
RAO 55	87.7 c	89.0 c	63.5 c	82.0 b	61.7 b	81.9 b	462.4 b	47.0 b
Statistical significance[b]								
Nutrient treatment	****	****	****	****	****	****	****	****
Bean cultivar	****	****	****	****	**	**	***	****
Nutrient x cultivar	ns	ns	ns	ns	ns	ns	**	ns
Coefficient of variation	6.57	25.42	25.62	18.53	9.94	8.02	6.62	8.04

Means in each column followed by the same letter for each set of treatments are not significantly different at 5% level using LSD,
Bean plant height at 42 DAP, PAR at 42 and 56 DAP and shoot dry weight were log transformed and back transformed means are reported,
[a]PAR (%) is the amount of photosynthetically active radiation intercepted by the beans,
[b]**, ***, ****, ns mean statistically significant at $p \leq 0.01$, 0.001, 0.0001 or not significant, respectively,.

Table 2.7 The effect of nutrients on white mold disease incidence and nodulation in beans at Freeville Farm in 1996

Treatment	White mold disease rating[a]		Nodule rating[b]	
	R8	R9	Total nodules	Effective nodules
NPK	7.5	7.5	5.0	5.0
OPK (minus N)	6.5	7.5	2.5	3.0
NOK (minus P)	2.5	3.0	5.0	5.0
NPO (minus K)	1.0	1.5	4.3	5.0
OOK (minus N and P)	1.0	2.0	3.0	3.5
OPO (minus N and K)	1.0	1.0	2.5	4.0
NOO (minus P and K)	1.0	1.0	4.5	5.0
OOO (minus N, P and K)	1.0	1.0	2.0	4.5

[a]Disease rating on a scale of 1 – 9 where 1 is no symptom and 9 is highly infected by the disease at R8 (pod filling stage of bean growth) and R9 (physiological maturity in beans), [b]Nodule number rated on a scale of 1 – 5 at R6 (flowering stage of bean growth) where 1 = excellent or more than 80 nodules/plant, 2 = good or 41 – 80 nodules/plant, 3 = intermediate or 21 – 40 nodules/plant, 4 = poor or 10 – 20 nodules/plant and 5 = very poor or less than 10 nodules/plant.

greatly affected yield under the two treatments. There was very low level of white mold attack on beans under the NOK treatment and no attack under the other nutrient treatments.

Effective nodules as noted by the red-pink internal color of the nodules were many in the OPK and OOK treatments and to some extent under the OPO treatment in 1996 (Table 2.7). This could have provided beans with the N needed for growth under these treatments. There were very few nodules in all treatments where N was applied indicating the

detrimental effect of N on nodulation. The OOO treatment although had many nodules, most of them were small and greenish or darkish in color indicating that they were ineffective.

There was a significant nutrient by bean cultivar treatment interaction for shoot dry weight (g m^{-2}) at 70 DAP in 1995 ($p = 0.0071$) (Figure 2.2). Under the NOO treatment, K 131 had significantly less shoot dry weight per unit area than BAT 25 ($p = 0.0001$) and RAO 55 ($p = 0.0003$). Bean cultivar RAO 55 had significantly more dry weight than K 131 ($p = 0.0187$) under the NPO treatment. Under the OOO treatment, RAO 55 had significantly more shoot dry matter than BAT 25 ($p = 0.017$) and K 131 ($p = 0.0016$). No significant differences were observed between the bean cultivars under the NPK, NOK, OPK, OOK and OPO treatments.

Bean and weed growth parameters in 1996 and 1997

Plant height, canopy cover and chlorophyll content

Nutrients had significant effect on bean and weed plant heights, bean canopy cover (expressed as percentage ground cover) and bean and weed chlorophyll contents in the 1996, 1997A and B seasons (Figure 2.3, Tables 2.8 and 2.9). In the 1996 season, the tallest plants (beans and weeds) were in the NPK nutrient plots (Figures 2.3 (i) and (ii)). In the 1997A season, the trend was similar to the 1996 results except that the tallest beans were in the NPK and NPO nutrient plots and the tallest weeds in the NPO nutrient plots (Figure 2.3 (iii)).

Nutrients had no significant effect on bean heights at 42 and 56 DAP in the 1997B season (Figure 2.3). Nutrients had significant effect on weed heights in the 1997B season and the tallest weeds were in the NPK

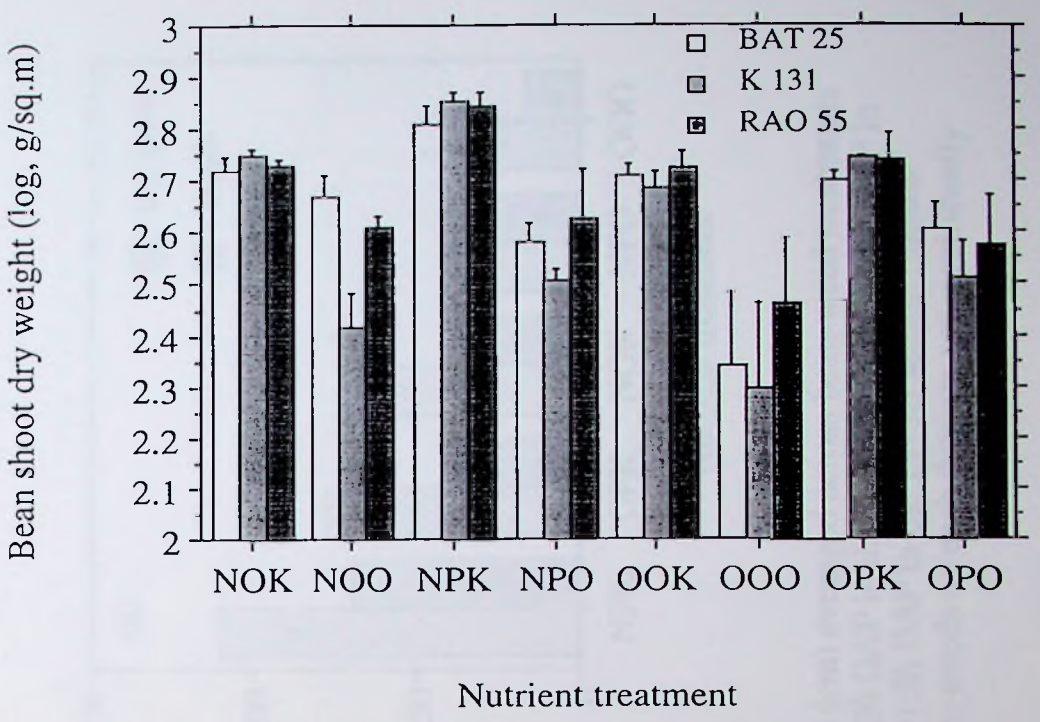


Figure 2.2 Bean cultivar by nutrient treatment interaction effect on bean shoot dry weight (log, g m^{-2}), 70 DAP in the 1995 season

and NPO treatments (Figures 2.3 (iv) and (v)).

Beans were taller than weeds in the 1996 and 1997B seasons at all recorded dates (Figures 2.3 (i), (iv) and (v)). In the 1997A season, the weeds were taller than the beans in the NPK, NPO, NOK and OPK treatments (Figure 2.3 (iii)). Beans were slightly taller than the weeds in the OOO treatment. Water deficits in the 1997A season (Table 2.5, Figure 2.1) could have affected bean response to nutrients compared to the weeds. Nutrients had no significant effect on the heights of beans grown in Uganda in the 1997B season. In the 1996 season, nutrients caused significant differences in the heights of beans. Beans under the NPK treatment were taller than beans in Uganda under similar treatment.

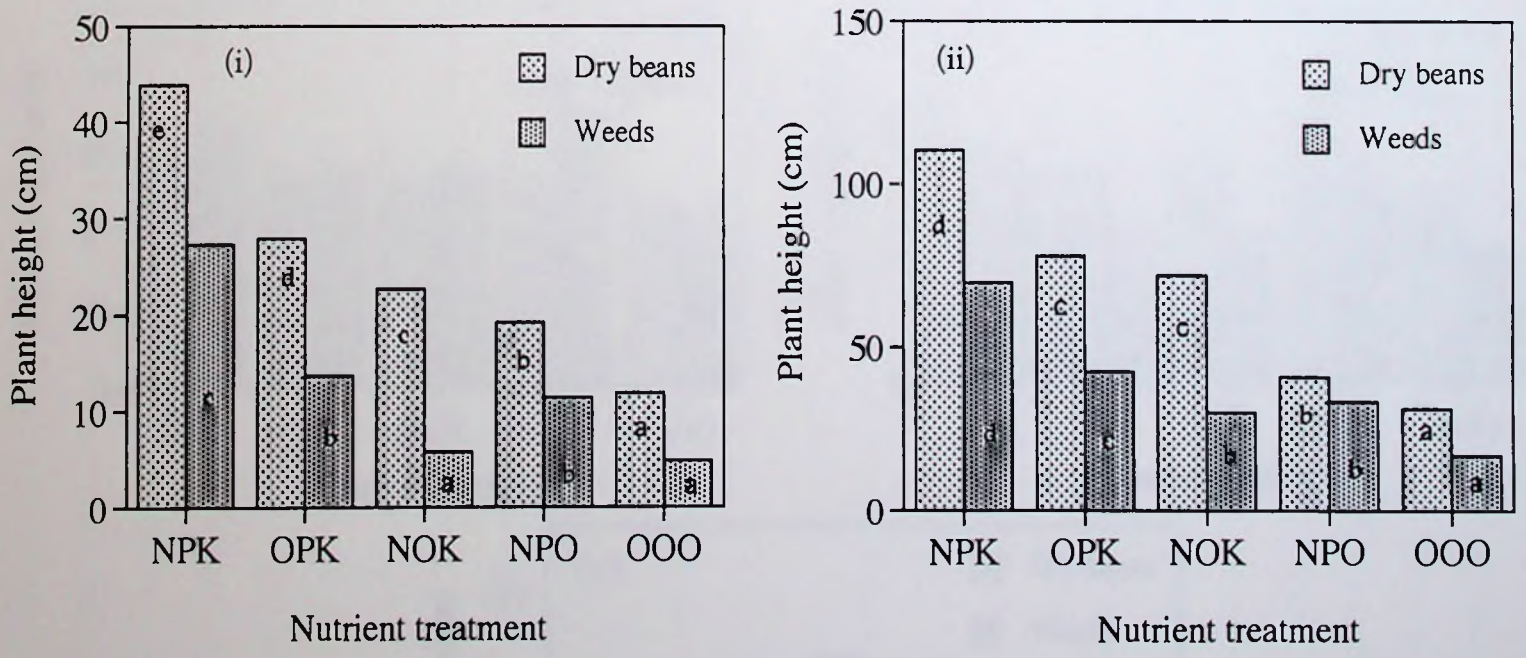
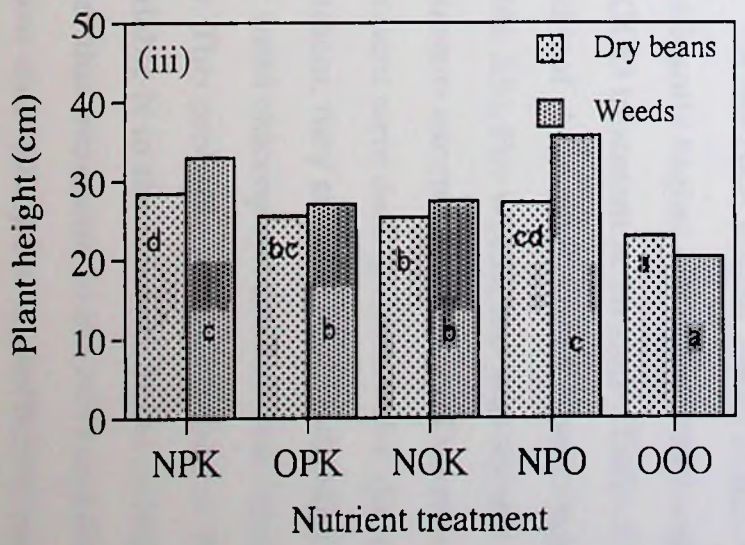
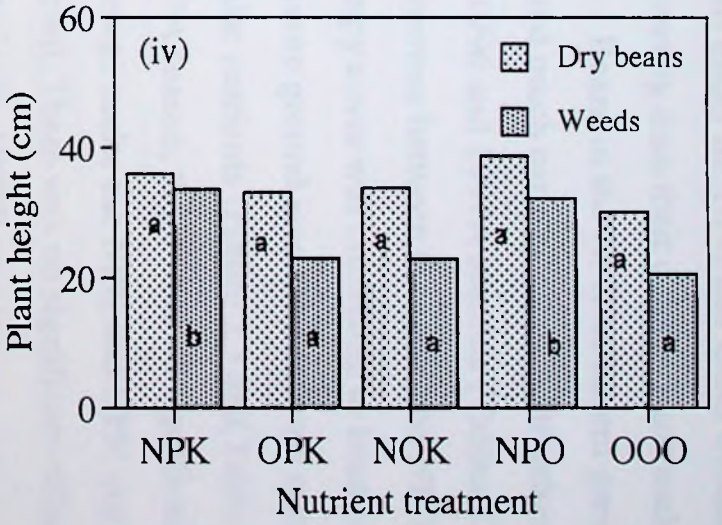
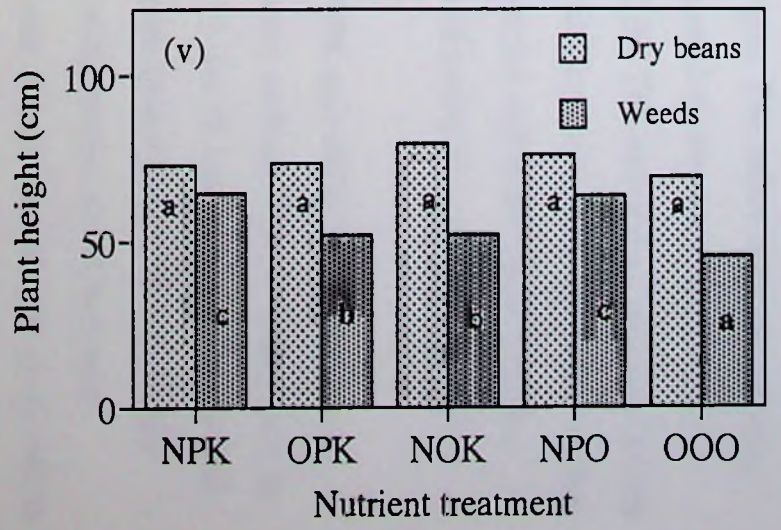


Figure 2.3 The effect of nutrients on bean and weed heights (cm) averaged across bean-weed treatments at each nutrient level at (i) 42 DAP in the 1996 season, (ii) 56 DAP in the 1996 season, (iii) 42 DAP in the 1997A season, (iv) 42 DAP in the 1997B season, and (v) 56 DAP in the 1997B season (means followed by the same letter on each graph for either beans or weeds on each date are not significantly different from one another at 5% level using LSD)

Figure 2.3 (Continued)







Beans under the NPO and OOO treatments were much shorter at Cornell University than their counter parts under similar treatments in Uganda.

Beans in the NPK treatment grew relatively fast and covered the ground much earlier compared to other treatments at all sampling dates in the 1996 and 1997A seasons (Tables 2.8). There were no significant differences between the NPK and NPO nutrients in the 1997A season. Canopy cover was correlated to bean height. The taller the bean plants, the more ground area they covered compared to shorter beans under similar nutrients (Figure 2.3 and Table 2.8). The exception was that in the 1997A season, there were no significant differences between bean canopy coverage under the NPK and OPK treatments while the plant heights differed. There was no significant effect of nutrients on bean canopy cover in the 1997B season.

In the 1996 season, beans in the NPK and NOK treatments had significantly higher leaf chlorophyll content and the lowest value was in the OOO treatment at 28 DAP (Table 2.9). At 42 and 56 DAP, bean and weed leaf chlorophyll contents were higher under the NOK treatment (Table 2.9). For weeds, this was significantly different from other treatments except under the NPO treatment. Beans and weeds in the NOK treatment were dark green in color due to lack of P while in the OPK treatment, they showed slight yellowing due to lack of N. At both dates, low weed chlorophyll amount was observed in the OPK treatment (Table 2.9). This probably was due to lack of N and competition for the little available N in the soil with beans as both beans and weeds were vigorous under this treatment. In the NPO and OOO treatments, bean leaves were yellow most likely due to inefficient use of N or competition from weeds

Table 2.8 The effect of nutrient and weed treatments on bean canopy cover (%) in the 1996, 1997A and B seasons

Treatment	1996		1997A	1997B		
	28 DAP	42 DAP	28 DAP	28 DAP	42 DAP	56 DAP
Nutrient treatment						
NPK	56.14 d	77.78 e	76.13 cd	60.11 a	71.11 a	69.63 a
OPK	39.45 c	61.00 d	72.09 bc	56.11 a	69.11 a	68.84 a
NOK	31.18 b	51.95 c	71.50 b	56.48 a	74.71 a	69.28 a
NPO	30.75 b	46.35 b	76.26 d	57.34 a	70.23 a	71.96 a
OOO	22.50 a	32.71 a	62.11 a	55.01 a	64.36 a	65.17 a
Bean-weed treatment						
Weed-free beans	35.82 a	56.78 b	73.09 a	57.29 a	74.33 b	72.73 b
Beans/galinsoga	37.08 a	52.48 a	72.32 a	55.19 a	68.53 a	66.59 a
Beans/nightshade[a]	35.24 a	52.61 a	69.44 a	58.54 a	66.85 a	67.61 a
Statistical significance[b]						
Nutrient treatment	****	****	****	ns	ns	ns
Bean-weed treatment	ns	***	ns	ns	*	*
Nutrient x bean-weed	ns	**	ns	ns	ns	ns
CV	33.71	29.95	12.67	11.09	12.23	10.85

Means in each column followed by the same letter for each treatment set are not significantly different at 5% level using LSD,

[a]Bean/nightshade in 1996 and bean/bidens in the 1997A and B seasons,

[b]*, **, ***, ****, ns mean statistically significant at $p \leq 0.05, 0.01, 0.001, 0.0001$ or not significant, respectively.

and lack of nutrients in the OOO nutrient plots.

Weeds had significant effects on plant heights (Figure 2.4) but the effects were not consistent across seasons. In the 1996 season, beans grown with galinsoga were taller than beans grown with nightshade and weed-free beans at 42 DAP (Figure 2.4 (i)). Similarly, in the 1997B season, weed-free beans and beans grown together with bidens were

Table 2.9 The effect of nutrient and bean-weed treatments on bean and weed leaf chlorophyll content (index values) in the 1996 season

Treatment	28 DAP	42 DAP		56 DAP	
	Beans	Beans	Weeds	Beans	Weeds
Nutrient treatment					
NPK	35.67 c	32.32 b	34.03 b	35.22 bc	31.45 b
OPK	31.67 b	31.02 b	30.83 a	33.88 b	27.89 a
NOK	34.00 c	36.42 c	36.91 d	36.28 c	36.11 d
NPO	30.12 d	27.20 a	36.06 cd	26.05 a	35.33 cd
OOO	26.98 a	28.92 a	34.90 bc	28.27 a	33.11 bc
Bean-weed treatment					
Weed-free beans	31.12 a	31.30 a	-	32.18 a	-
Beans/galinsoga	32.38 a	30.99 a	34.42 a	31.42 a	31.76 ab
Sole galinsoga	-	-	35.48 a	-	33.27 bc
Beans/nightshade	31.50 a	31.23 a	34.01 a	32.22 a	31.12 a
Sole nightshade	-	-	34.27 a	-	34.96 c
Statistical significance[a]					
Nutrient treatment	****	****	****	****	****
Bean-weed treatment	ns	ns	ns	ns	**
Nutrient x bean-weed	ns	ns	ns	ns	ns
CV	12.49	11.15	8.80	13.71	12.10

Means in each column followed by the same letter for each treatment set are not significantly different at 5% level using LSD,

[a] **, ****, ns mean statistically significant at $p \leq 0.01$, 0.0001 or not significant, respectively.

significantly taller than beans grown with galinsoga at 56 DAP (Figure 2.4 (v)). Bean height was reduced by galinsoga in both the 1997A and B seasons and by both weeds in the 1997A season at 56 DAP (Figures 2.4 (iii) and (v)). In the 1996 and 1997B seasons, beans growing together with weeds were taller than the weeds (Figure 2.4). Beans were also taller than bidens and not galinsoga in the 1997A season (Figure 2.4 (iii)).

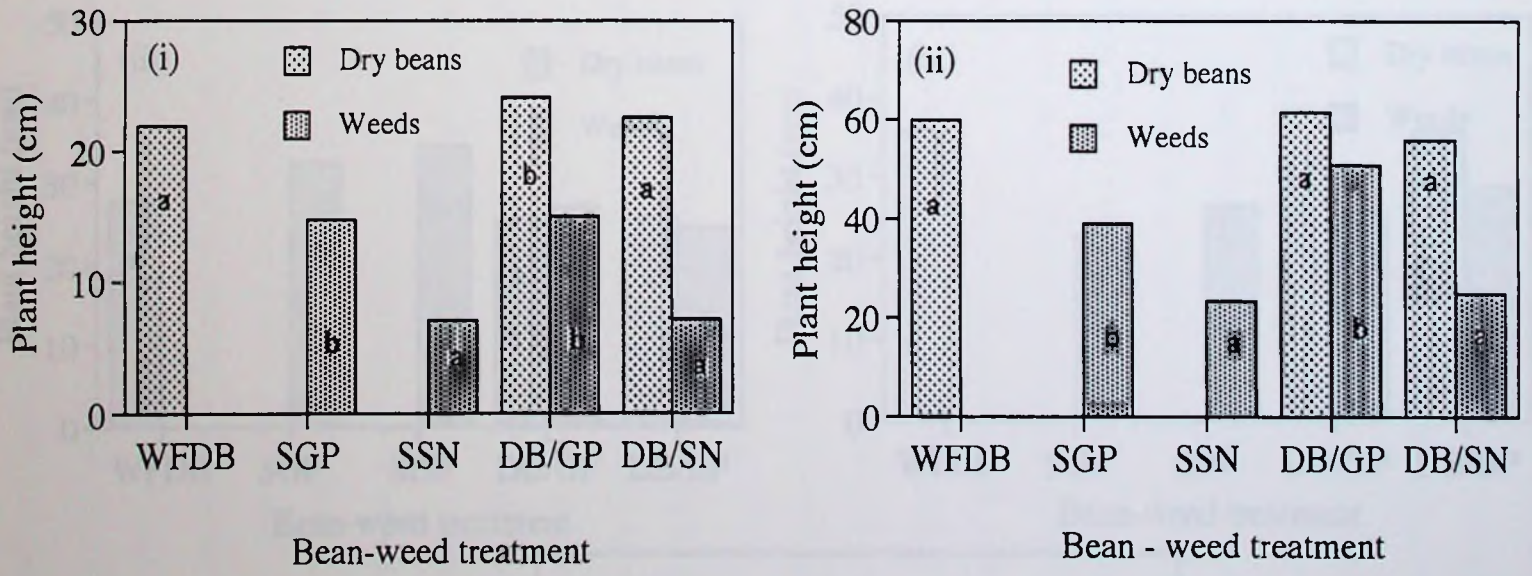
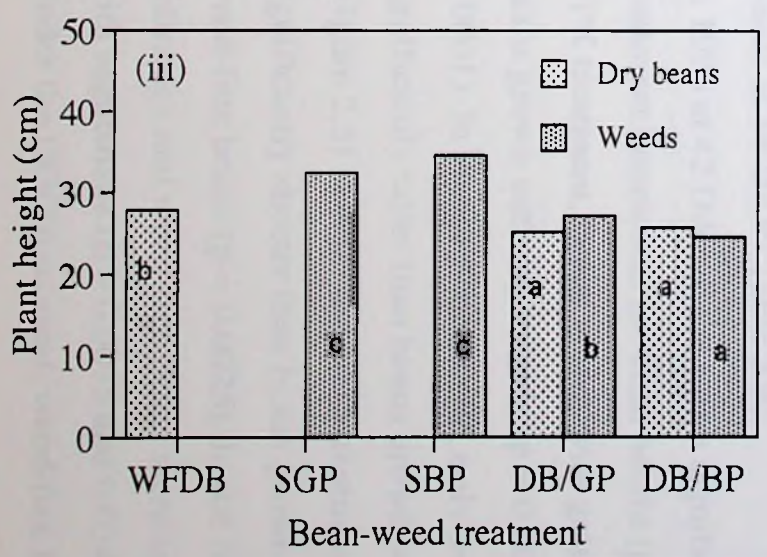
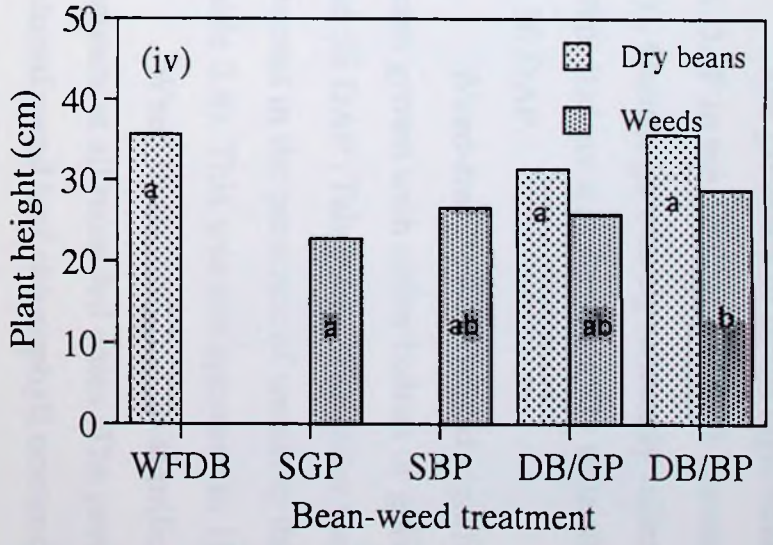
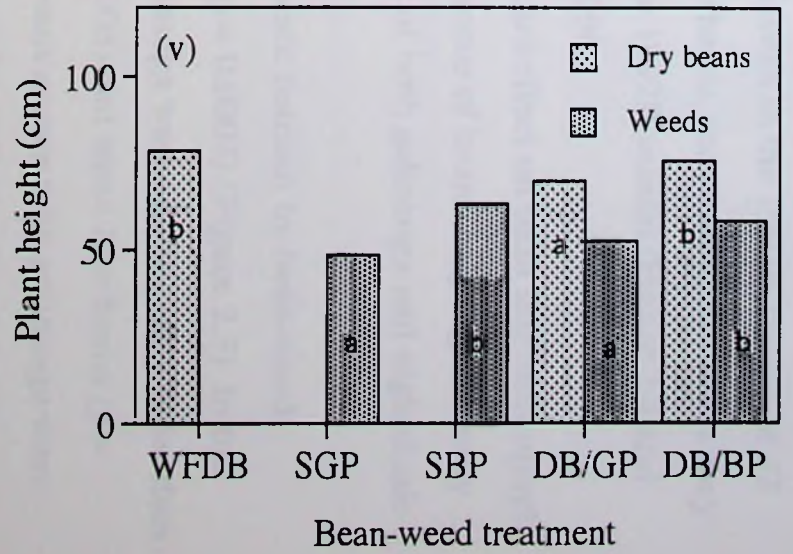


Figure 2.4 The effect of bean-weed treatments on bean and weed heights (cm) averaged across nutrients at (i) 42 DAP in the 1996 season, (ii) 56 DAP in the 1996 season, (iii) 42 DAP in the 1997A season, (iv) 42 DAP in the 1997B season, and (v) 56 DAP in the 1997B season (means followed by the same letter on the graphs for either beans or weeds at each date are not significantly different from one another at 5% level using LSD. Abbreviations: WFDB = weed-free dry beans, SGP = sole *G. parviflora*, SSN = sole *S. nigrum*, SBP = sole *B. pilosa*, DB/GP = dry beans and *G. parviflora* grown together, DB/SN = dry beans and *S. nigrum* grown together, and DB/BP = dry beans and *B. pilosa* grown together)

Figure 2.4 (Continued)







The presence of beans significantly affected weed height at 42 and 56 DAP in the 1996 and 1997B seasons, respectively (Figures 2.4 (i) and (v)). Galinsoga was significantly taller than nightshade at 42 DAP in 1996. Bidens was significantly taller than galinsoga in the 1997B season at 56 DAP.

Weed-free beans covered significantly more ground area than beans grown with either bidens or galinsoga in the 1997B season at 42 and 56 DAP (Table 2.8). The taller the beans, the more ground area they covered in the presence of weeds in the 1997B season (Figure 2.4 and Table 2.8). This was not apparent in 1996.

Weed treatments had no significant effect on bean leaf chlorophyll contents at all recorded dates. The presence of beans only significantly reduced weed leaf chlorophyll content of both galinsoga and nightshade weeds at 56 DAP (Table 2.9).

In 1996 at 42 DAP, there was a significant nutrient by bean-weed treatment interaction for bean height ($p = 0.0003$) (Figure 2.5). In the NPK treatment, beans grown with galinsoga were significantly taller than beans grown with nightshade ($p = 0.0005$) and weed-free beans ($p = 0.0001$). In the OPK treatment, only beans grown with galinsoga were significantly taller than beans grown with nightshade ($p = 0.0254$) (Figure 2.5). Under the NPO treatment, beans grown with galinsoga were significantly shorter than beans grown with nightshade ($p = 0.0011$) and weed-free beans ($p = 0.0025$). In the NOK treatment, beans grown with galinsoga and weed-free beans were significantly taller than beans grown with nightshade ($p = 0.0045$ and 0.0344, respectively) (Figure 2.5). Under the OOO treatment, weed-free beans were significantly shorter

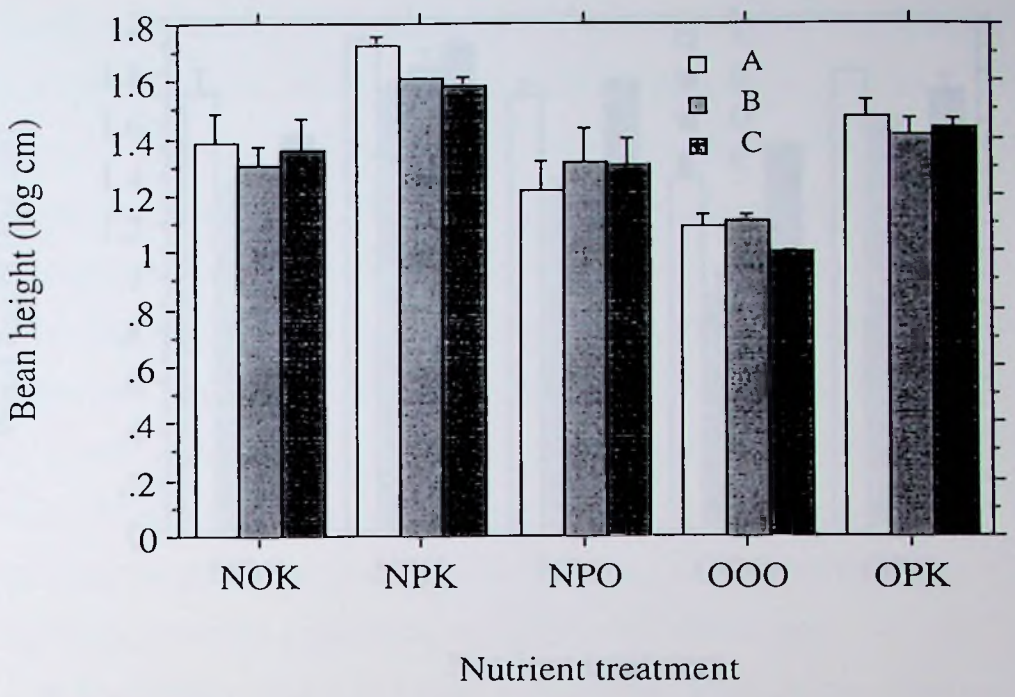


Figure 2.5 Bean-weed by nutrient treatment interaction effect on bean height (log bean height in cm), 42 DAP in the 1996 season (where A = beans grown with galinsoga, B = beans grown with nightshade, and C = weed-free beans)

than beans grown with nightshade ($p = 0.0007$) and galinsoga ($p = 0.0025$) (Figure 2.5).

At 56 DAP in 1996, there was a significant nutrient by bean-weed interaction for weed plant height ($p = 0.0001$) (Figure 2.6). In the NPK treatment, galinsoga grown together with beans was significantly taller than nightshade grown together with beans ($p = 0.0018$). Sole galinsoga under the NPK treatment was taller than nightshade grown together with beans ($p = 0.0036$). Galinsoga grown together with beans under the OPK treatment was taller than sole nightshade ($p = 0.0001$). Under the same

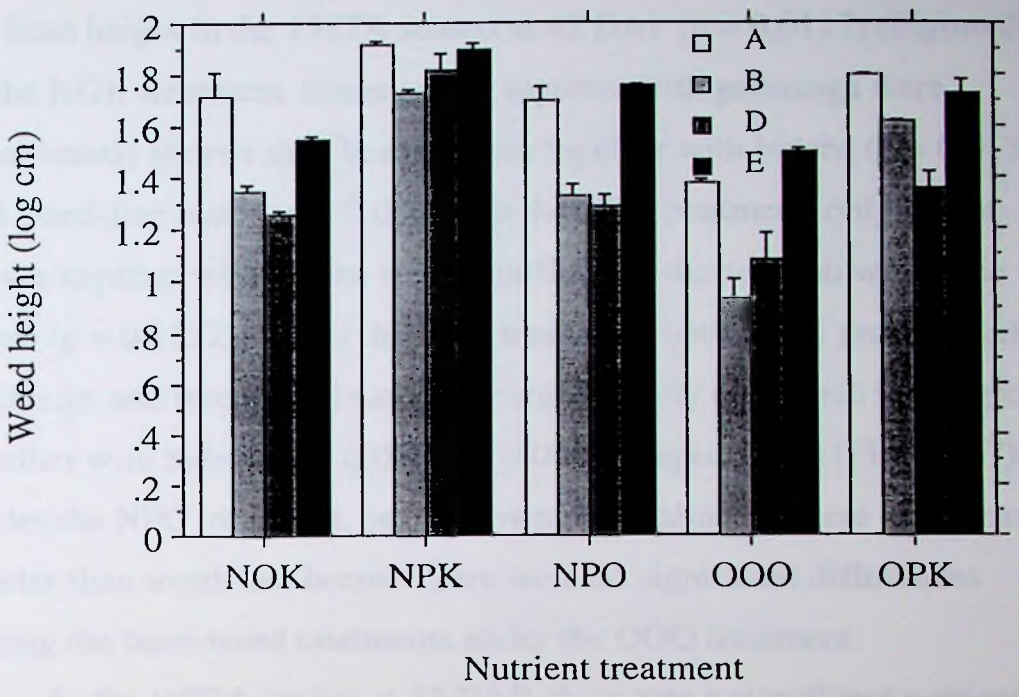


Figure 2.6 Bean-weed by nutrient treatment interaction effect on weed plant height (log weed height in cm), 56 DAP in the 1996 season (where A = galinsoga grown with beans, B = nightshade grown with beans, D = sole nightshade, and E = sole galinsoga)

treatment OPK, nightshade grown with beans was taller than sole nightshade ($p = 0.0001$), and sole galinsoga was significantly taller than sole nightshade ($p = 0.001$). In the NPO treatment, galinsoga either grown with beans or as sole weed was significantly different from nightshade treatments sole or grown with beans ($p = 0.0001$ in all cases) (Figure 2.6). Galinsoga grown with beans in the NOK treatment was significantly taller than all the weeds in the other bean-weed treatments. In the OOO treatment, all the weeds were significantly different from one another under all bean-weed treatments.

There was a significant nutrient by bean-weed treatment interaction for bean height in the 1997A season at 42 DAP ($p = 0.0117$) (Figure 2.7 In the NOK treatment, beans grown together with galinsoga were significantly shorter than beans grown together with bidens ($p = 0.0136$) and weed-free beans ($p = 0.0024$). In the NPK treatment, only beans grown together with bidens were significantly shorter than weed-free beans ($p = 0.0352$). Under the OPK treatment, both beans grown together galinsoga and weed-free beans were significantly taller than beans grown together with bidens ($p = 0.009$ and 0.0005, respectively) (Figure 2.7). Under the NPO treatment, beans grown with galinsoga were significantly shorter than weed-free beans. There were no significant differences among the bean-weed treatments under the OOO treatment.

In the 1997A season at 42 DAP, there was a significant nutrient by bean-weed treatment interaction for weed plant height ($p = 0.0019$) (Figure 2.8). Under the NPK treatment, sole bidens was significantly taller than weeds in other treatments. In case of weeds under the NOK treatment, only sole galinsoga was significantly taller than galinsoga grown with beans (Figure 2.8). Under the NPO treatment, sole bidens was significantly taller than bidens grown together with beans ($p = 0.0001$), and galinsoga grown together with beans ($p = 0.0122$). Sole galinsoga was significantly taller than bidens grown together with beans ($p = 0.0263$). Under the OPK treatment, all sole weeds were significantly taller than their counterparts growing together with beans. Sole bidens was significantly different from bidens or galinsoga grown together with beans ($p = 0.0001$ and $p = 0.0327$, respectively). Both sole galinsoga and

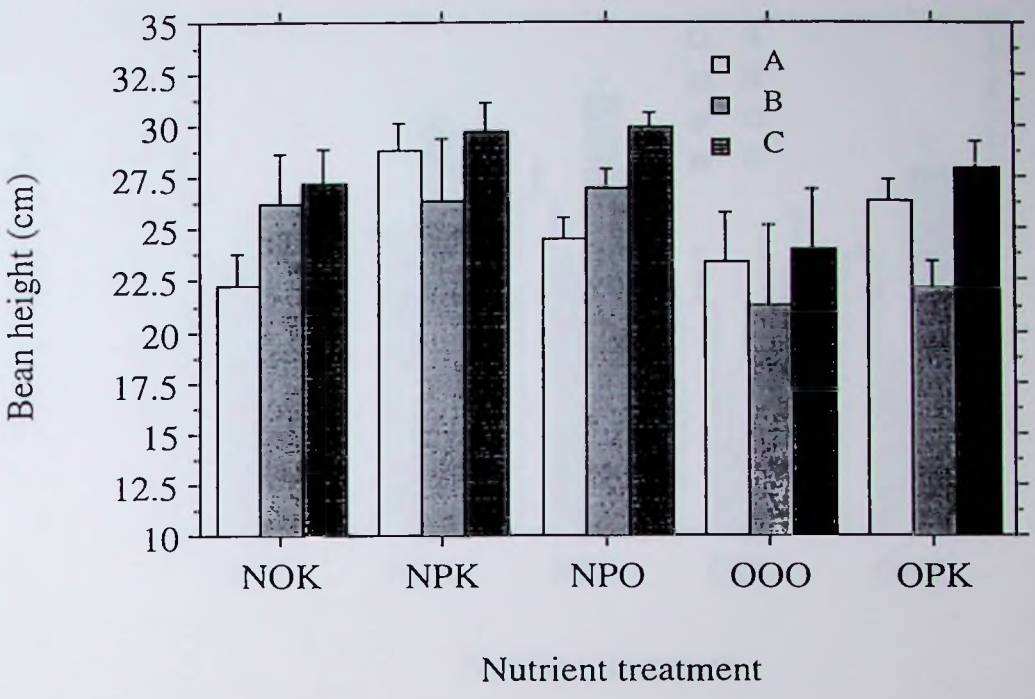


Figure 2.7 Bean-weed by nutrient treatment interaction effect on bean height (cm), 42 DAP in the 1997A season (where A = beans grown with galinsoga, B = beans grown with bidens, and C = weed-free beans)

galinsoga grown together with beans were significantly taller than bidens grown with beans ($p = 0.001$). In case of the OOO treatment, sole galinsoga and bidens were significantly taller than bidens grown with beans ($p = 0.0001$ and $p = 0.001$, respectively). At the same time, bidens grown with beans were significantly shorter than galinsoga grown with beans ($p = 0.0001$).

At 42 DAP in the 1996 growing season, there was a significant nutrient by bean-weed treatment interaction for bean canopy cover ($p = 0.0044$) (Figure 2.9). In the NPK and OPK treatments, weed-free beans covered significantly larger soil surface area than beans grown with

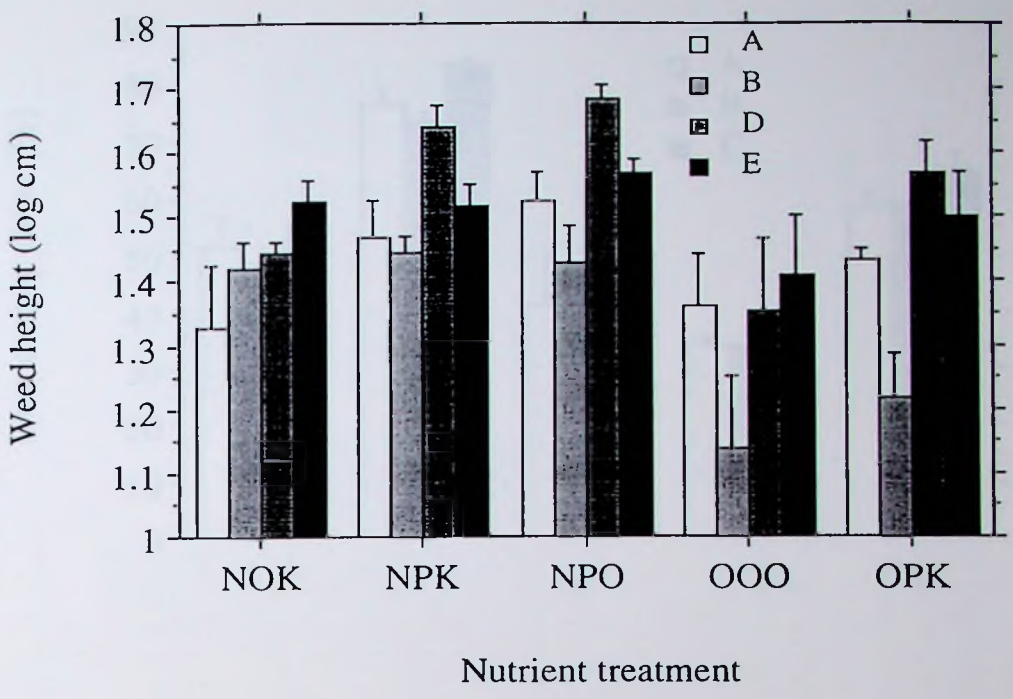


Figure 2.8 Bean-weed by nutrient treatment interaction effect on weed height (log weed height in cm), 42 DAP in the 1997A season (where A = galinsoga grown with beans, B = bidens grown with beans, D = sole bidens, and E = sole galinsoga)

galinsoga ($p = 0.0053$ and 0.0094, respectively) and beans grown together with nightshade ($p = 0.0004$ and 0.0138, respectively). In the NPO treatment, beans grown with galinsoga covered less ground area than beans grown with nightshade ($p = 0.007$) or weed-free beans ($p = 0.0011$). Weed-free beans covered less ground area than beans grown with galinsoga ($p = 0.0435$) under the OOO treatment. Weed-free beans covered significantly more ground area than beans grown with nightshade ($p = 0.0053$) under the NOK treatment. Under the NPK, OPK, NOK and NPO treatments, the greater ground coverage by weed-free

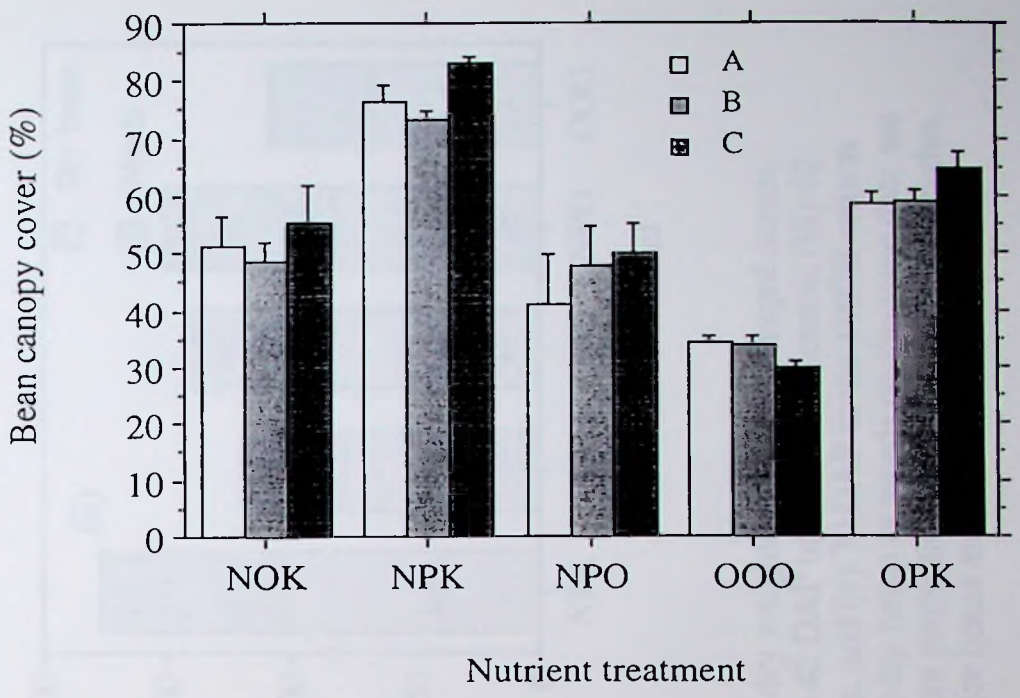


Figure 2.9 Bean-weed by nutrient treatment interaction effect on bean canopy cover (percent), 42 DAP in the 1996 season (where A = beans grown with galinsoga, B = beans grown with nightshade, and C = weed-free beans)

beans could be attributed to restrictions on growth of beans imposed by the actively growing weeds under these treatments.

Shoot and root dry weight and root/shoot ratio

Nutrients significantly affected bean shoot dry weights at 56 DAP (1996), 42 DAP (1997A) and 56 and 70 DAP (1997B) and weeds at all recorded dates in all years (Figure 2.10). In the 1996 season, bean shoot dry weight was consistently high in the NPK treatment and low in the OOO treatment. In the 1997A and B seasons, similar trends to 1996 were observed although shoot dry weights were significantly high in the NPK

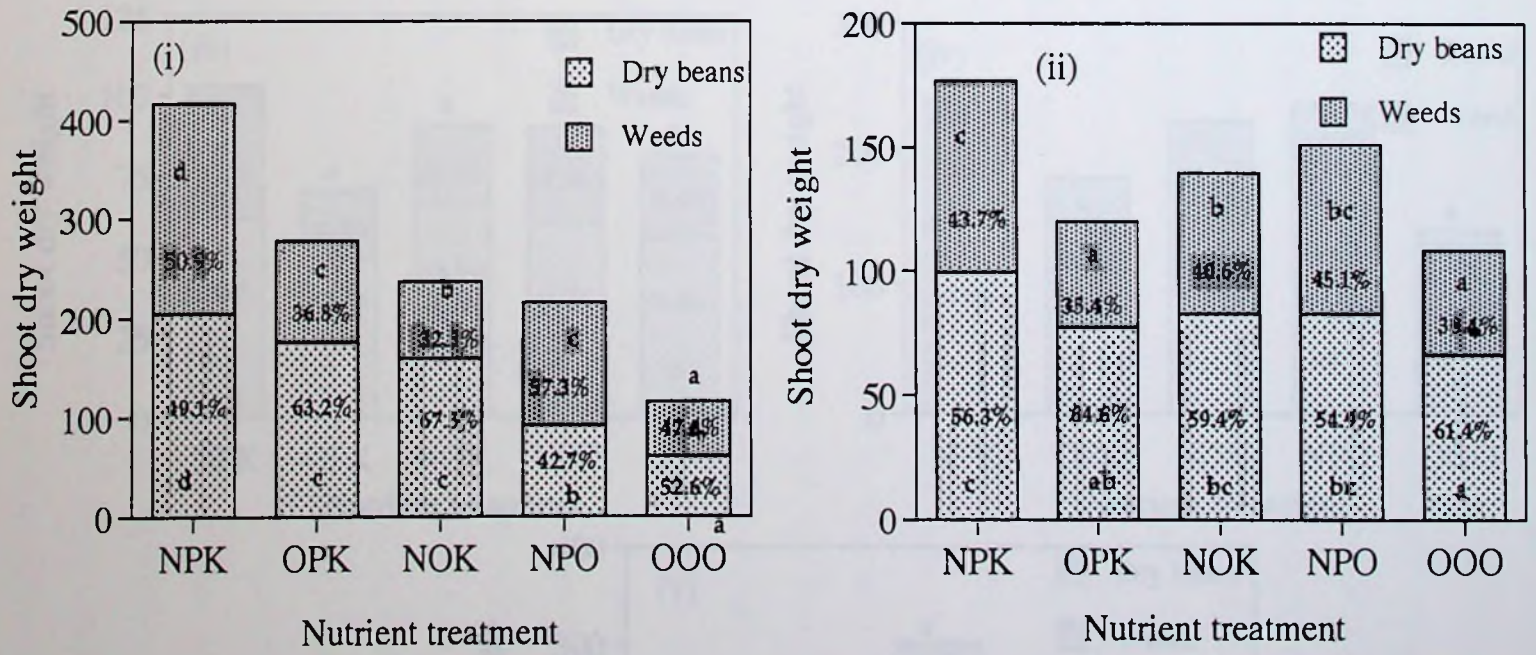
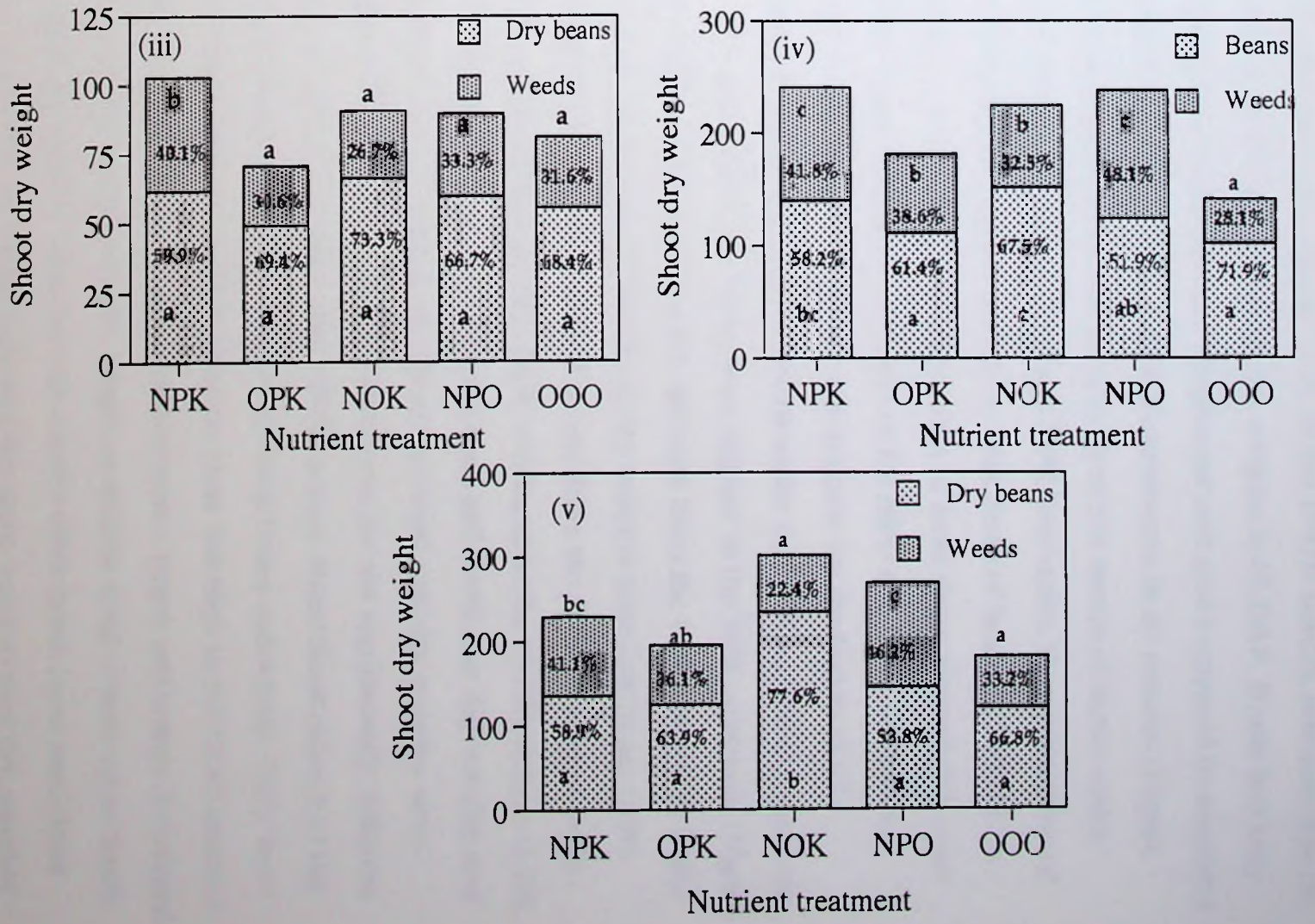


Figure 2.10 The effect of nutrients on bean and weed shoot dry weights (g/sq.m) averaged across bean-weed treatments at (i) 56 DAP in the 1996 season, (ii) 42 DAP in the 1997A season, (iii) 42 DAP in the 1997B season, (iv) 56 DAP in the 1997B season, and (v) 70 DAP in the 1997B season (means followed by the same letter on each graph for either dry beans or weeds on the same date are not significantly different at 5% level using LSD. The percent proportions of total shoot dry weights, that is, bean shoot dry weight plus weed shoot dry weight, for beans and weeds at each nutrient treatment are indicated on the graphs)

Figure 2.10 (Continued)



and NOK treatments (Figure 2.10). In the 1997B season, nutrients had no significant effect on bean shoot dry weights at 42 DAP. Beans had very high proportions of shoot dry weights per unit area compared to weed dry weights in the NOK, OPK and OOO treatments in all seasons (Figure 2.10). This may indicate the more competitive nature of beans under these nutrients. Under the NPO and NPK treatments, the proportions of weed shoot dry weights were higher than those of beans at 56 DAP in 1996 (Figure 2.10 (i)). The proportions of bean shoot dry weights were slightly higher than those of weeds in the NPO and NPK treatments during the other seasons. This could account for the higher yield reductions in beans caused by weeds under the NPK and NPO treatments.

Weed shoot dry weights were highest in the NPK treatment (Figure 2.10), but were not significantly different from the NPO treatment in the 1997A and B seasons. Weed shoot dry weights were low in the OOO treatment but not significantly different from the OPK treatment in the 1997A and B seasons and the NOK treatment in the 1997B (Figure 2.10).

Nutrients significant affected bean and weed root dry weights and root/shoot ratios (Table 2.10). Bean and weed root dry weights were significantly greater in the NPK treatment but not significantly different from the NPO treatment in the 1997B season. Root/shoot ratios had the opposite trend to root dry weights for both beans and weeds. They were significantly low in the NPK nutrient plots and high in the OOO nutrient plots in 1996. Under low nutrient treatments, beans and weeds developed more root dry matter (weight, length or surface area) to take up as much nutrients as possible from the soil. On the other hand, bean root/shoot ratios in the 1997B season followed the same trend as root dry weights

Table 2.10 The effect of nutrient and bean-weed treatments on root dry weights, and root/shoot ratios, 56 DAP

Treatment	1996				1997B		
	Beans		Weeds		Beans		Weeds
	Root dwt g m^{-2}	Root/shoot ratio	Root dwt g m^{-2}	Root/shoot ratio	Root wt g m^{-2}	Root/shoot ratio	Root dwt g m^{-2}
Nutrient treatment							
NPK	29.38d	0.15 a	51.76 c	0.25 a	13.71 b	0.22 b	15.60 d
OPK	28.88 bc	0.14 a	31.33 b	0.31 b	9.81 a	0.21 b	6.31 ab
NOK	27.73 cd	0.18 a	23.71 a	0.32 bc	9.10 a	0.15 a	8.93 bc
NPO	21.68 b	0.24 b	38.90 b	0.32 bc	9.55 a	0.18 ab	11.12 cd
OOO	15.17 a	0.25 b	20.14 a	0.38 c	10.21 a	0.19 ab	5.26 a
Bean-weed treatment							
Weed-free beans	29.17 b	0.19 a	-	-	12.68 b	0.19 a	-
Beans/galinsoga	20.42 a	0.18 a	32.89 b	0.26 b	8.28 a	0.18 a	4.71 a
Sole galinsoga	-	-	41.98 c	0.19 a	-	-	5.04 a
Beans/nightshade/bidens	20.37 a	0.19 a	19.86 a	0.43 c	10.79 b	0.20 a	15.78 b
Sole nightshade/bidens	-	-	35.16 bc	0.42 c	-	-	15.49 b
Statistical significance[a]							
Nutrient treatment	***	***	****	**	**	*	***
Bean-weed treatment	***	ns	****	****	***	ns	****
Nutrient x bean-weed	ns	ns	ns	ns	ns	ns	ns
Coefficient of variation	10.61	17.52	14.74	19.71	17.77	17.10	46.46

Means in each column followed by a similar letter for each treatment set are not significantly different at 5% level using LSD,
Bean and weed root dry weights and root/shoot ratios were log square root transformed, respectively, at all dates and the back transformed means are reported,
[a] *, **, ***, ****, ns mean statistically significant at $p \leq 0.05, 0.01, 0.001, 0.0001$ or not significant, respectively.

(Table 2.10). Root/shoot ratio was high in the NPK treatment and low in the NOK treatment.

Weeds had significant effects on bean shoot dry weights at all sampling dates (Figure 2.11). Weed-free beans had significantly more shoot dry weight than beans grown with galinsoga and nightshade and bidens. In the 1997B season, galinsoga had more effect in reducing bean shoot dry weight early in the seasons but bidens later had more effect as the season progressed. The presence of beans also significantly reduced weed shoot dry weight at all recorded dates (Figure 2.11). Sole weeds had significantly more shoot dry weight compared to their counterparts grown with beans.

Averaged across nutrients, the proportion of galinsoga shoot dry weight per unit area was higher than bean shoot dry weight and very low for nightshade at 56 DAP in 1996 (Figure 2.11 (i)). However, bean shoot dry weight was the same when in competition with both weeds indicating that galinsoga is less competitive than nightshade when grown with beans. In the 1997A season, both galinsoga and bidens had lower proportions of shoot dry weights compared to beans although galinsoga was much lower (Figure 2.11 (ii)). In the 1997B season, bidens had as high a proportion of shoot dry weight as beans but very low for galinsoga compared to beans (Figures 2.11 (iii), (iv) and (v)). This could be indicating the more competitive nature of bidens compared to galinsoga when grown together with beans in Uganda.

Similarly, the presence of weeds reduced bean root dry weight in the 1996 and 1997B seasons (Table 2.10). There were significant differences between root dry weights of weed-free beans and beans

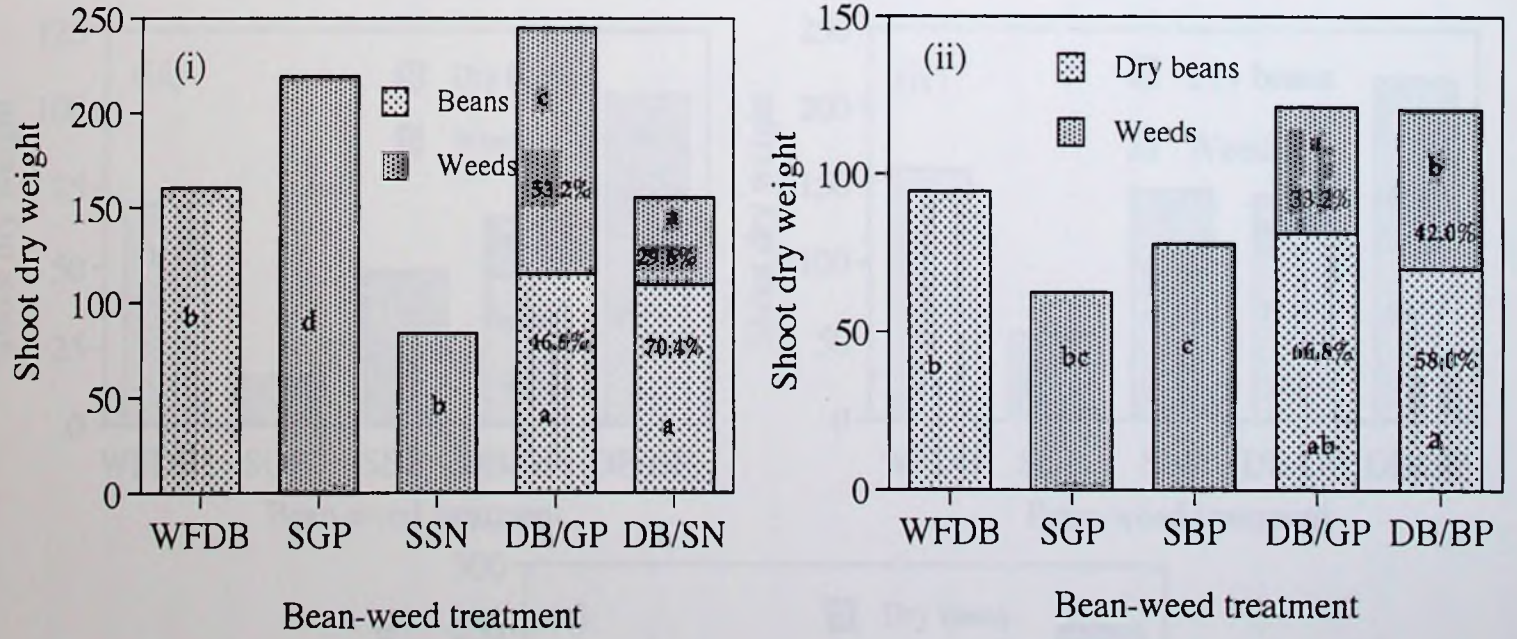
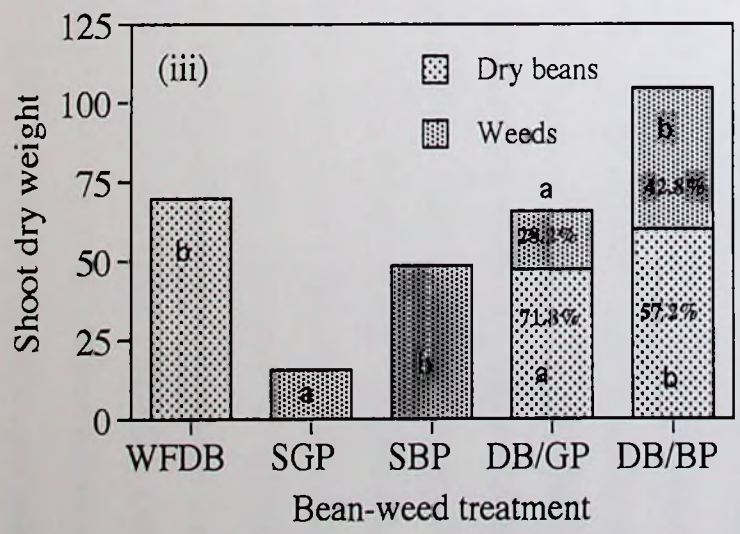
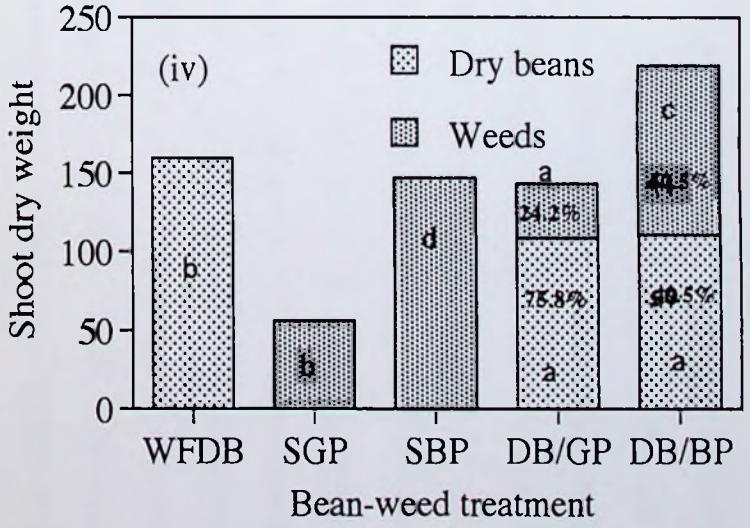
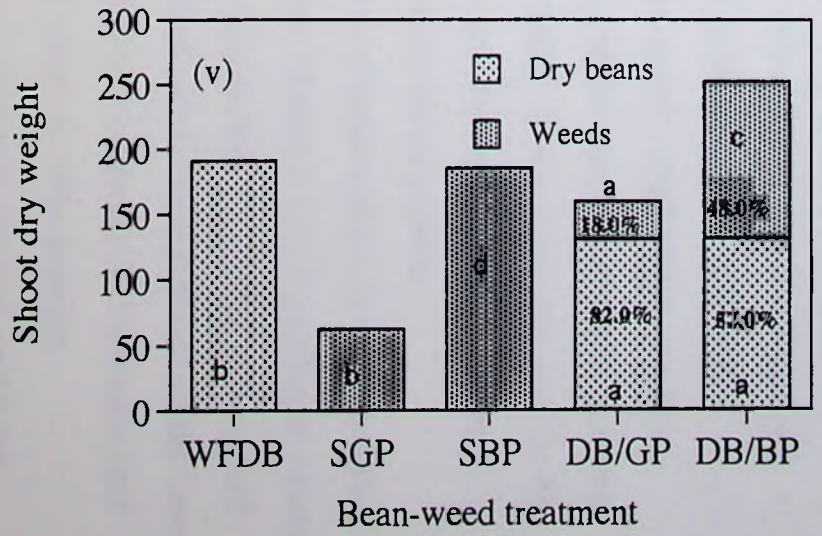


Figure 2.11 The effect of bean-weed treatments on bean and weed shoot dry weights (g/sq.m) averaged across nutrients at (i) 56 DAP in the 1996 season, (ii) 42 DAP in the 1997A season, (iii) 42 DAP in the 1997B season, (iv) 56 DAP in the 1997B season, and (v) 70 DAP in the 1997B season (means followed by the same letter on each graph for either beans or weeds are not significantly different at 5% level using LSD. The percent proportions of total shoot dry weights for either beans or weeds when grown together are indicated on the graphs. Abbreviations on the graphs are: WFDB = weed-free dry beans, SGP = sole *G. parviflora*, SBP = sole *B. pilosa*, SSN = sole *S. nigrum*, DB/GP = dry beans and *G. parviflora* grown together, DB/SN = dry beans and *S. nigrum* when grown together, and DB/BP = dry beans and *B. pilosa* when grown together)

Figure 2.11 (Continued)







grown with nightshade or galinsoga in 1996. The presence of weeds had no significant effect on root/shoot ratios in both years.

The presence of beans affected weed root dry weight in both years and root/shoot ratios in 1996 (Table 2.10). In the 1997B season, there were no significant differences in root dry weights between sole weeds and their counterparts grown with beans. Weed species differences existed for root dry weight with lower dry weights in galinsoga than bidens (Table 2.10). Nightshade weeds had significantly higher root/shoot ratios compared to galinsoga weeds. Nightshade tends to ramify deeper in the soil than galinsoga at the expense of shoot growth especially where soil resources are limiting. Galinsoga roots tend to be more concentrated in the top soil layer and are thin especially where nutrients are available and so puts on more shoot growth.

The presence of beans also had significant effect on weed number per unit area in the 1997A and B seasons (Table 2.11). Significantly more weeds survived under sole cropping of galinsoga than when grown with beans. There is high probability that interspecific competition could have been more important here than intraspecific competition. Nutrients had no significant effect on the number of weeds in both seasons.

There were significant interactions between nutrient and bean-weed treatments for bean shoot dry weights at 56 and 70 DAP in the 1997B seasons ($p = 0.0474$ and 0.0358, respectively) (Figures 2.12 and 2.13). In the NPK treatment, weed-free beans had significantly more dry matter than beans grown together with galinsoga ($p = 0.0002$) at 56 DAP (Figure 2.12). Both weed-free beans and beans grown together with bidens had significantly more dry matter than beans grown together with

Table 2.11 The effect of nutrient and bean-weed treatments on weed number per square meter at NAARI in the 1997A and B seasons

Treatment	97A	97B		
	56 DAP	42 DAP	56 DAP	70 DAP
Nutrient treatment				
NPK	123.6 a	158.5 a	130.3 a	129.7 a
OPK	121.9 a	147.9 a	147.9 a	127.1 a
NOK	130.9 a	143.6 a	136.1 a	147.6 a
NPO	106.4 a	164.8 a	169.8 a	148.3 a
OOO	106.1 a	155.6 a	123.6 a	124.7 a
Bean-weed treatment				
Beans/galinsoga	65.2 a	121.1 a	96.3 a	71.3 a
Sole galinsoga	84.9 a	109.1 a	133.7 b	142.6 b
Beans/bidens	198.6 b	237.7 b	164.1 bc	162.6 bc
Sole bidens	164.4 b	184.9 b	203.7 c	194.9 c
Statistical significance[a]				
Nutrient treatment	ns	ns	ns	ns
Bean-weed treatment	****	****	****	****
Nutrient x bean-weed	ns	ns	ns	ns
CV	15.47	9.31	11.03	9.30

Means in each column followed by the same letter for each treatment set are not significantly different at 5% level using LSD,
Weed shoot dry weight were log transformed and back log transformed means are reported,
[a]****, ns mean statistically significant at $p \leq 0.0001$ or not significant, respectively.

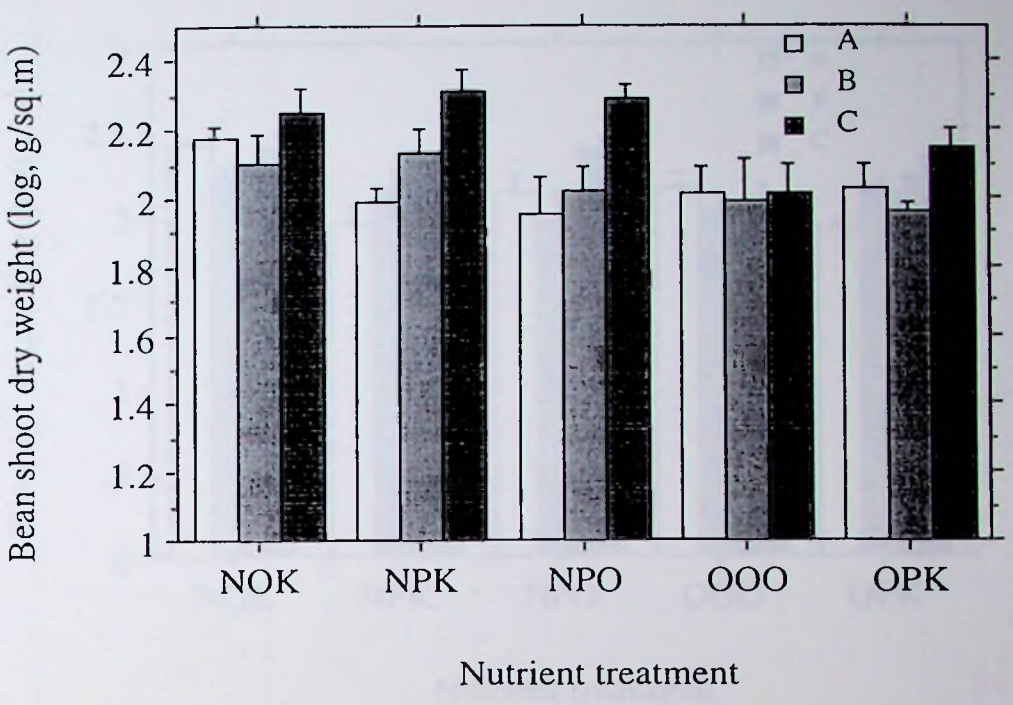


Figure 2.12 Bean-weed by nutrient treatment interaction effect on bean shoot dry weight (log dry weight, g m^{-2}), 56 DAP in the 1997B season (where A = beans grown with galinsoga, B = beans grown with bidens, and C = weed-free beans)

galinsoga at 70 DAP in the NPK treatment (p = 0.0483 and 0.0119, respectively) (Figure 2.13). Weed-free beans had significantly more shoot dry weights than beans grown with bidens (p = 0.0198) and galinsoga (p = 0.0071) at 56 and 70 DAP, respectively, in the OPK treatment. In the NPO treatment, at both 56 and 70 DAP, weed-free beans had significantly more dry matter than beans grown with galinsoga (p = 0.0001 and 0.0253, respectively) (Figures 2.12 and 2.13). In the same treatment, weed-free beans had significantly more dry matter than beans grown with bidens (p = 0.0014 and 0.0006, respectively). No significant

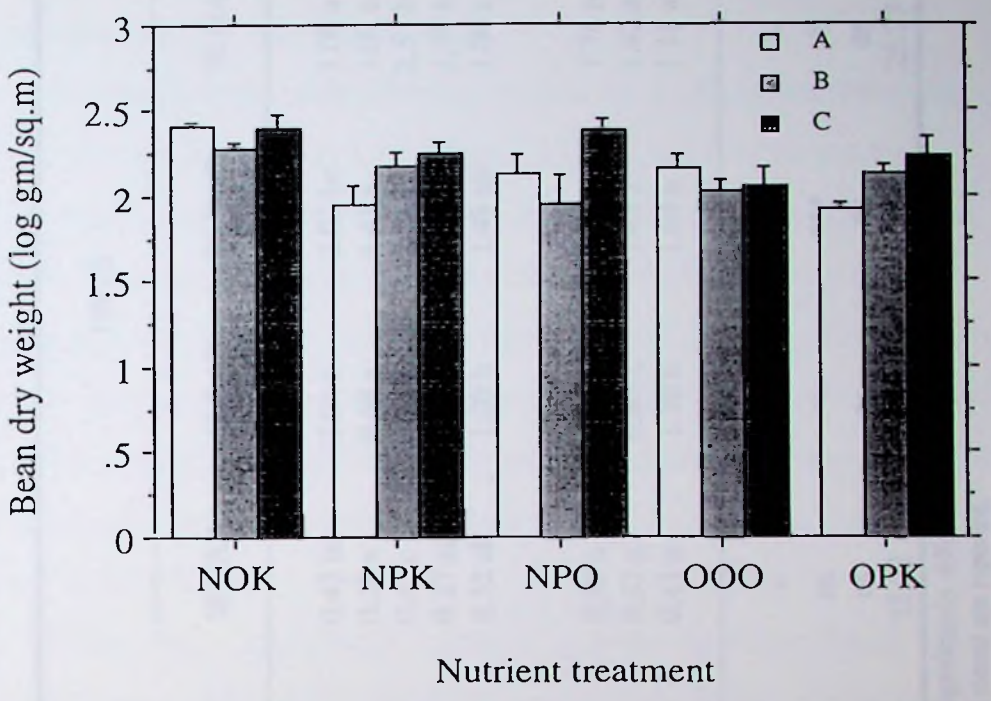


Figure 2.13 Bean-weed by nutrient treatment interaction effect on bean shoot dry weight (log dry weight, g m^{-2}), 70 DAP in the 1997B season (where A = beans grown with galinsoga, B = beans grown with bidens, and C = weed-free beans)

differences among the different bean-weed treatments were observed under the NOK and OOO treatments.

Bean leaf area index (LAI)

Nutrients had significant effects on LAI at all dates recorded (Table 2.12). Leaf area index followed similar trends as bean shoot dry weights at all sampling dates in all years (Figure 2.10 and Table 2.12). Significantly higher LAI values were observed for NPK in the 1996 and 1997A and for NOK treatment in the 1996 and 1997B seasons, as compared to OOO treatment. Consistently lower LAI values were

Table 2.12 The effect of nutrient and weed treatments on bean LAI in the 1996, 1997A and B seasons

Treatment	1996		1997A	1997B			
	42 DAP	56 DAP	42 DAP	28 DAP	42 DAP	56 DAP	70 DAP
Nutrient treatment							
NPK	3.49 e	4.40 c	1.33 b	0.43 bc	1.04 b	2.01 bc	1.08 a
OPK (minus N)	2.68 d	4.50 c	0.97 a	0.28 a	0.68 a	1.41 a	1.02 a
NOK (minus P)	1.95 c	4.16 c	1.05 ab	0.47 c	1.25 b	2.18 c	2.51 b
NPO (minus K)	1.32 b	2.45 b	0.89 a	0.37 abc	1.12 b	1.91 abc	1.79 b
OOO (minus N, P and K)	0.79 a	1.55 a	0.94 a	0.32 ab	1.00 b	1.49 ab	1.00 a
Bean-weed treatment							
Weed-free beans	2.21 b	4.26 b	1.21 b	0.39 a	1.13 b	2.33 b	1.74 b
Beans/galinsoga	1.82 a	3.00 a	0.96 a	0.32 a	0.80 a	1.45 a	1.42 ab
Beans/nightshade/bidens[a]	1.76 a	2.71 a	0.94 a	0.41 a	1.10 b	1.64 a	1.18 a
Statistical Significance[b]							
Nutrient treatment	****	****	*	*	*	*	*
Bean-weed treatment	*	****	*	ns	*	***	*
Nutrient x bean-weed	*	ns	ns	ns	ns	ns	ns
Coefficient of variation	29.10	23.63	18.99	22.22	19.64	17.92	25.27

Means in each column followed by the same letter for each treatment set are not significantly different at 5% alpha level using LSD,
Leaf area index values were all square root transformed and the back transformed means are reported,
[a]Nightshade was planted in the 1996 season at Cornell University and bidens in the 1997A and B seasons at NAARI, Uganda,
[b]*, ***, ****, or ns mean statistically significant at $p \leq 0.05, 0.001, 0.0001$ or not significant, respectively.

observed in the OOO treatment (1996) and both the OOO and OPK treatments (1997A and B seasons).

Weeds significantly affected bean LAI at all record dates except in the 1997B season at 28 DAP (Table 2.12). Weed-free beans had significantly higher LAI values than beans grown with weeds in the 1996 and 1997A seasons. In the 1997B season, weed-free beans had significantly higher LAI than beans grown with galinsoga and bidens at 56 DAP and beans grown with galinsoga at 42 DAP (Table 2.12). At 70 DAP, there were no significant differences between weed-free beans and beans grown with galinsoga, or beans grown with galinsoga and beans grown with bidens.

There was a significant nutrient by bean-weed treatment interaction for bean LAI at 42 DAP in the 1996 season ($p = 0.041$) (Figure 2.14). Leaf area index had a similar trend as bean shoot dry weights at 42 DAP. In the NPK, OPK and OOO treatments, bean LAI values were not significantly different under all the weed treatments. Beans in the NPO treatment under all bean-weed treatments were significantly different from one another with higher LAI in weed-free beans. Under the NOK treatment, weed-free beans had significantly higher LAI than beans grown together with nightshade ($p = 0.0394$) but not significantly different from beans grown together with galinsoga.

Days to flowering and maturity in beans

Beans in the NPK plots flowered earlier than the rest of the treatments (Table 2.13). Flowering was delayed in the NPO and OOO treatments. Although P is important for early flowering, it seems enough

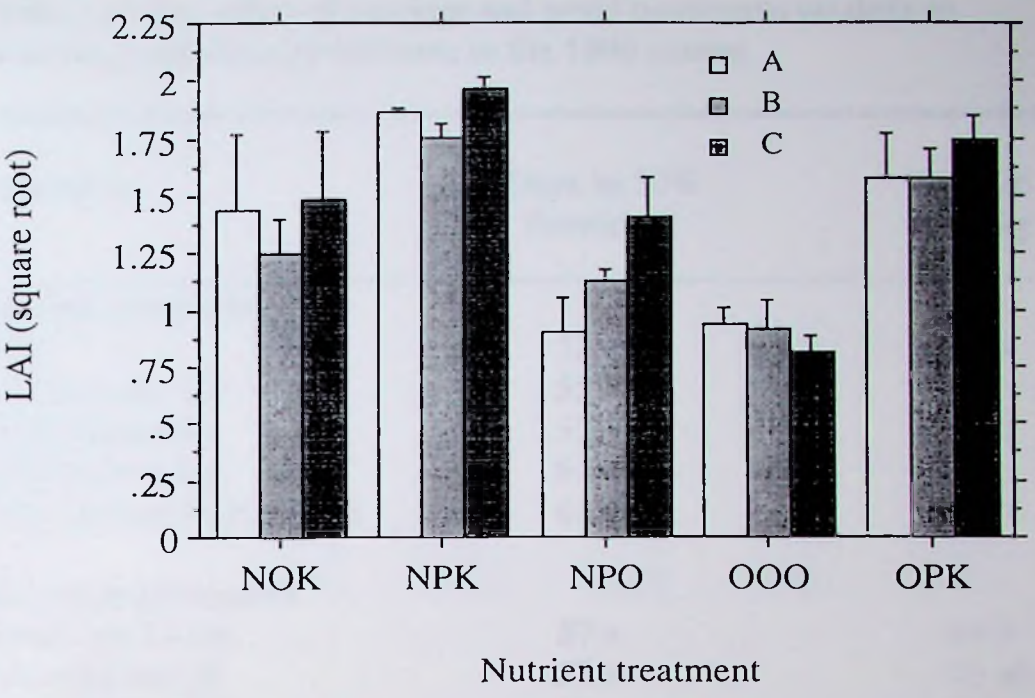


Figure 2.14 Bean-weed by nutrient treatment interaction effect on bean LAI (square root transformed), 42 DAP in 1996 season (where A = beans grown with galinsoga, B = beans grown with nightshade, and C = weed-free beans)

dry matter accumulation is also essential for plants to reach flowering age. That could have been the reason for delayed flowering under the NPO treatment despite availability of P. Weeds had no significant effects on days to flowering in beans in the 1996 season.

There were no significant effects of nutrients and weeds on the days to flowering in beans in the 1997A and B seasons in Uganda. A prolonged dry spell could have been responsible for the 1997A observation. The continuous rain in the 1997B season promoted vegetative growth which delayed flowering across all treatments.

Table 2.13 The effect of nutrient and weed treatments on days to flowering and maturity in beans in the 1996 season

Treatment	Days to 50% flowering	Days to maturity
Nutrient treatment		
NPK	52 a	87 a
OPK (minus N)	55 b	92 b
NOK (minus P)	57 c	96 d
NPO (minus K)	61 d	95 c
OOO (minus N, P and K)	61 d	93 b
Bean-weed treatment		
Weed-free beans	57 a	94 b
Beans/galinsoga	57 a	93 ab
Beans/nightshade	57 a	92 a
Statistical Significance[a]		
Nutrient treatment	****	****
Bean-weed treatment	ns	*
Nutrient x bean-weed treatment	ns	**
Coefficient of variation	7.00	4.00

Means in each column followed by the same letter for each treatment set are not significantly different at 5% level using LSD,

[a]*, **, ****, ns mean statistically significant at $p \leq 0.05, 0.01, 0.0001$ or not significant, respectively.

In the 1996 season, there was a significant nutrient by bean-weed treatment interaction for days to maturity in beans ($p=0.0012$) (Figure 2.15). In the NPK treatment, weed-free beans matured later than beans grown with both galinsoga and nightshade ($p = 0.0021$ and 0.0096, respectively). In the OPK treatment, beans grown with galinsoga matured earlier than beans grown with nightshade ($p = 0.0209$) and weed-free

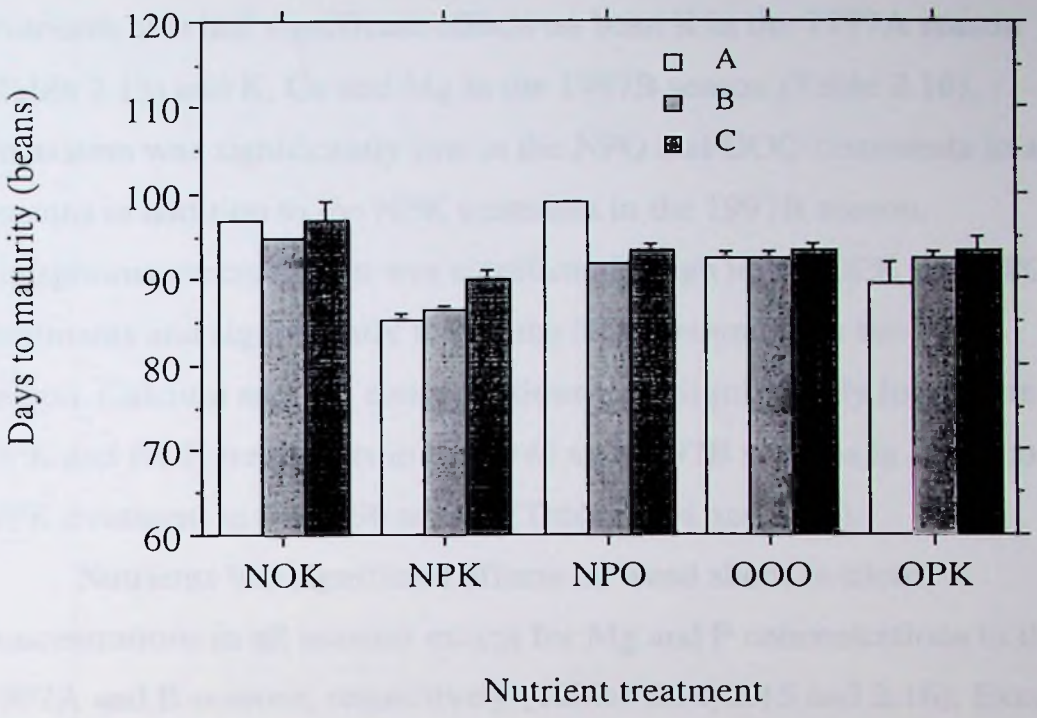


Figure 2.15 Bean-weed by nutrient treatment interaction effect on days to maturity in beans in the 1996 season (where A = beans grown with galinsoga, B = beans grown with nightshade, and C = weed-free beans)

beans ($p = 0.0045$). Beans grown with galinsoga under the NPO treatment matured much later than beans grown with nightshade ($p = 0.0001$) and weed-free beans ($p = 0.0005$). In the OOO and NOK treatments, beans under all weed treatments were not significantly different from one another.

Shoot tissue concentration and nutrient contents of beans and weeds

Bean and weed shoot nutrient concentration

Nutrients had no significant effect on bean shoot N concentrations in the 1996, 1997A and B seasons. Nutrients significantly affected P, K,

Ca, and Mg tissue concentrations in the 1996 season (Table 2.14). Nutrients also had significant effects on bean K in the 1997A season (Table 2.15) and K, Ca and Mg in the 1997B season (Table 2.16). Potassium was significantly low in the NPO and OOO treatments in all seasons in addition to the NPK treatment in the 1997B season. Phosphorus concentration was significantly high in the OPK and NPO treatments and significantly low in the NOK treatment in the 1996 season. Calcium and Mg concentrations were significantly low in the OPK and NOK treatments in the 1996 and 1997B seasons in addition to NPK treatment in the 1996 season (Tables 2.14 and 2.16).

Nutrients had significant effects on weed shoot nutrient concentrations in all seasons except for Mg and P concentrations in the 1997A and B seasons, respectively (Tables 2.14, 2.15 and 2.16). Except for percent N, weeds had higher concentrations of P, K, Ca and Mg compared to beans under most nutrients in the 1996 and 1997A seasons (Tables 2.14 and 2.15). This observation was similar for P and K concentrations in the 1997B season (Table 2.16).

Weeds had significant effects on bean K and Ca (1996), Ca and Mg (1997A) and only Ca (1997B) tissue concentrations (Tables 2.14, 2.15 and 2.16). In most cases, weed-free beans had significantly higher nutrient concentrations than beans grown with weeds. Weed-free beans were not significantly different from beans grown with galinsoga for Ca and Mg concentrations in the 1997A season and beans grown with bidens for Ca concentration in the 1997B season (Tables 2.15 and 2.16).

The presence of beans significantly affected weed shoot nutrient

Table 2.14 The effect of nutrient and bean-weed treatments on bean and weed shoot nutrient concentrations in the 1996 season

Treatment	% N		% P		% K		% Ca		% Mg	
	Beans	Weeds	Beans	Weeds	Beans	Weeds	Beans	Weeds	Beans	Weeds
Nutrient treatment										
NPK	3.34 a	2.36 b	0.38 bc	0.52 c	3.12 b	4.57 c	1.75 a	2.37 b	0.31 a	0.44 a
OPK (minus N)	3.39 a	1.97 a	0.41 cd	0.55 c	3.40 b	3.51 c	1.76 a	2.53 b	0.38 b	0.46 a
NOK (minus P)	3.37 a	2.51 b	0.26 a	0.25 a	3.30 b	3.93 b	1.81 a	1.94 a	0.37 b	0.43 a
NPO (minus K)	3.70 a	2.47 b	0.43 d	0.56 c	0.86 a	1.50 a	2.62 c	3.00 c	0.82 c	0.93 b
OOO (minus N, P, K)	3.54 a	1.90 a	0.35 b	0.34 b	0.79 a	1.43 a	2.16 b	2.50 b	0.96 d	0.99 b
Bean-weed treatment										
Weed-free beans	3.52 a	-	0.38 a	-	2.27 b	-	2.15 b	-	0.57 b	-
Beans/galinsoga	3.54 a	1.94 a	0.36 a	0.48 c	2.05 a	2.56 ab	1.93 a	2.64 b	0.51 a	0.65 b
Sole galinsoga	-	2.07 a	-	0.42 ab	-	2.37 a	-	2.70 b	-	0.67 b
Beans/nightshade	3.35 a	2.37 b	0.36 a	0.45 bc	1.97 a	3.67 c	1.97 a	2.36 a	0.53 a	0.62 ab
Sole nightshade	-	2.56 b	-	0.40 a	-	2.81 b	-	2.18 a	-	0.57 a
Statistical significance[a]										
Nutrient treatment	ns	**	****	****	****	****	****	****	****	****
Bean-weed treatment	ns	**	ns	*	*	****	**	***	**	**
Nutrient x bean-weed	ns	ns	ns	***	ns	**	ns	ns	*	ns
CV	9.98	21.55	14.43	17.17	31.73	27.22	19.79	18.60	24.75	20.50

Means in each column followed by the same letter for each treatment set are not significantly different at 5% alpha level using LSD,
Percent K and Mg (beans) and percent K, P and Mg (weeds) were square root transformed and the back transformed means are reported,
*, **, ***, ****, or ns mean statistically significant at $p \leq 0.05, 0.01, 0.001, 0.0001$ or not significant, respectively.

Table 2.15 The effect of nutrient and bean-weed treatments on bean and weed shoot nutrient concentrations in the 1997A season

Treatment	% N		% P		% K		% Ca		% Mg	
	Beans	Weeds	Beans	Weeds	Beans	Weeds	Beans	Weeds	Beans	Weeds
Nutrient treatment										
NPK	3.36 a	2.85 ab	0.34 a	0.33 a	3.00 b	4.04 ab	1.79 a	1.83 b	0.26 a	0.34 a
OPK (minus N)	3.23 a	2.91 ab	0.31 a	0.39 b	2.77 ab	4.03 ab	1.73 a	1.79 b	0.26 a	0.33 a
NOK (minus P)	3.09 a	3.13 c	0.34 a	0.33 a	3.14 b	4.30 b	1.75 a	1.74 ab	0.27 a	0.32 a
NPO (minus K)	3.35 a	2.71 a	0.33 a	0.31 a	2.62 a	3.60 a	1.72 a	1.61 a	0.29 a	0.32 a
OOO (minus N, P, K)	3.27 a	3.00 bc	0.34 a	0.41 b	2.55 a	4.11 b	1.64 a	1.61 a	0.28 a	0.31 a
Bean-weed treatment										
Weed-free beans	3.35 a	-	0.34 a	-	2.85 a	-	1.83 b	-	0.29 b	-
Bean/galinsoga	3.35 a	2.70 a	0.32 a	0.36 a	2.85 a	4.13 a	1.73 b	1.79 bc	0.27 b	0.29 a
Sole galinsoga	-	2.79 ab	-	0.33 a	-	3.85 a	-	1.84 c	-	0.30 a
Bean/bidens	3.25 a	2.98 b	0.34 a	0.38 a	2.79 a	4.02 a	1.62 a	1.57 a	0.26 a	0.34 b
Sole bidens	-	3.18 c	-	0.34 a	-	4.04 a	-	1.69 ab	-	0.36 b
Statistical significance[a]										
Nutrient treatment	ns	**	ns	**	*	*	ns	*	ns	ns
Bean-weed treatment	ns	****	ns	ns	ns	ns	***	***	***	****
Nutrient x bean-weed	ns	ns	ns	ns	ns	ns	ns	*	ns	ns
CV	8.66	14.25	14.84	12.75	13.77	10.84	14.91	15.25	10.09	11.12

Means in each column followed by the same letter for each treatment set are not significantly different at 5% alpha level using LSD,
Percent K and Mg (beans) and percent K, P and Mg (weeds) were square root transformed and the back transformed means are reported,
[a]*, **, ***, ****, or ns mean statistically significant at $p \leq 0.05, 0.01, 0.001, 0.0001$ or not significant, respectively.

Table 2.16 The effect of nutrient and bean-weed treatments on bean and weed shoot nutrient concentrations in the 1997B season

Treatment	% N		% P		% K		% Ca		% Mg	
	Beans	Weeds	Beans	Weeds	Beans	Weeds	Beans	Weeds	Beans	Weeds
Nutrient treatment										
NPK	3.66 a	3.21 bc	0.33 a	0.41 a	3.76 ab	4.56 ab	1.78 c	1.35 b	0.58 b	0.43 c
OPK (minus N)	3.28 a	2.76 a	0.32 a	0.43 a	4.17 bc	4.12 a	1.42 a	1.02 a	0.38 a	0.34 a
NOK (minus P)	3.56 a	3.31 c	0.33 a	0.43 a	4.46 c	5.13 b	1.46 a	1.26 b	0.41 a	0.38 ab
NPO (minus K)	3.64 a	3.08 abc	0.33 a	0.46 a	4.18 bc	4.69 ab	1.74 bc	1.31 b	0.50 b	0.42 bc
OOO (minus N, P, K)	3.45 a	2.93 ab	0.30 a	0.47 a	3.25 a	4.38 a	1.54 ab	1.01 a	0.53 b	0.35 a
Bean-weed treatment										
Weed-free beans	3.48 a	-	0.32 a	-	4.00 a	-	1.63 b	-	0.49 a	-
Beans/galinsoga	3.51 a	2.78 a	0.33 a	0.45 a	4.00 a	4.60 a	1.43 a	1.26 bc	0.45 a	0.35 a
Sole galinsoga	-	3.14 b	-	0.47 a	-	4.85 a	-	1.40 c	-	0.35 a
Beans/bidens	3.57 a	3.30 b	0.32 a	0.44 a	3.90 a	4.67 a	1.70 b	1.19 b	0.50 a	0.46 b
Sole bidens	-	3.09 b	-	0.41 a	-	4.28 a	-	0.95 a	-	0.38 a
[a]Statistical significance[a]										
Nutrient treatment	ns	*	ns	ns	**	*	**	***	****	*
Beans-weed treatment	ns	*	ns	ns	ns	ns	**	****	ns	****
Nutrient x bean-weed	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
CV	11.39	13.86	16.38	22.24	16.69	19.28	16.64	19.09	10.28	25.46

Means in each column followed by a similar letter for each treatment set are not significantly different at 5% level using LSD,
Percent Mg and Ca concentrations (beans) were a square root transformed and the back transformed means are reported,
[a]*, **, ***, ****, ns mean statistically significant at $p \leq 0.05, 0.01, 0.001, 0.0001$ or not significant, respectively.

concentrations in all years except for P and K concentrations in the 1997A and B seasons (Tables 2.14, 2.15 and 2.16).

Weeds grown with beans had significantly higher concentrations of P and K compared to their sole counterparts in the 1996 season (Table 2.14). Calcium and Mg concentrations were significantly higher in galinsoga either sole or grown with beans compared to nightshade in the 1996 season. This was similar to the observation made in the 1997A and B seasons for Ca concentration although bidens had significantly higher concentration of Mg compared to galinsoga in both seasons (Table 2.15 and 2.16). In all cases except for N concentration, weeds had higher concentrations of P, K, Ca and Mg compared to beans when averaged across nutrients in the different bean-weed treatments.

Bean Mg concentration showed a significant nutrient by bean-weed treatment interaction ($p = 0.0193$) in 1996 (Figure 2.16). Bean Mg concentration under the OOO treatment was significantly different under all weed treatments. In the NPO treatment, only weed-free beans had significantly higher Mg concentration compared to beans grown with nightshade ($p = 0.017$). Weed-free beans in the OPK treatment were significantly different from beans grown together with galinsoga ($p = 0.0295$) and the rest were not significant. Under both the NOK and NPK treatments, there were no significant differences between beans under the various weed treatments.

Weed K concentration showed a significant nutrient by bean-weed treatment interaction ($p = 0.0006$) in 1996 (Figure 2.17). Under the NPK treatment, nightshade grown with beans had significantly higher K concentration than galinsoga grown together with beans ($p = 0.0001$),

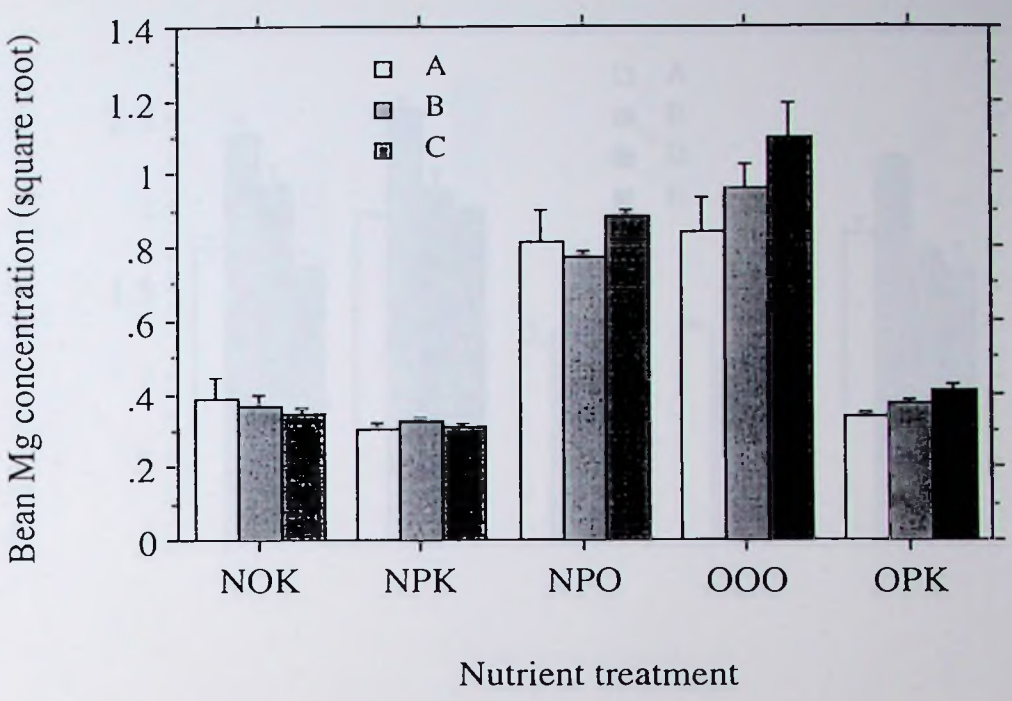


Figure 2.16 Bean-weed by nutrient treatment interaction effect on bean Mg concentration (%) (square root transformed), 56 DAP in the 1996 season (where A = beans grown with galinsoga, B = beans grown with nightshade, and C = weed-free beans)

sole nightshade ($p = 0.0007$), and sole galinsoga ($p = 0.0001$). Weeds in the OPK treatment followed the same trend as weeds in the NPK treatment with nightshade grown together with beans significantly different from the other weed treatments (Figure 2.17). In the NOK treatment, all the weeds under the different bean-weed treatments were significantly different from one another except for galinsoga grown together with beans and sole galinsoga. Weeds under the NPO and OOO treatments showed no significant differences under all bean-weed treatments.

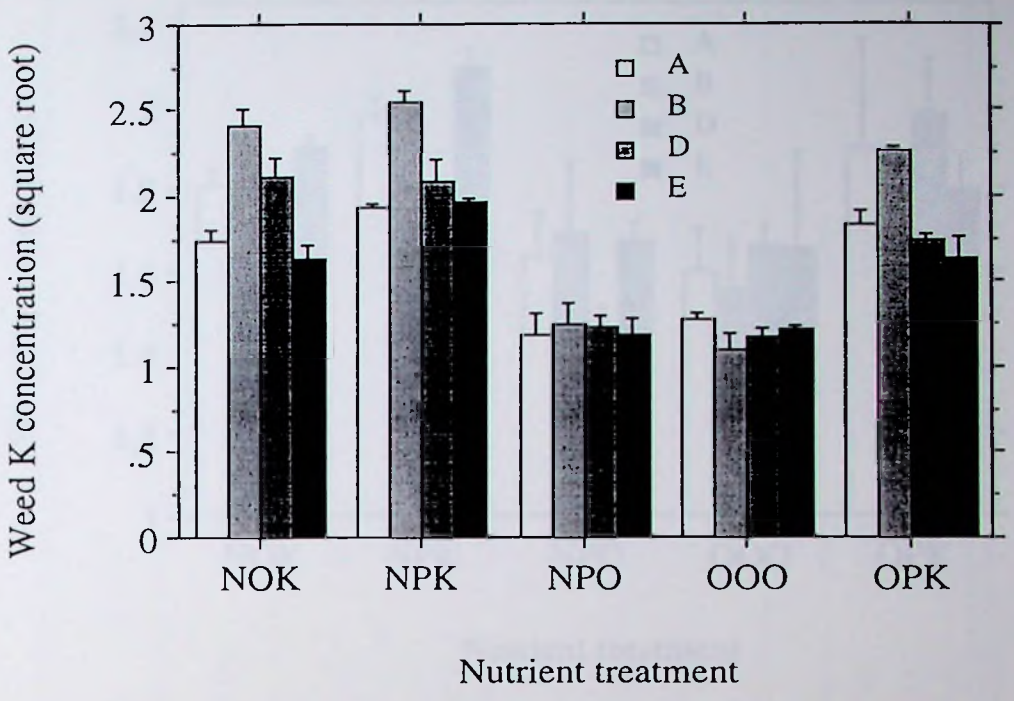


Figure 2.17 Bean-weed by nutrient treatment interaction effect on weed K concentration (%) (square root transformed), 56 DAP in the 1996 season (where A = galinsoga grown with beans, B = nightshade grown with beans, D = sole nightshade, and E = sole galinsoga)

There was also a significant nutrient by bean-weed interaction for weed Ca concentration in the 1997A season ($p = 0.0487$) (Figure 2.18). Under the NOK treatment, only sole galinsoga had significantly higher calcium concentration than bidens grown together with beans. Under the NPK treatment, galinsoga grown together with beans had significantly higher Ca concentration than bidens grown together with beans and sole bidens ($p = 0.0045$ and 0.0326, respectively). At the same time, sole

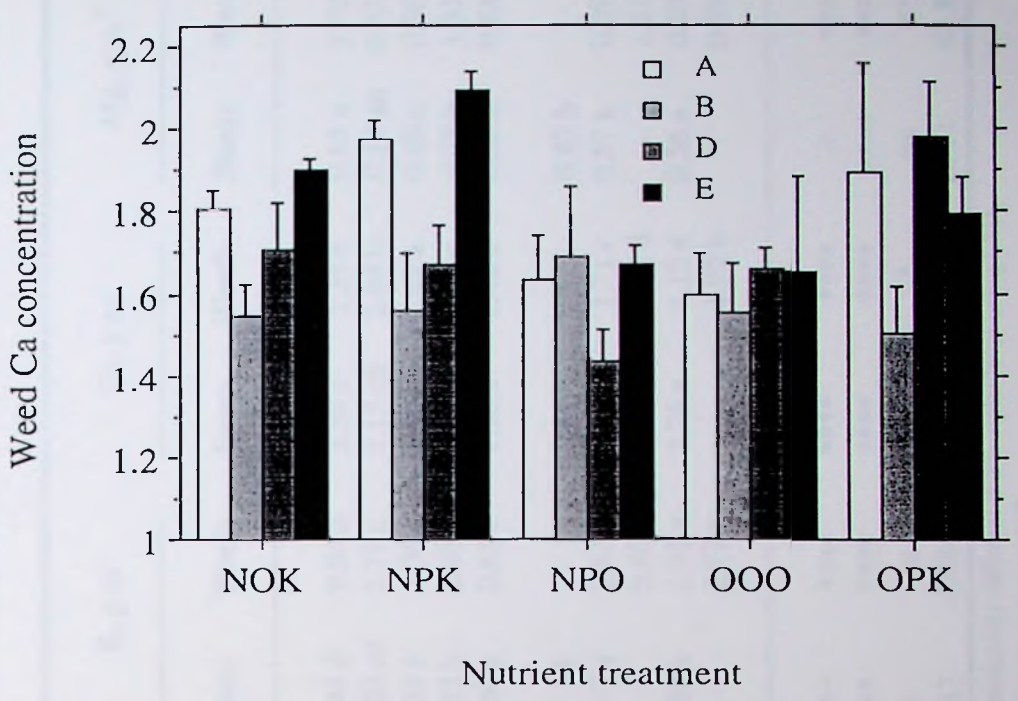


Figure 2.18 Bean-weed by nutrient treatment interaction effect on weed Ca concentration (%), 56 DAP in the 1997A season (where A = galinsoga grown with beans, B = bidens grown with beans, D = sole bidens, and E = sole galinsoga)

galinsoga had significantly higher Ca concentration than sole bidens and bidens grown together with beans ($p = 0.0004$ and 0.0037, respectively). Under the OPK treatment, only bidens grown together with beans had significantly lower Ca concentration than sole galinsoga ($p = 0.0415$), galinsoga grown together with beans ($p = 0.0076$) and sole bidens ($p = 0.0014$).

Bean and weed nutrient content (g m^{-2})

Nutrients significantly affected nutrient content of beans and weeds (Tables 2.17, 2.18 and 2.19). For most nutrients, both beans and

Table 2.17 The effect of nutrient and bean-weed treatments on shoot nutrient content of beans and weeds in the 1996 season

Treatment	N, g m^{-2}		P, g m^{-2}		K, g m^{-2}		Ca, g m^{-2}		Mg, g m^{-2}	
	Beans	Weeds	Beans	Weeds	Beans	Weeds	Beans	Weeds	Beans	Weeds
Nutrient treatment										
NPK	6.82 d	5.33 d	0.77 c	1.21 d	6.44 d	9.94 d	3.58 d	5.39 d	0.65 a	1.02 c
OPK (minus N)	6.01 cd	2.18 b	0.72 c	0.62 b	6.03 cd	3.77 c	3.13 cd	2.89 b	0.67 ab	0.53 b
NOK (Minus P)	5.44 c	2.00 b	0.42 b	0.21 a	5.33 c	3.06 c	2.89 bc	1.69 a	0.60 a	0.36 a
NPO (minus K)	3.51 b	3.32 c	0.41 b	0.78 c	0.83 b	2.06 b	2.49 b	4.31 c	0.79 b	1.35 d
OOO (minus N, P, K)	2.20 a	1.10 a	0.22 a	0.20 a	0.50 a	0.85 a	1.36 a	1.46 a	0.61 a	0.58 b
Bean-weed treatment										
Weed-free beans	5.81 b	-	0.63 b	-	4.18 b	-	3.43 b	-	0.87 b	-
Beans/galinsoga	4.21 a	2.77 b	0.43 a	0.70 c	2.77 a	3.62 c	2.27 a	3.71 c	0.57 a	0.89 c
Sole galinsoga	-	4.85 c	-	1.03 d	-	5.80 d	-	6.31 d	-	1.51 d
Beans/nightshade	3.95 a	1.15 a	0.42 a	0.22 a	2.69 a	1.92 a	2.26 a	1.13 a	0.56 a	0.29 a
Sole nightshade	-	2.31 b	-	0.38 b	-	2.77 b	-	1.96 b	-	0.49 b
Statistical significance[a]										
Nutrient treatment	****	****	****	****	****	****	****	****	*	****
Bean-weed treatment	***	****	***	****	****	****	****	****	****	****
Nutrient x bean-weed	ns	ns	ns	ns	ns	ns	ns	*	ns	**
CV	23.49	38.28	26.77	48.04	47.83	47.84	20.77	43.91	16.71	43.83

Means in each column followed by the same letter for each treatment set are not significantly different at 5% alpha level using LSD,
Nutrient contents (g m^{-2}) were all square root transformed and the back transformed means are reported,
[a]*, **, ***, ****, or ns mean statistically significant at $p \leq 0.05, 0.01, 0.001, 0.0001$ or not significant, respectively.

Table 2.18 The effect of nutrient and bean-weed treatments on shoot nutrient content of beans and weeds in the 1997A season

Treatment	N, g m^{-2}		P, g m^{-2}		K, g m^{-2}		Ca, g m^{-2}		Mg, g m^{-2}	
	Beans	Weeds	Beans	Weeds	Beans	Weeds	Beans	Weeds	Beans	Weeds
Nutrient treatment										
NPK	3.44 c	2.30 b	0.34 b	0.27 b	3.02 c	3.23 b	1.84 c	1.47 d	0.27 c	0.28 d
OPK (minus N)	2.53 ab	1.32 a	0.25 a	0.18 a	2.18 ab	1.83 a	1.36 ab	0.81 ab	0.21 ab	0.15 ab
NOK (minus P)	2.85 bc	1.89 b	0.29 ab	0.20 a	2.65 bc	2.16 b	1.47 b	1.04 bc	0.23 abc	0.19 bc
NPO (minus K)	2.82 bc	1.89 b	0.28 ab	0.22 ab	2.27 ab	2.57 b	1.44 b	1.13 c	0.24 bc	0.23 c
OOO (minus N, P, K)	2.24 a	1.30 a	0.23 a	0.18 a	1.81 a	1.79 a	1.11 a	0.69 a	0.19 a	0.14 a
Bean-weed treatment										
Weed-free beans	3.23 b	-	0.33 b	-	2.75 b	-	1.75 c	-	0.28 c	-
Beans/galinsoga	2.78 b	1.14 a	0.26 a	0.15 a	2.39 ab	1.77 a	1.44 b	0.77a	0.22 b	0.13 a
Sole galinsoga	-	1.83 b	-	0.21 bc	-	2.54 bc	-	1.21 b	-	0.20 b
Beans/bidens	2.32 a	1.56 b	0.24 a	0.20 ab	2.01 a	2.18 ab	1.15 a	0.82 a	0.18 a	0.18 b
Sole bidens	-	2.54 c	-	0.27 c	-	3.21 c	-	1.36 b	-	0.30 c
Statistical significance[a]										
Nutrient treatment	**	****	*	*	***	**	**	****	*	****
Bean-weed treatment	**	****	**	**	**	***	***	****	***	****
Nutrient x bean-weed	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
CV	17.24	26.08	19.11	25.30	23.11	27.35	19.05	26.48	19.11	29.66

Means in each column followed by the same letter for each treatment set are not significantly different at 5% alpha level using LSD,
Nutrient contents (g m^{-2}) were all square root transformed and the back transformed means are reported,
[a]*, **, ***, ****, or ns mean statistically significant at $p \leq 0.05, 0.01, 0.001, 0.0001$ or not significant, respectively

Table 2.19 The effect of nutrient and bean-weed treatments on shoot nutrient content of beans and weeds in the 1997B season

Treatment	N, g m^{-2}		P, g m^{-2}		K, g m^{-2}		Ca, g m^{-2}		Mg, g m^{-2}	
	Beans	Weeds	Beans	Weeds	Beans	Weeds	Beans	Weeds	Beans	Weeds
Nutrient treatment										
NPK	5.26 b	3.62 d	0.47 bc	0.45 c	5.39 b	5.13 cd	2.56 b	1.46 c	0.83 c	0.48 c
OPK (minus N)	3.71 a	2.17 b	0.37 ab	0.34 b	4.72 b	3.17 b	1.61 a	0.76 b	0.43 a	0.27 b
NOK (minus P)	5.53 b	2.79 c	0.50 c	0.35 b	6.86 c	4.25 c	2.23 b	1.00 b	0.64 bc	0.32 b
NPO (minus K)	4.69 ab	3.76 d	0.43 bc	0.55 c	5.45 bc	5.70 d	2.28 b	1.52 c	0.66 bc	0.50 c
OOO (minus N, P, K)	3.62 a	1.41 a	0.32 a	0.21 a	3.40 a	2.01 a	1.63 a	0.45 a	0.56 ab	0.16 a
Beans-weed treatment										
Weed-free beans	5.73 b	-	0.52 b	-	6.60 b	-	2.68 b	-	0.80 b	-
Beans/galinsoga	3.90 a	1.09 a	0.36 a	0.17 a	4.45 a	1.78 a	1.56 a	0.48 a	0.49 a	0.14 a
Sole galinsoga	-	1.93 b	-	0.28 b	-	2.96 b	-	0.86 b	-	0.22 b
Beans/bidens	4.06 a	3.83 c	0.37 a	0.50 c	4.39 a	5.42 c	1.96 a	1.38 c	0.58 a	0.53 c
Sole bidens	-	4.79 d	-	0.62 d	-	6.72 d	-	1.49 c	-	0.58 c
Statistical significance[a]										
Nutrient treatment	**	****	**	****	***	****	**	****	**	****
Bean-weed treatment	***	****	***	****	***	****	***	****	***	****
Nutrient x bean-weed	ns	ns	ns	ns	ns	ns	ns	*	ns	*
CV	15.53	15.53	15.22	15.97	15.44	18.20	17.77	17.11	18.18	16.34

Means in each column followed by a similar letter for each treatment set are not significantly different at 5% level using LSD,
Nutrient contents (g m^{-2}) were all square root transformed and the back transformed means are reported,
[a]*, **, ***, ****, ns mean statistically significant at $p \leq 0.05$, 0.01, 0.001, 0.0001 or not significant, respectively.

weeds had less nutrient content under the OOO treatment than other treatments in all years in addition to the OPK treatment in the 1997B season. For beans, more total nutrients were realized under the NPK, OPK and NOK treatments in the 1996, and in the NPK, NOK and NPO treatments in the 1997A and B seasons (Tables 2.17, 2.18 and 2.19). In case of weeds, high nutrient content was observed under the NPK, NPO and OPK treatments in the 1996, and in the NPK and NPO in the 1997B season (Tables 2.17 and 2.19). Low response to nutrients in the 1997A season was due to the dry spell. Beans under all nutrient treatments had more total N than weeds. Under the OPK and NOK treatments, beans had a much higher N, P, K, Ca and Mg content than the weeds (Tables 2.17, 2.18 and 2.19). Weeds had higher content of P, K, Ca and Mg nutrients under the NPO and NPK treatments than beans in the 1996 season. Similarly, weeds had higher content of K than beans under the NPK and NPO treatments in the 1997A and only under the NPO treatment in the 1997B season. Weeds also had higher content of K and Ca under the OOO treatment while beans had higher content of N, P and Mg in the 1996 season. In the 1997A and B seasons, beans had much higher content of all nutrients in the OOO treatment.

Weed-free beans had significantly more N, P, K Ca and Mg than beans grown with weeds in the 1996 and 1997 seasons (Tables 2.17, 2.18 and 2.19). There were no significant differences between beans grown with galinsoga and nightshade (1996) and galinsoga and bidens (1997B). The same trend was observed in the 1997A season except there were no significant differences between weed-free beans and beans grown with galinsoga for N and K contents (Table 2.18). Beans under the different

weed treatments were significantly different from one another in case of Ca and Mg.

Beans had significant effects on weed nutrient content (Table 2.17, 2.18 and 2.19). In all cases, sole weeds had significantly more nutrients than weeds grown with beans. In the 1996 season, sole galinsoga and in the 1997A and B seasons sole bidens had significantly more nutrients than the rest of the weed treatments. Sole bidens was not significantly different from sole galinsoga in case of P, K and Ca content in the 1997A season and Ca and Mg in the 1997B season.

Total nutrient content per unit area was greater in beans grown with galinsoga for all nutrients compared to weed-free beans in the 1996 season (Table 2.17). The total nutrient content for beans plus nightshade grown together was nearly the same with weed-free beans. In the 1997A season, the total nutrient content of beans and bidens, and beans and galinsoga were higher than weed-free beans for all nutrients (Table 2.18). In the 1997B season, beans and bidens grown together had higher nutrient content than weed-free beans (Table 2.19). Beans grown with galinsoga had similar nutrient content as weed-free beans in the 1997B season.

Weed P content (g m^{-2}) showed a significant nutrient by bean-weed treatment interaction ($p = 0.0301$) in the 1996 season (Figure 2.19). Weeds under the different bean-weed treatments in the NPK nutrient were all significantly different from one another. In both the OPK and NPO treatments, galinsoga grown with beans and sole galinsoga were not significant different while the rest were significantly different. Similarly,

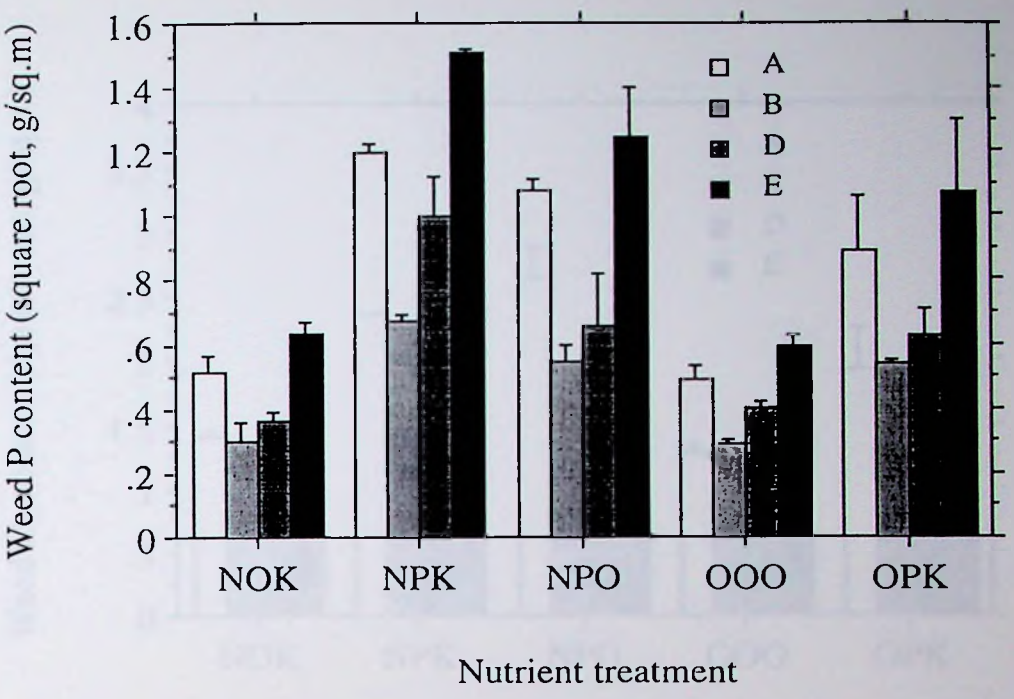


Figure 2.19 Bean-weed by nutrient treatment interaction effect on weed P content (square root, g m^{-2}), 56 DAP in the 1996 season (where A = galinsoga grown with beans, B = nightshade grown with beans, D = sole nightshade, and E = sole galinsoga)

nightshade grown with beans and sole nightshade were not significantly different. Under the NOK treatment, galinsoga grown with beans had significantly more P than nightshade grown with beans ($p = 0.0322$). Sole galinsoga had significantly more P than nightshade grown with beans ($p = 0.0022$) and sole nightshade ($p = 0.0088$). In the OOO treatment, only sole galinsoga had significantly more P than nightshade grown with beans ($p = 0.0051$).

Weed Ca and Mg content also had significant nutrient by bean-weed treatment interactions in the 1996 season ($p = 0.0443$ and 0.0068, respectively) (Figures 2.20 and 2.21). The patterns were virtually

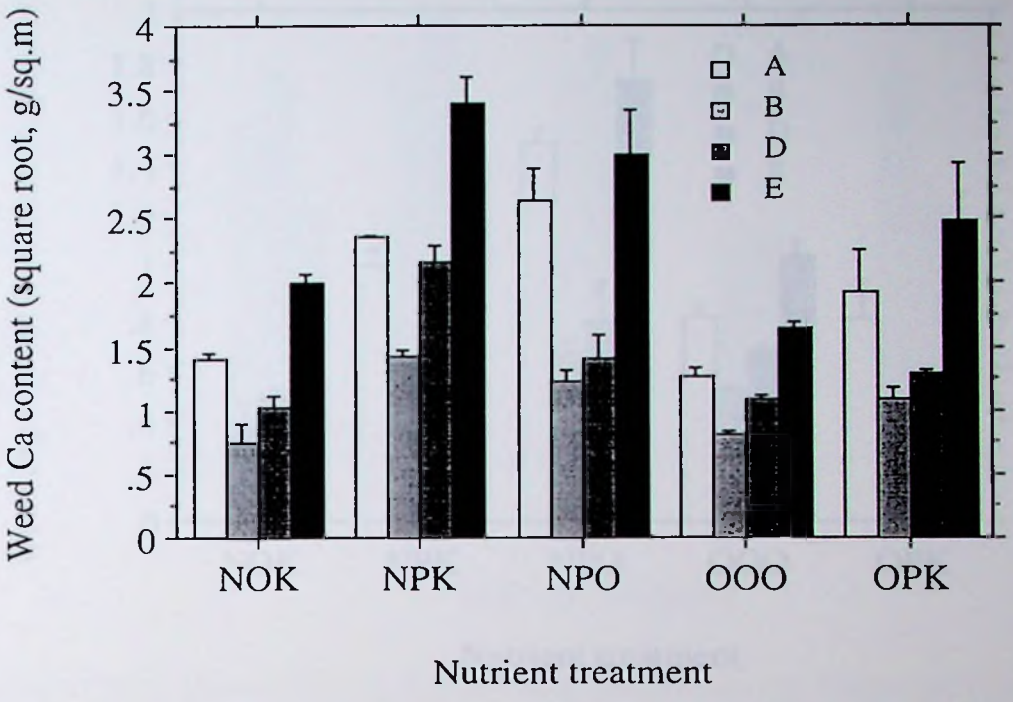


Figure 2.20 Bean-weed by nutrient treatment interaction effect on weed Ca content (square root, g m^{-2}), 56 DAP in the 1996 season (where A = galinsoga grown with beans, B = nightshade grown with beans, D = sole nightshade, and E = sole galinsoga)

identical to the P content, indicating similar nutrient uptake mechanisms for these nutrients.

Significant nutrient by bean-weed treatment interaction was observed for weed Ca content ($p = 0.0446$) in the 1997B season (Figure 2.22). Under the NPK treatment, weed Ca content (g m^{-2}) was significantly higher for sole bidens than other weed treatments. Bidens grown with beans had significantly more Ca than galinsoga grown with beans ($p = 0.0001$) and sole galinsoga ($p = 0.0346$). Under the OPK treatment, bidens grown with beans had significantly more Ca than all

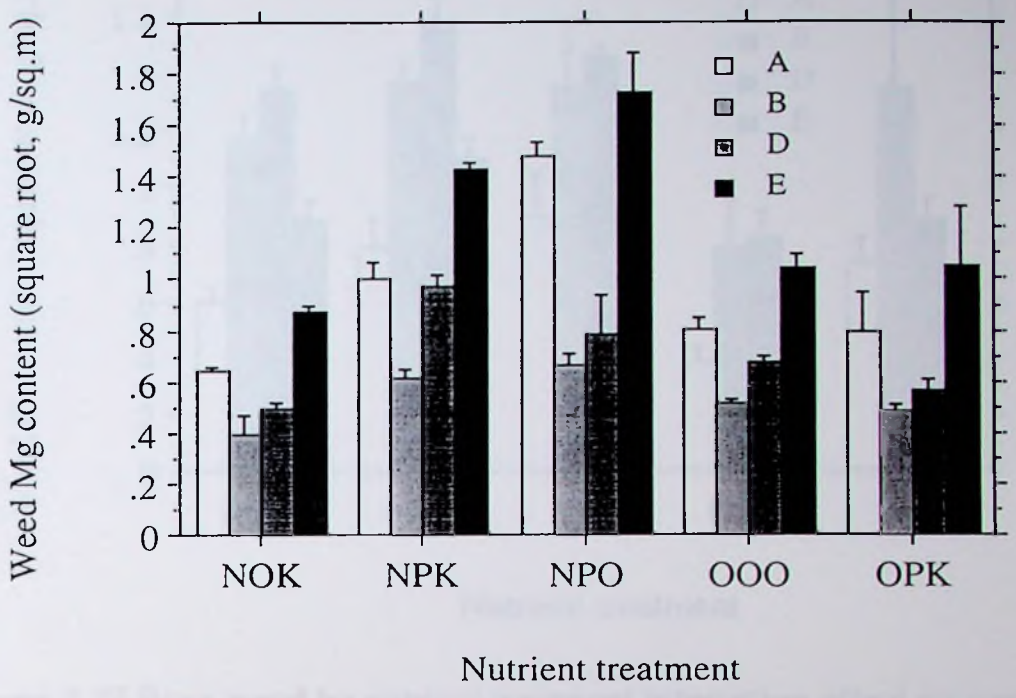


Figure 2.21 Bean-weed by nutrient treatment interaction effect on weed Mg content (square root, g m^{-2}), 56 DAP in the 1996 season (where A = galinsoga grown with beans, B = nightshade grown with beans, D = sole nightshade, and E = sole galinsoga)

other weed treatments. Under the NOK treatment, sole bidens had significantly more Ca than galinsoga grown with beans ($p = 0.0001$) and sole galinsoga ($p = 0.005$). Bidens grown with beans had significantly more Ca than galinsoga grown with beans ($p = 0.0001$) and sole galinsoga ($p = 0.0275$). For the NPO treatment, sole bidens had significantly more Ca than galinsoga grown with beans ($p = 0.0001$). Bidens grown with beans had significantly more Ca than galinsoga grown with beans ($p = 0.0005$). Under the OOO treatment, sole bidens had significantly more Ca than galinsoga grown with beans ($p = 0.0064$).

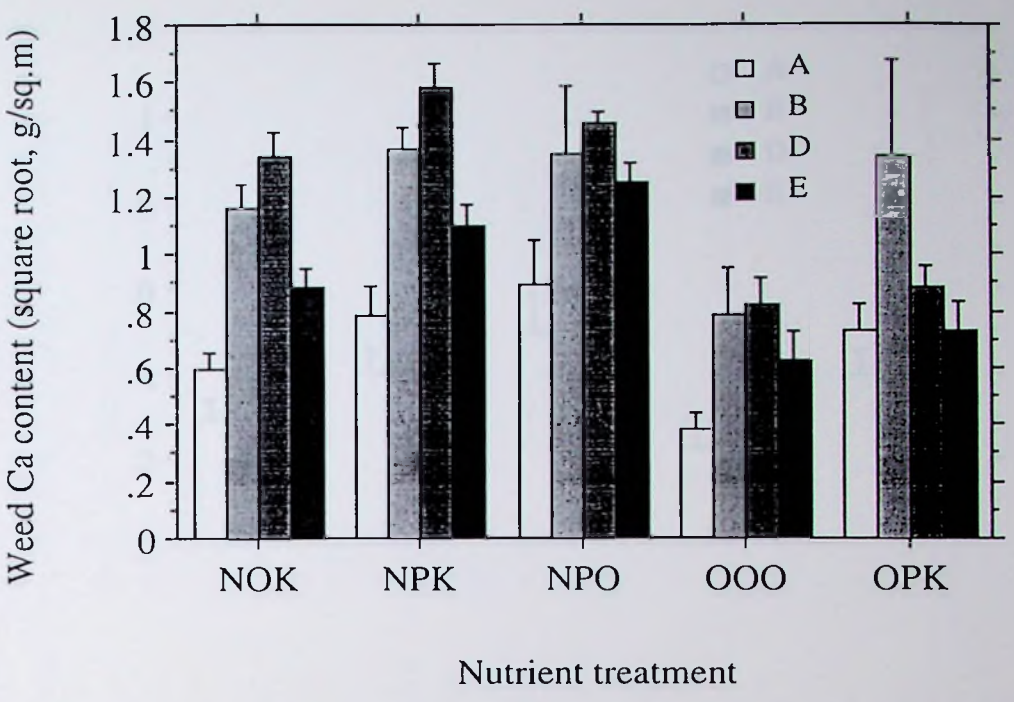


Figure 2.22 Bean-weed by nutrient treatment interaction effect on weed Ca content (square root, g m^{-2}), 56 DAP in the 1997B season (where A = galinsoga grown with beans, B = bidens grown with beans, D = sole bidens, and E = sole galinsoga)

Bidens grown with beans had significantly more Ca than galinsoga grown with beans ($p = 0.0132$).

There was also a significant nutrient by bean-weed treatment interaction for weed Mg content ($p = 0.0128$) in the 1997B season (Figure 2.23). The pattern of Mg nutrient content was similar to Ca content, indicating similar nutrient uptake mechanisms for these two divalent cations.

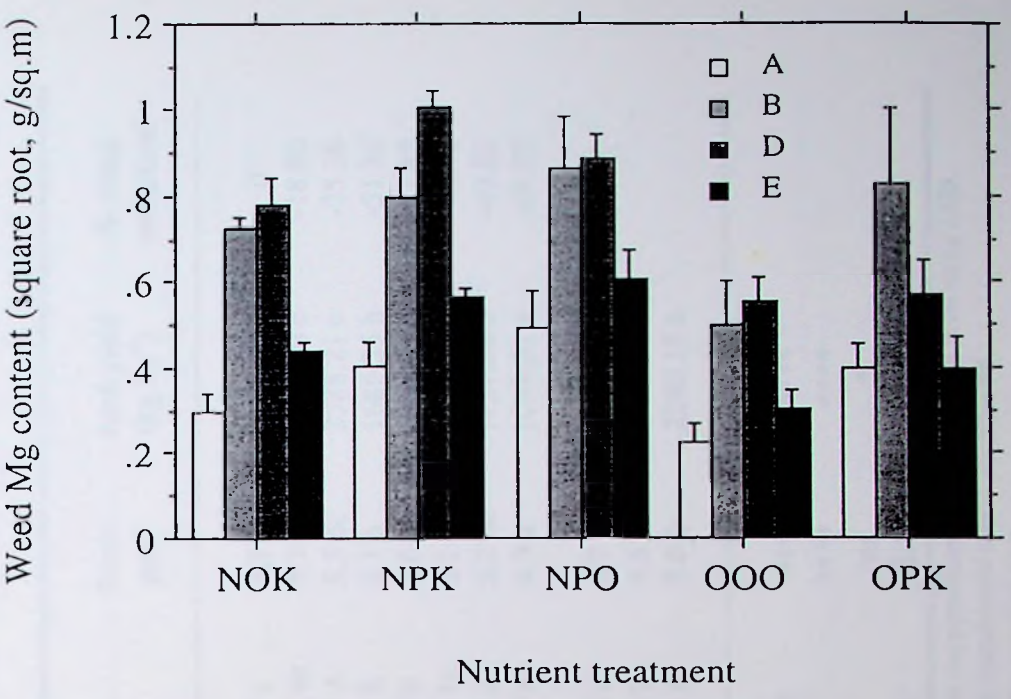


Figure 2.23 Bean-weed by nutrient treatment interaction effect on weed Mg content (square root, g m^{-2}), 56 DAP in the 1997B season (where A = galinsoga grown with beans, B = bidens grown with beans, D = sole bidens, and E = sole galinsoga)

Bean yield per hectare and yield components

Effect of nutrients and bean cultivars, 1995 and 1996

Nutrients significantly affected bean seed yield per hectare in both years (Tables 2.20 and 2.21). Bean yield per hectare was much lower under the prevailing weather conditions of the 1996 season compared to the 1995 season. The high rainfall experienced in 1996 (Table 2.5) led to heavy white mold attack on beans which could have caused yield reduction. This was more pronounced under the NPK and OPK treatments. These are the treatments where bean growth was very

Table 2.20 The effect of nutrients and bean cultivars on bean yield parameters and yield ha^{-1} (kg) in 1995

Treatment	% plant survival	Harvest index	Pods m^{-2}	Seeds pod^{-1}	Seed yield (kg ha^{-1})	% yield reduction[a]
Nutrient treatment						
NPK	93.13 c	50.51 a	358.1 e	5.7 c	3467.37 d	0
OPK (minus N)	88.94 c	53.07 a	293.8 de	5.7 c	2811.90 c	-18.90
NOK (minus P)	88.40 c	48.09 a	287.7 d	5.5 bc	2588.21 c	-25.36
NPO (minus K)	57.80 a	45.18 a	175.4 b	5.1 b	1686.55 b	-51.36
OOK (minus N, P)	90.56 c	49.43 a	274.8 d	5.6 c	2500.35 c	-27.89
OPO (minus N, K)	71.34 b	48.63 a	212.8 bc	5.1 b	1786.49 b	-48.48
NOO (minus P, K)	91.65 c	47.45 a	243.2 cd	5.2 bc	1737.80 b	-49.88
OOO (minus N,P,K)	64.71 ab	47.29 a	134.0 a	4.5 a	1099.01 a	-68.30
Bean cultivars						
BAT 25	76.25 a	52.16 c	245.5 a	5.7 b	2285.60 b	
K 131	83.20 b	44.24 a	228.6 a	4.6 a	1737.80 a	
RAO 55	83.00 b	49.71 b	248.3 a	5.6 b	2296.15 b	
Statistical significance[b]						
Nutrient treatment	****	ns	****	***	****	
Bean cultivars	**	*	ns	****	****	
Nutrient x bean cultivar	ns	ns	*	ns	*	
Coefficient of variation	20.07	11.22	7.63	15.10	5.95	

Means in each column followed by the same letter for each set of treatments are not significantly different at 5% level using LSD,
Bean harvest index, pods m^{-2} and bean yield ha^{-1} were log transformed and back transformed means are reported,
[a] % yield reduction is calculated in comparison to the NPK bean seed yield as the standard base,
[b] *, **, ***, ****, ns mean statistically significant at $p \leq 0.05, 0.01, 0.001, 0.0001$ or not significant, respectively.

Table 2.21 The effect of nutrients on bean yield parameters and yield ha^{-1} (kg) in the 1996 season

Treatment	% plant survival	Harvest index	Pods m^{-2}	Seeds pod^{-1}	Seed yield (kg ha^{-1})	% yield reduction or increase[a]
Nutrient treatment						
NPK	86.81 a	46.14 a	266.1 b	5.1 d	1406.05 bc	0
OPK (minus N)	76.05 a	46.64 a	249.5 b	4.8 cd	1425.61 bc	+1.39
NOK (minus P)	88.44 a	49.48 a	321.4 b	4.6 bcd	1706.08 c	+21.34
NPO (minus K)	75.32 a	48.09 a	131.8 ab	4.3 abc	711.21 ab	-49.42
OOK (minus N, P)	80.92 a	54.46 a	265.5 b	4.6 bcd	1749.85 c	+24.45
OPO (minus N, K)	80.04 a	50.81 a	132.4 ab	4.3 abc	743.02 ab	-47.16
NOO (minus P, K)	92.94 a	53.90 a	165.2 ab	3.8 a	827.94 ab	-41.12
OOO (minus N,P,K)	79.43 a	54.19 a	99.1 a	4.1 ab	567.54 a	-59.64
Statistical significance[b]						
Nutrient treatment	ns	ns	*	*	*	
Coefficient of variation	9.63	7.90	9.39	9.93	6.83	

Means in each column followed by the same letter for each set of treatments are not significantly different at 5% level using LSD,
Bean harvest index, pods m^{-2} and bean seed yield ha^{-1} were log transformed and back transformed means are reported,
[a] % yield reduction or increase is calculated in comparison to the NPK bean seed yield as the standard base,
[b] *, ns mean statistically significant at $p \leq 0.05$, or not significant, respectively.

vigorous with a lot of canopy creating an environment suitable for survival of the disease.

In 1995, there was a significant nutrient by bean cultivar treatment interaction for seed yield per hectare ($p = 0.0133$) (Figure 2.24). Under the NPO, OOK and NOO treatments, both BAT 25 and RAO 55 yielded significantly more than K 131. There was, however, no significant difference between BAT 25 and RAO 55. In the OPO treatment, BAT 25 yielded significantly more than K 131. Under the OOO treatment, RAO 55 had significantly more seed yield than both K 131 and BAT 25 ($p = 0.0021$ and 0.0305, respectively). There were no significant differences between the bean cultivars under the NPK, NOK and OPK treatments.

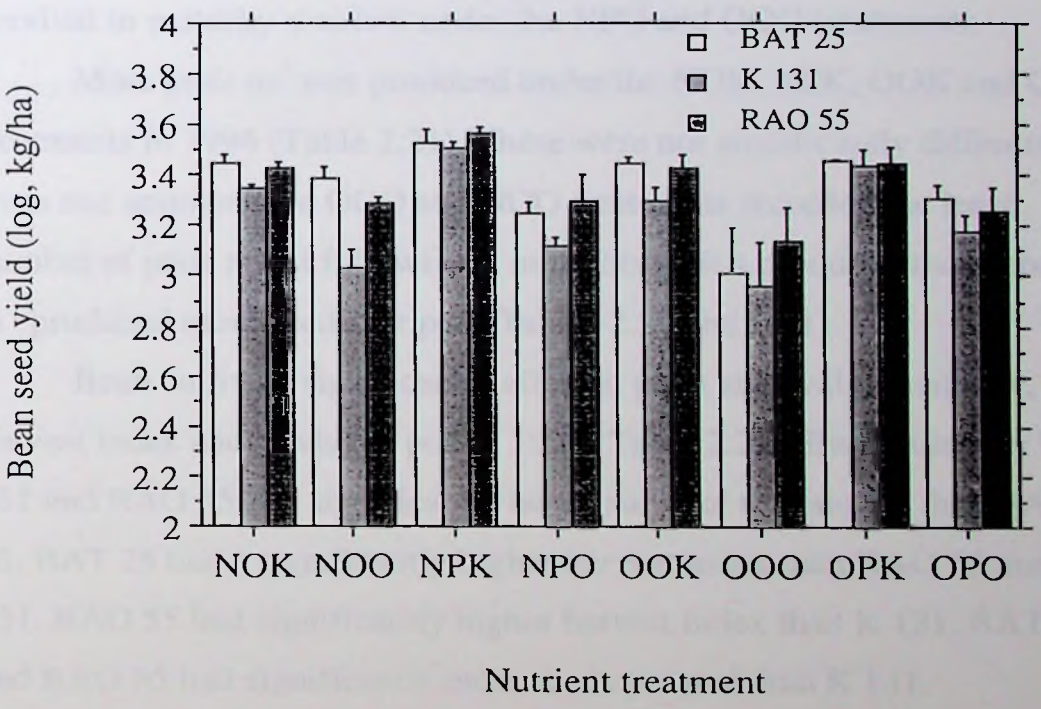


Figure 2.24 Bean cultivar by nutrient treatment interaction effect on bean seed yield (log, kg ha^{-1}) in the 1995 season

In 1996, there were higher bean yields under the OOK, NOK, OPK and NPK treatments which were not significantly different from one another (Table 2.21). The lowest yield was recorded under the OOO treatment which was not significantly different from the NPO, OPO and NOO treatments. In comparison to the NPK treatment, bean yields were reduced under the NOO, OPO, NPO and OOO treatments and increased under the OPK, NOK and OOK treatments.

Nutrients significantly affected the number of pods m^{-2} and seeds per pod in the 1995 and 1996 seasons in addition to plant survival to maturity in 1995 (Tables 2.20 and 2.21). Better bean survival was recorded under the NPK, NOO, OOK, OPK and NOK treatments which were not significantly different from one another (Table 2.20). Bean survival to maturity was low under the NPO and OOO treatments.

More pods m^{-2} was produced under the NOK, NPK, OOK and OPK treatments in 1996 (Table 2.21). These were not significantly different from one another. The OOO and NOO treatments recorded the least number of pods m^{-2}. It follows that nutrients which produced more pods m^{-2} produced more seeds per pod (Tables 2.20 and 2.21).

Bean cultivars significantly affected plant survival to maturity, harvest index and seeds per pod in 1995 (Table 2.20). Bean cultivars K 131 and RAO 55 had significantly better survival to maturity than BAT 55. BAT 25 had a significantly higher harvest index than RAO 55 and K 131. RAO 55 had significantly higher harvest index than K 131. BAT 25 and RAO 55 had significantly more seeds per pod than K 131.

There was a significant nutrient by bean-weed treatment interaction for bean pods m^{-2} ($p = 0.0384$) in 1995 (Figure 2.25). Under the NOO

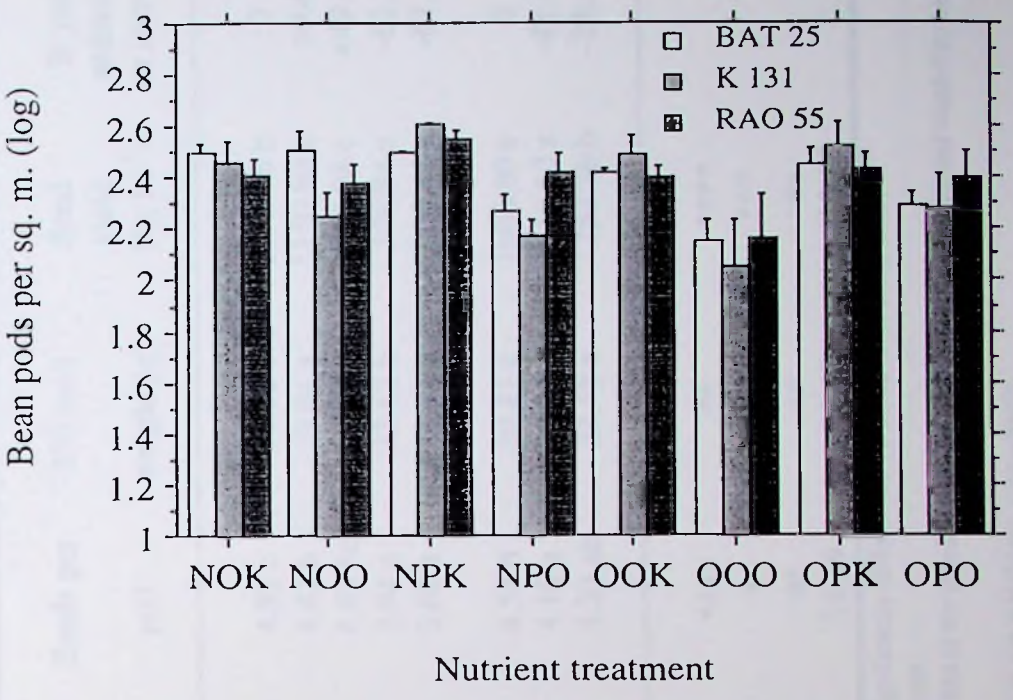


Figure 2.25 Bean cultivar by nutrient treatment interaction effect on pods m^{-2} in the 1995 season

treatment, BAT 25 had significantly more pods m^{-2} than K 131 ($p = 0.0023$). In the NPO treatment, RAO 55 had significantly more pods per unit area than K 131 ($p = 0.0045$). There were no significant differences between the bean cultivars under the other nutrient treatments.

Effect of nutrients and weeds on bean yield in 1996 and 1997

Both nutrient and bean-weed treatments significantly affected bean yield per hectare in the 1996 and 1997B seasons (Tables 2.22 and 2.24). In the 1997A season, only the presence of weeds significantly affected bean yields (Table 2.23). The NOK treatment recorded the highest yield per hectare which was significantly different from the rest of the nutrients

Table 2.22 The effect of nutrients and weeds on bean yield parameters and yield ha^{-1} (kg) in 1996

Treatment	% plant survival	Harvest index	Pods m^{-2}	Seeds per pod	200 seed weight (g)	Seed yield (kg ha^{-1})	% yield reduction or increase[a]
Nutrient treatment							
NPK	85.40 b	43.41 b	208.9 bc	4.98 c	30.02 a	1051.96 b	0
OPK (minus N)	76.84 a	45.42 bc	195.4 b	4.42 b	29.04 a	1150.80 b	+9.40
NOK (minus P)	84.87 b	49.45 c	261.2 c	4.65 bc	29.62 a	1573.98 c	+49.62
NPO (minus K)	75.50 a	39.00 a	74.6 a	3.94 a	33.62 b	399.94 a	-61.98
OOO (minus NPK)	78.43 a	49.44 c	71.6 a	3.68 a	33.97 b	406.44 a	-61.36
Bean-weed treatment							
Weed-free beans	81.21 a	48.91 b	194.5 b	4.58 b	30.41 a	1066.60 c	0
Beans/galinsoga	80.34 a	42.13 a	111.2 a	4.10 a	30.87 a	616.60 a	-42.19
Beans/nightshade	79.07 a	45.00 a	131.5 a	4.32 ab	32.48 a	753.36 b	-29.37
Statistical significance[b]							
Nutrient treatment	*	**	****	****	**	****	
Bean-weed treatment	ns	**	****	*	ns	***	
Nutrient x bean-weed	ns	ns	ns	ns	ns	ns	
Coefficient of variation	8.95	14.74	13.19	14.49	10.13	10.15	

Means in each column followed by the same letter for each treatment set are not significantly different at 5% alpha level using LSD,
Pods m^{-2} and yield ha^{-1} were log transformed and back transformed means are reported,
[a] % yield reduction or increase is calculated in comparison to the NPK bean seed yield as the standard base for the nutrient treatments and weed-free bean seed yield as the standard base for the bean-weed treatments,
[b] *, **, ***, ****, ns, mean statistically significant at $p \leq 0.05, 0.01, 0.001, 0.0001$, or not significant, respectively.

Table 2.23 The effect of nutrients and weeds on bean yield parameters and yield ha^{-1} (kg) in the 1997A season

Treatment	% plant survival	Harvest index	Pods m^{-2}	Seeds per pod	200 seed weight (g)	Seed yield (kg ha^{-1})	% yield reduction or increase[a]
Nutrient treatment							
NPK	74.13 a	38.73 ab	59.6 a	3.59 a	39.73 a	170.22 a	0
OPK (minus N)	73.28 a	41.40 ab	49.1 a	4.01 a	39.45 a	162.18 a	-4.72
NOK (minus P)	71.94 a	43.05 bc	66.1 a	3.24 a	40.55 a	188.36 a	+10.66
NPO (minus K)	59.29 a	33.42 a	76.2 a	3.25 a	38.65 a	165.58 a	-2.73
OOO (minus N, P, K)	70.47 a	52.00 c	67.3 a	3.15 a	40.17 a	171.79 a	+0.92
Bean-weed treatment							
Weed-free bean	69.66 a	45.71 a	88.1 b	3.24 a	41.17 b	246.60 c	0
Beans/galinsoga	69.34 a	38.99 a	59.4 a	3.76 a	38.96 a	164.44 b	-33.32
Beans/bidens	69.66 a	39.54 a	47.8 a	3.33 a	39.00 a	124.17 a	-49.65
Statistical significance[b]							
Nutrient treatment	ns	**	ns	ns	ns	ns	
Bean-weed treatment	ns	ns	***	ns	*	****	
Nutrient x bean-weed	ns	ns	ns	ns	ns	ns	
Coefficient of variation	5.74	8.85	12.65	18.69	7.90	8.02	

Means in each column followed by the same letter for each treatment set are not significantly different at 5% alpha level using LSD,

Seeds per pod were square root transformed, and plant survival, harvest index, pods m^{-2} and yield per hectare were log transformed and the back transformed means are reported,

[a] % yield reduction or increase is calculated in comparison to the NPK bean seed yield as the standard base for the nutrient treatments and weed-free bean seed yield as the standard base for the bean-weed treatments,

[b] *, **, ***, ****, ns, mean statistically significant at $p \leq 0.05, 0.01, 0.001, 0.0001$, or not significant, respectively.

Table 2.24 The effect on nutrients and weeds on bean yield parameters and yield ha^{-1} (kg) in the 1997B season

Treatment	% plant survival	Harvest index	Pods m^{-2}	Seeds per pod	200 seed weight (g)	Seed yield (kg ha^{-1})	% yield reduction or increase[a]
Nutrient treatment							
NPK	73.06 a	41.13 a	156.3 ab	4.3 a	33.63 a	668.81 a	0
OPK (minus N)	69.53 a	40.95 a	124.7 a	4.3 a	32.38 a	623.73 a	-6.74
NOK (minus P)	80.89 a	42.06 a	211.4 c	4.1 a	33.93 a	914.11 b	+36.68
NPO (minus K)	71.40 a	43.82 a	161.8 b	4.1 a	33.07 a	668.34 a	+0.07
OOO (minus N, P, K)	75.76 a	45.66 a	135.5 ab	4.3 a	32.62 a	642.69 a	-3.91
Bean-weed treatment							
Weed-free beans	79.52 a	45.88 b	212.3 b	4.1 a	33.62 a	1023.29 b	0
Beans/galinsoga	71.28 a	40.01 a	137.4 a	4.2 a	32.26 a	597.04 a	-41.65
Beans/bidens	70.45 a	42.28 ab	128.5 a	4.3 a	33.50 a	552.08 a	-46.05
Statistical significance[b]							
Nutrient treatment	ns	ns	**	ns	ns	*	
Bean-weed treatment	ns	*	****	ns	ns	****	
Nutrient x bean-weed	ns	ns	*	ns	ns	ns	
Coefficient of variation	6.55	14.13	8.96	8.80	5.77	5.04	

Means in each column followed by a similar letter for each treatment set are not significantly different at 5% level using LSD,
Bean survival, pods m^{-2} and yield ha^{-1} were log transformed and back transformed means are reported,
[a] % yield reduction or increase is calculated in comparison to the NPK bean seed yield as the standard base for the nutrient treatments and weed-free bean seed yield as the standard base for the bean-weed treatments,
[b] *, **, ***, ****, ns mean statistically significant at $p \leq 0.05, 0.01, 0.001, 0.0001$ or not significant, respectively.

in both the 1996 and 1997B seasons (Tables 2.22 and 2.24). Beans under the NPK and OPK treatments, and the NPO and OOO treatments were not significantly different from one another in 1996. In the 1997B season, apart from the NOK treatment, the rest of the treatments were not significantly different in yield.

Compared to NPK as a standard treatment in the 1996 season, the OPK and NOK treatments increased bean yields by 9.4 and 49.6%, respectively (Table 2.22). The OOO and NPO treatments reduced bean yields by 62.0 and 61.4%, respectively, compared to the NPK treatment. In the 1997A season, there were no significant differences in yields. In the 1997B season, only the NOK treatment significantly increased yield by 36.7% compared to the NPK treatment (Table 2.24). The dry spell experienced in the 1997A season (Figure 2.1) could have caused inefficient utilization of nutrients by the beans. The low yields of the NPK treatment in the 1996 and 1997B seasons are most likely attributable to competition with the actively growing weeds and white mold disease which was more devastating in the NPK and to some extent the OPK treatment (Table 2.7). Heavy vegetative growth in the NPK treatment and too much rain and humidity (Figure 2.1) could have contributed to increased disease incidence.

The presence of nightshade and galinsoga greatly reduced yield by 29.4 and 42.2 %, respectively, in 1996 (Table 2.22). In the presence of galinsoga and bidens, bean yields were reduced by 33.3 and 49.7%, respectively, in the 1997A season and by 41.7 and 46.1%, respectively, in the 1997B season compared to the weed-free beans (Tables 2.23 and 2.24). Beans grown with the different weeds in the 1996 and 1997A

seasons were significantly different from one another. Beans grown together with galinsoga in 1996 recorded the lowest yield per hectare. Nightshade did not compete with beans up to maturity since it was removed at 56 DAP, which could have affected their action on bean yields. In the 1997A and B seasons, beans grown together with bidens recorded the lowest yield although this was not significantly different from beans grown together with galinsoga in the 1997B season.

When the yields of beans in competition with weeds under each nutrient are considered, the highest yields in absolute values (kg ha^{-1}) were observed under the NOK treatment (Appendix A, Table A2). Under the NOK treatment, the yields of beans when grown with weeds were much higher than in the other nutrients. In 1996 under the NOK treatment, galinsoga and nightshade caused only 19.5 and 2.3%, respectively, yield losses compared to the weed-free bean yield. Similarly, lower yield reductions in absolute values were observed under the NOK treatment in the 1997A and B seasons (Appendix A, Table A2). In comparison to their weed-free counterpart yields in each treatment, yields were more reduced in the NPK and NPO (1996) and NPK, OPK, NPO and OOO (1997A and B seasons) nutrients.

Nutrients significantly affected plant survival to maturity, harvest index, pods m^{-2}, seeds per pod and two hundred seed weight in the 1996 season (Table 2.22). Nutrients also had significant effects on harvest index in the 1997A season, and only pods m^{-2} in the 1997B season (Tables 2.23 and 2.24). Significantly more beans survived to maturity under the NPK treatment in 1996 although this was not significantly different from the NOK treatment. Percentage bean survival was low

under the NPO treatment although this was not significantly different from the OPK and OOO treatments in 1996. Bean harvest index values were highest in the OOO and NOK treatments in the 1996 and 1997A seasons in addition to the OPK treatment in 1996. High harvest index indicates a higher proportion of seeds compared to shoot dry weight.

There were more pods m^{-2} in the NOK treatment although this was not significantly different from the NPK treatment in 1996 (Table 2.22). The NPO and OOO treatments displayed the lowest number of pods per m^2 in 1996. Seeds per pod followed a similar trend to pods m^{-2} in 1996. There were more seeds per pod under the NPK treatment which was not significantly different from the NOK treatment. On the other hand, nutrient plots which had many seeds per pod (NPK, NOK and OPK) had light seeds. Nutrients with few seeds per pod had significantly heavier seeds (NPO and OOO) in 1996. This could have been due to the sharing of assimilates among the many seeds in one pod (NPK, NOK and OPK) compared to a few seeds in one pod (NPO and OOO).

Weeds significantly reduced bean harvest index compared to weed-free beans in the 1996 and 1997B seasons (Tables 2.22 and 2.24). The presence of weeds also significantly reduced pods m^{-2} in all seasons and seeds per pod in the 1996 season (Tables 2.22, 2.23 and 2.24). In the 1997A season, weeds significantly reduced seed weight as measured by 200 seed weight.

There was a significant interaction between nutrient and bean-weed treatments for pods m^{-2} in the 1997B season ($p = 0.021$) (Figure 2.26). In the NPK treatment, weed-free beans had significantly more pods m^{-2} than

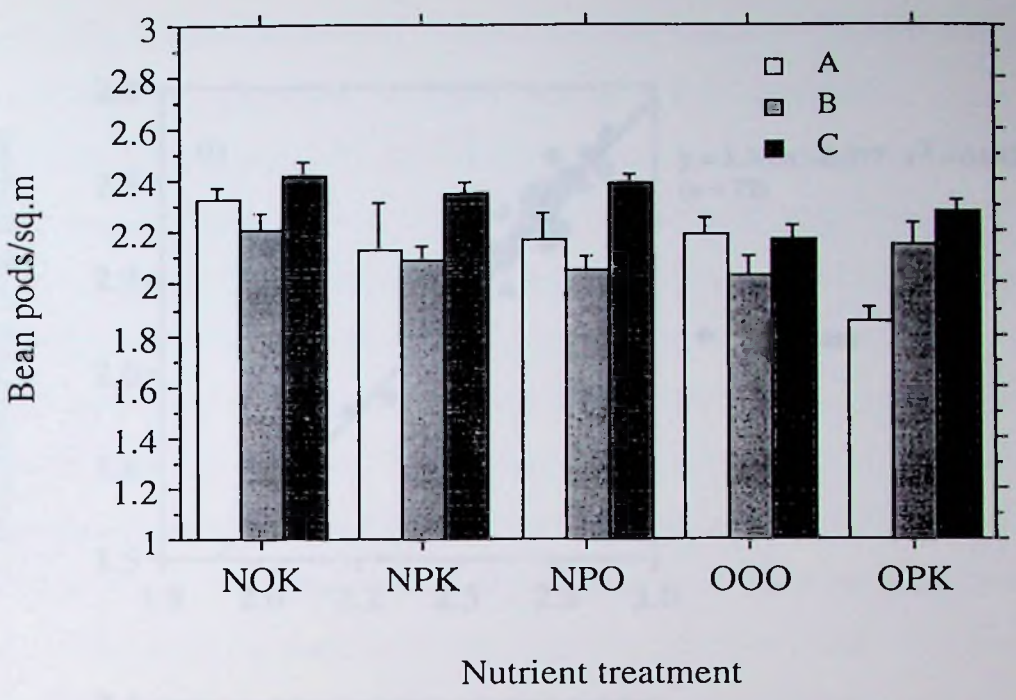


Figure 2.26 Bean-weed by nutrient treatment interaction effect on bean pods m^{-2} (log) in the 1997B season (where A = beans grown with galinsoga, B = beans grown with bidens, and C = weed-free beans)

beans grown with galinsoga and bidens ($p = 0.0191$ and 0.0077, respectively). Under the NOK and NPO treatments, weed-free beans had significantly more pods m^{-2} than beans grown with bidens ($p = 0.0265$ and 0.0008, respectively) (Figure 2.26). In the OPK treatment, beans grown with galinsoga had significantly lower pods m^{-2} than beans grown with bidens or weed- free beans ($p = 0.003$ and 0.0001, respectively). There were no significant differences among the various bean treatments under the OOO treatment.

Bean shoot dry weight (g m^{-2}) had a linear relationship with bean seed yield (g m^{-2}) in the 1995, 1996, 1997A and B seasons (Figures 2.27

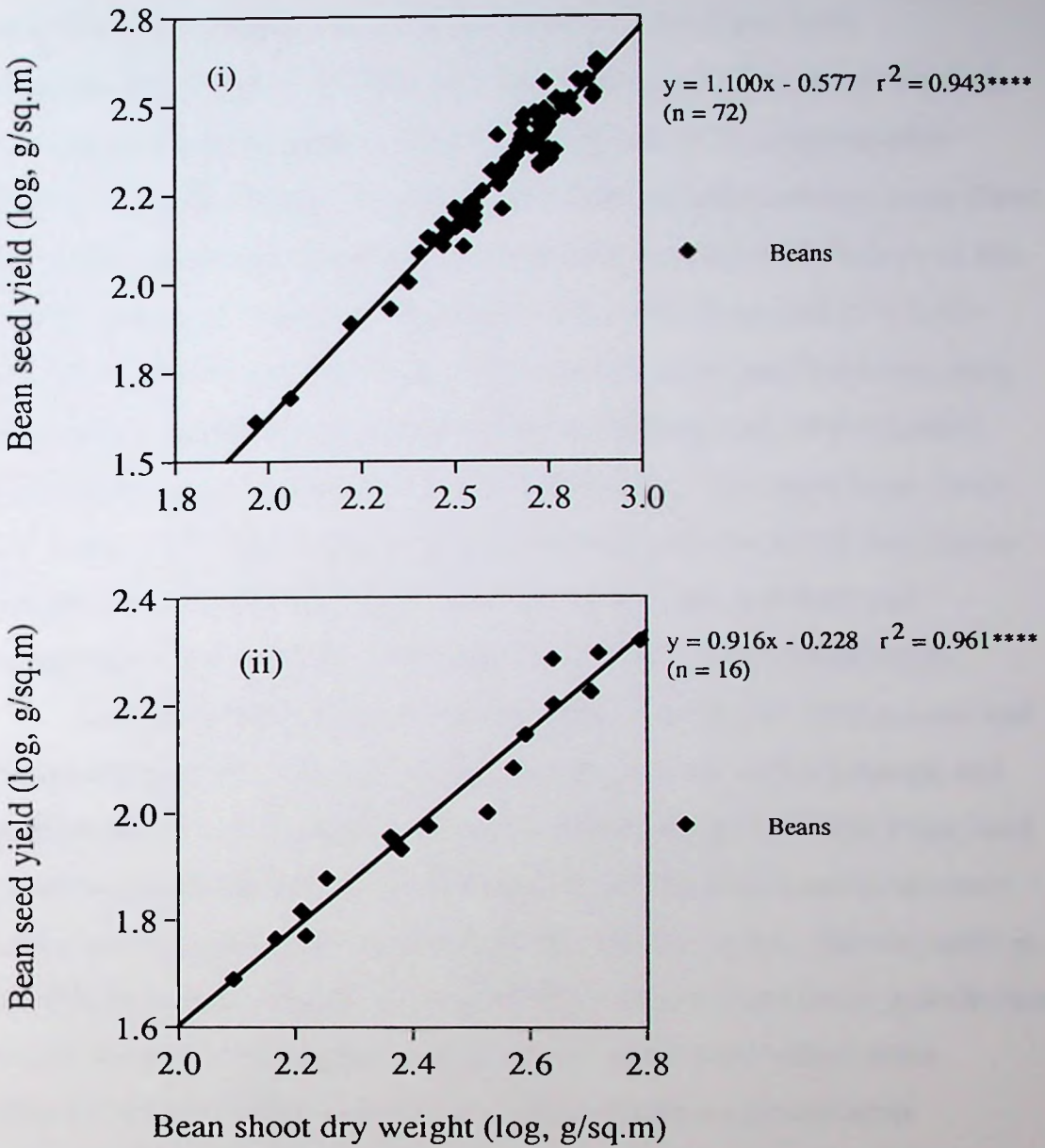


Figure 2.27 The relationship between bean shoot dry weight at 70 DAP and bean seed yield (all log transformed, g/sq.m) averaged across nutrients and beans cultivars in the (i) 1995 and (ii) 1996 seasons (**** means statistically significant at p = 0.0001 and n is the sample size used for the regression analysis)

and 2.28). Bean cultivar seed yields increased linearly with increasing bean shoot dry weights in 1995 and 1996 (r^2 = 0.94 and 0.96, respectively) (Figures 2.27 (i) and (ii)). Similarly for beans grown with galinsoga and nightshade in 1996 (r^2 = 0.69 and 0.76, respectively) (Figure 2.28 (i)). There were also linear relationships between bean shoot dry weights and seed yields for beans grown together with bidens in the 1997A season (r^2 = 0.55) or galinsoga in the 1997B season (r^2 = 0.55) (Figures 2.28 (ii) and (iii)). This indicates that more yield of beans may need better and more shoot growth for the manufacture of the needed assimilates for seed production and maintenance. The more bean shoot dry matter yield, the more seed yield per unit area observed. Any factor which reduces bean shoot dry matter yield like soil nutrients and competition from weeds is most likely to affect seed yield of beans.

Leaf area index values of beans at 56 DAP in the 1996 season had linear relationship with seed yield for beans grown with galinsoga and nightshade (r^2 = 0.72 and 0.71, respectively) (Figure 2.29 (i)). Bean seed yield increased linearly with increasing LAI. The relationship between LAI and bean seed yield was weak in the 1997A season. The dry spell in the 1997A season (Figure 2.1) apparently reduced bean shoot growth due to low response to nutrients and therefore, lower LAI values were attained. In the 1997B season, LAI values for beans grown with galinsoga had a linear relationship with bean seed yield (r^2 = 0.53) (Figure 2.29 (ii)). Bean seed yield increased with increasing LAI values.

The number of bean pods m^{-2} was linearly correlated with seed yield in the 1995, 1996 and 1997B seasons (Figures 2.30 and 2.31). Bean seed yield increased linearly with increasing number of bean pods in

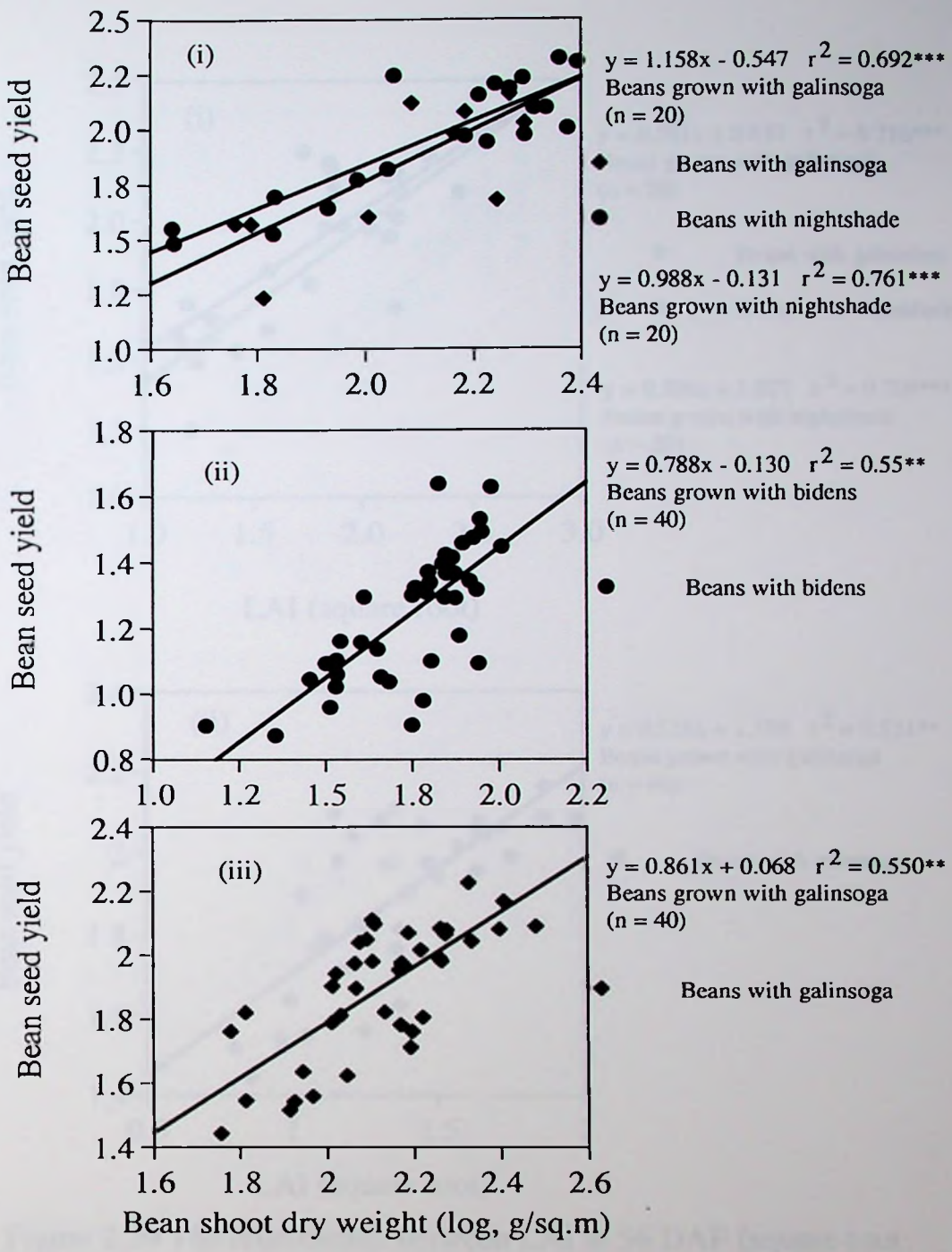


Figure 2.28 The relationship between bean shoot dry weight at 56 DAP and seed yield (all log transformed, g/sq.m) as affected by weeds averaged across nutrients in the (i) 1996, (ii) 1997A and (iii) 1997B seasons (**, *** mean statistically significant at p = 0.01 and 0.001, respectively and n is the sample size used for the regression analysis)

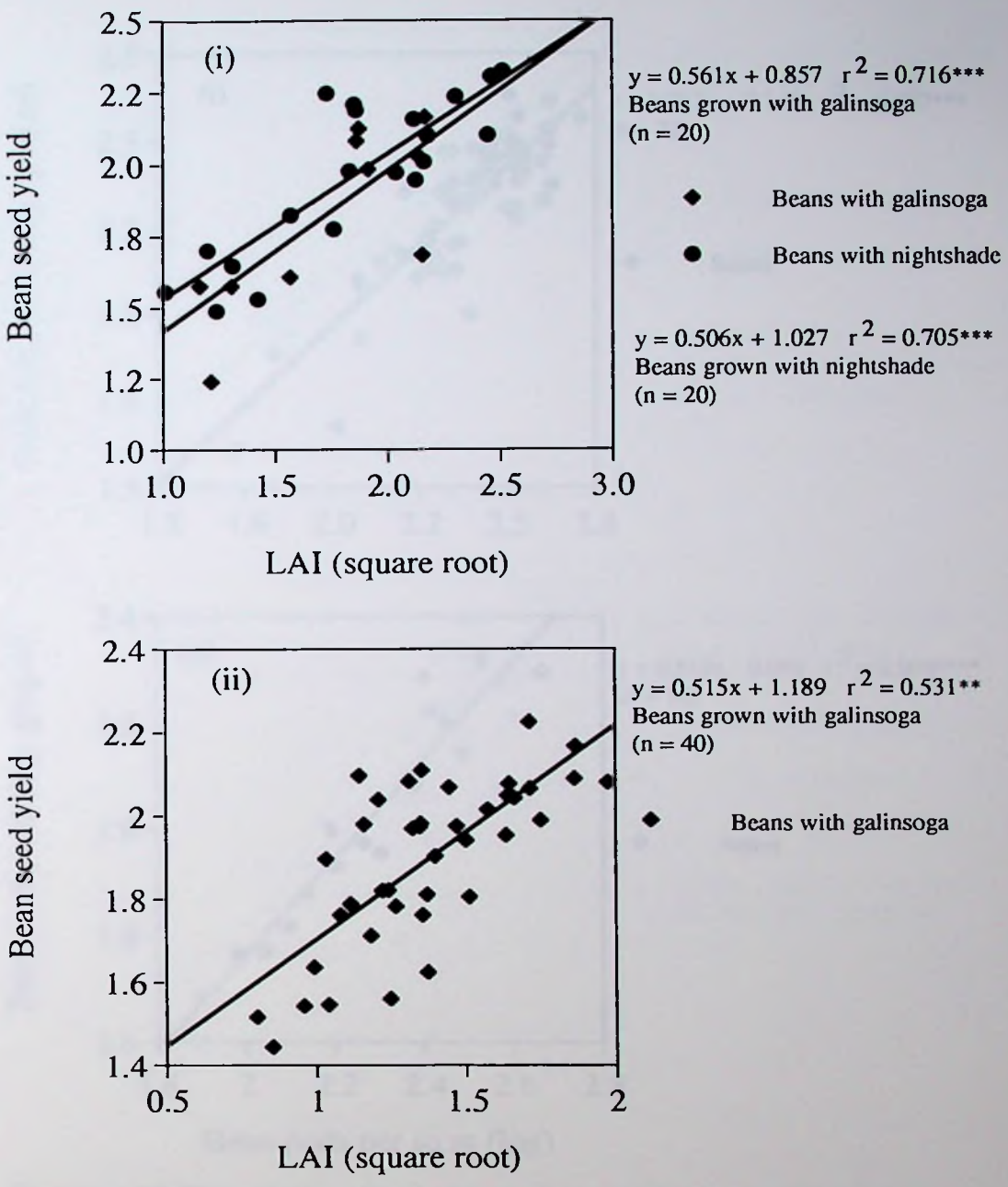


Figure 2.29 The relationship between LAI at 56 DAP (square root transformed) and bean seed yield (log, transformed, g/sq.m) as affected by weeds averaged across nutrients in the (i) 1996 and (ii) 1997B seasons (**, *** mean statistically significant at p = 0.01 and 0.001, respectively, and n is the sample size used for the regression analysis)

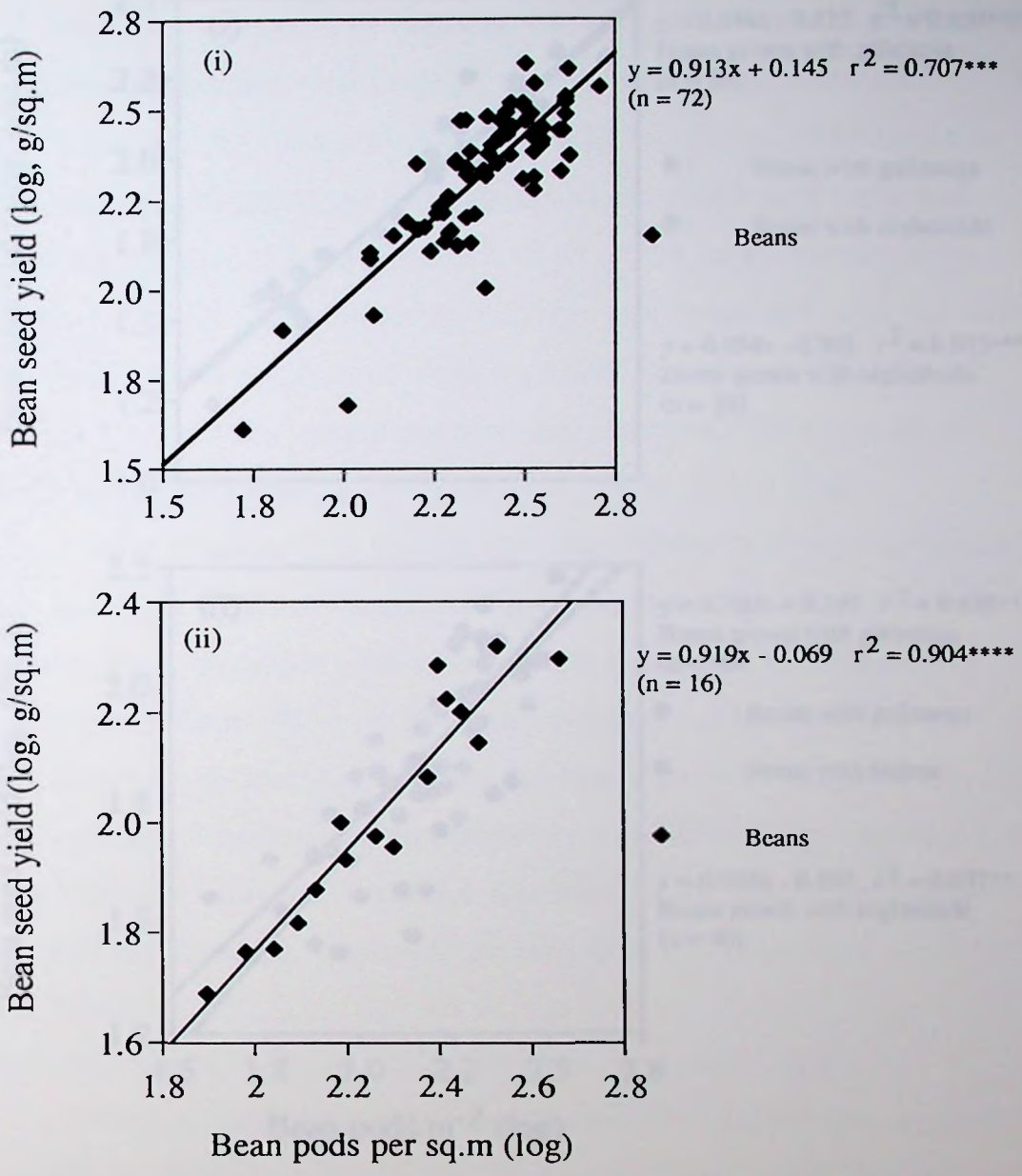


Figure 2.30 The relationship between bean pods/sq.m and seed yield, g/sq.m (all log transformed) averaged across nutrients and bean cultivars in the (i) 1995 and (ii) 1996 seasons (***, **** mean statistically significant at p = 0.001 and 0.0001, respectively, and n is the sample size used for the regression analysis)

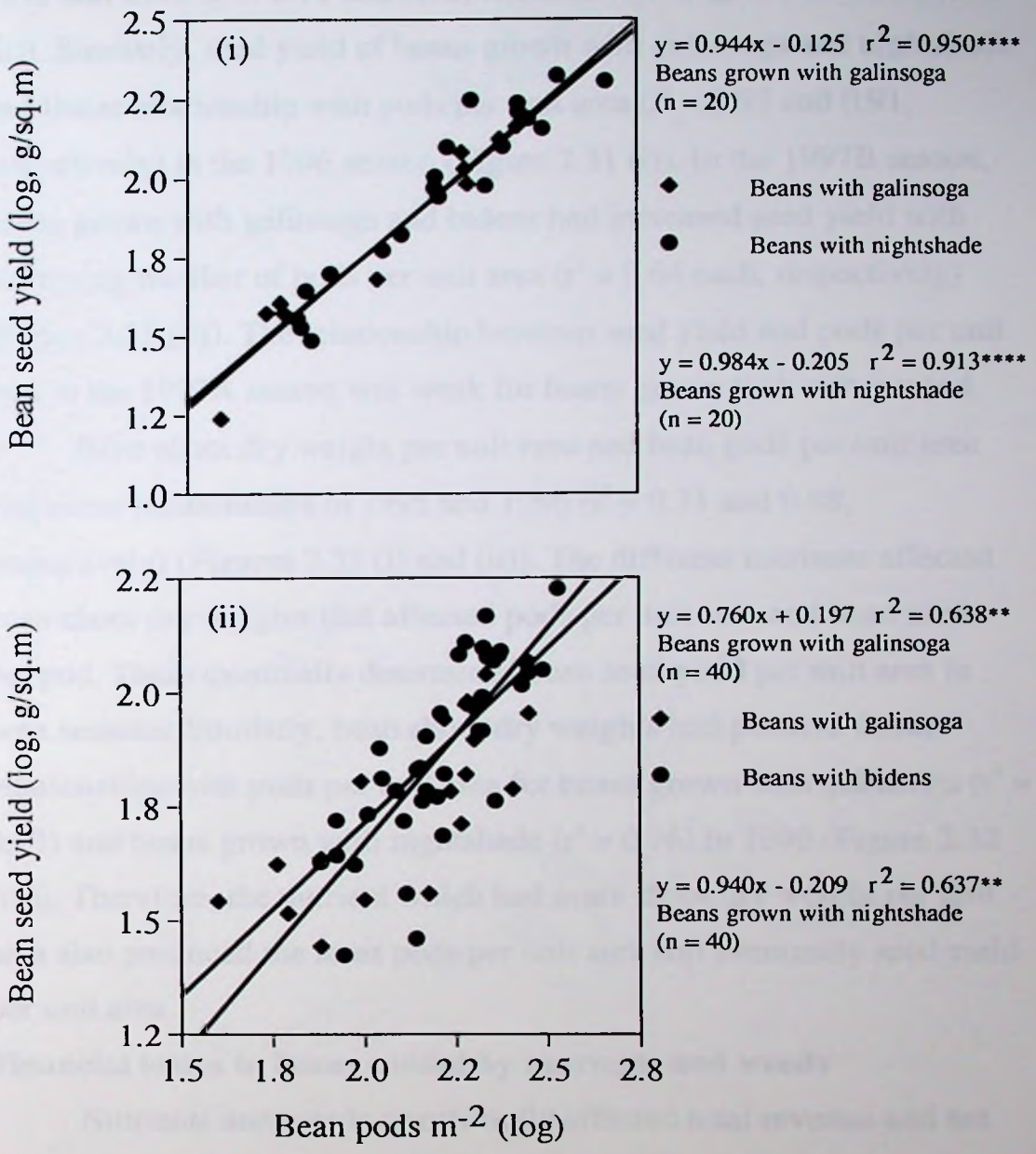


Figure 2.31 The relationship between pods/sq.m and bean seed yield, g m^{-2}, (both log transformed) as affected by weeds averaged across nutrients in the (i) 1996 and (ii) 1997B seasons (**, **** mean statistically significant at p = 0.01 and 0.0001, respectively, and n is the sample size used for the regression analysis)

1995 and 1996 (r^2 = 0.71 and 0.90, respectively) (Figures 2.30 (i) and (ii)). Similarly, seed yield of beans grown with galinsoga and nightshade had linear relationship with pods per unit area (r^2 = 0.95 and 0.91, respectively) in the 1996 season (Figure 2.31 (i)). In the 1997B season, beans grown with galinsoga and bidens had increased seed yield with increasing number of pods per unit area (r^2 = 0.64 each, respectively) (Figure 2.31 (ii)). The relationship between seed yield and pods per unit area in the 1997A season was weak for beans grown with either weed.

Bean shoot dry weight per unit area and bean pods per unit area had linear relationships in 1995 and 1996 (r^2 = 0.71 and 0.88, respectively) (Figures 2.32 (i) and (ii)). The different nutrients affected bean shoot dry weights that affected pods per unit area and bean seeds per pod. These eventually determined bean seed yield per unit area in both seasons. Similarly, bean shoot dry weights had positive linear relationships with pods per unit area for beans grown with galinsoga (r^2 = 0.73) and beans grown with nightshade (r^2 = 0.76) in 1996 (Figure 2.32 (iii)). Therefore, the nutrient which had more shoot dry weight per unit area also produced the most pods per unit area and eventually seed yield per unit area.

Financial losses to beans caused by nutrients and weeds

Nutrients and weeds significantly affected total revenue and net profit in the 1997A and B seasons (Figures 2.33 and 2.34). The calculation was based on Kampala City price and was assumed for an area within a 30 km radius of Kampala City. Bean price would be much lower in the upcountry areas and with higher costs of production especially transport costs and costs of inputs than in Kampala suburb.

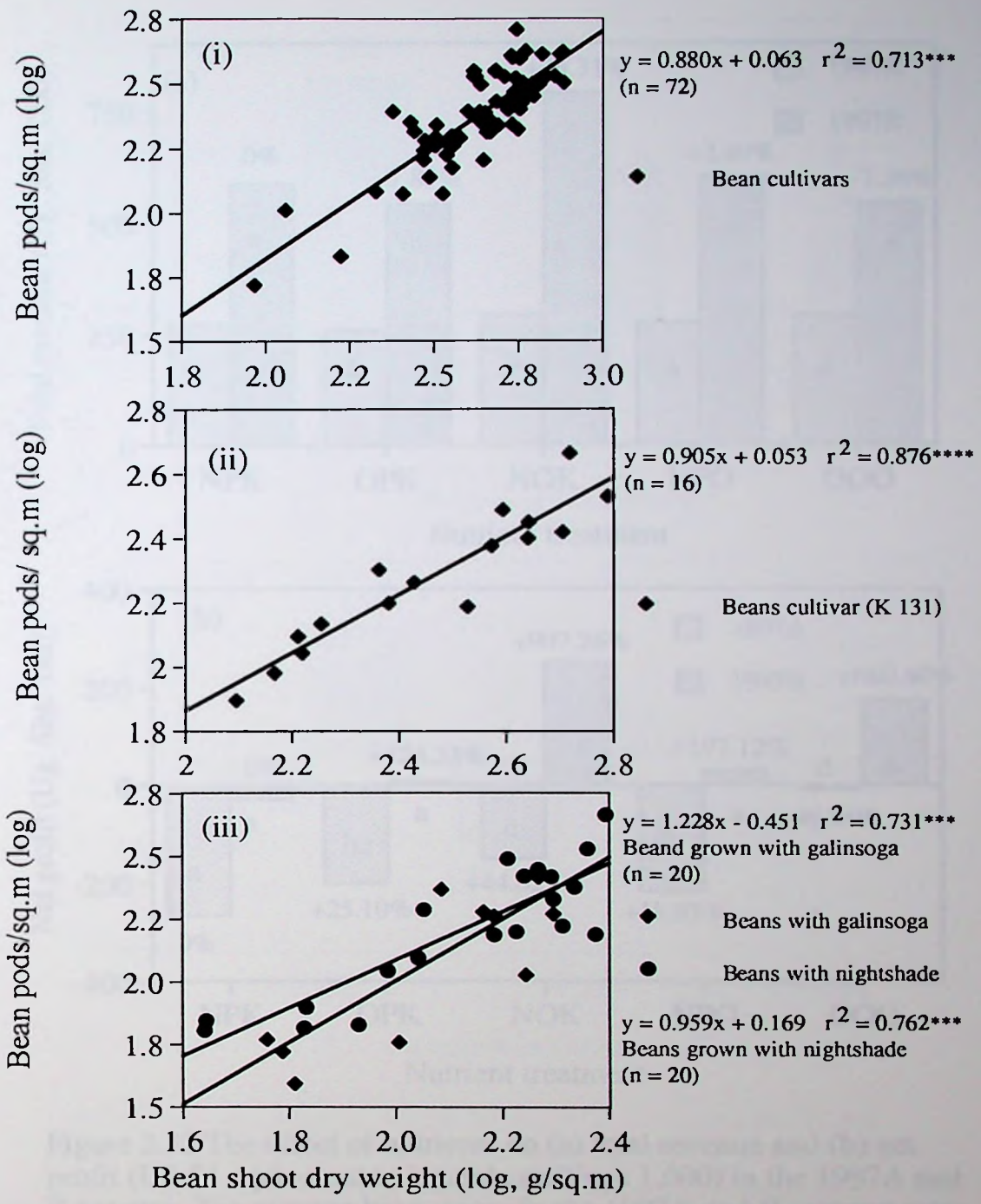


Figure 2.32 The relationship between bean shoot dry weight, g/sq.m and pods m^{-2} (all log transformed) averaged across nutrients, bean cultivars and weed treatments in the (i) 1995, (ii) 1996 (sole and weed-free beans) and (iii) 1996 (beans grown with weeds) seasons (***, **** mean statistically significant at p = 0.001 and 0.0001, respectively, and n is the sample size used for the regression analysis)

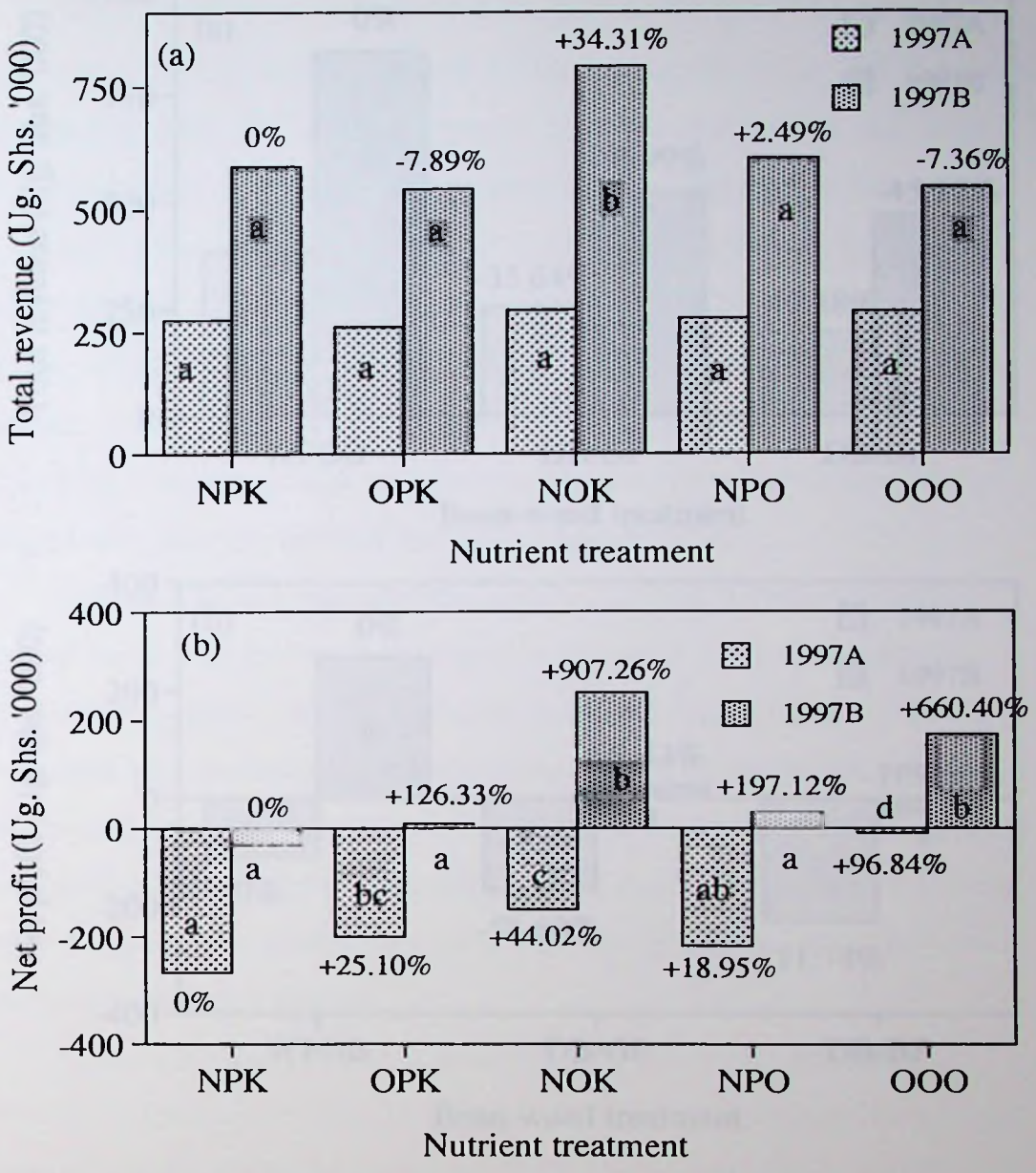


Figure 2.33 The effect of nutrients on (a) total revenue and (b) net profit (US $1 equivalent to Uganda shillings 1,000) in the 1997A and B seasons. The average bean prices in the 1997A and B seasons were Ug. Shs. 1,500 and 800 per kg of beans, respectively. Bean total revenue and net profit followed by the same letter on each graph for 1997A and B seasons are not significantly different at 5% level using LSD

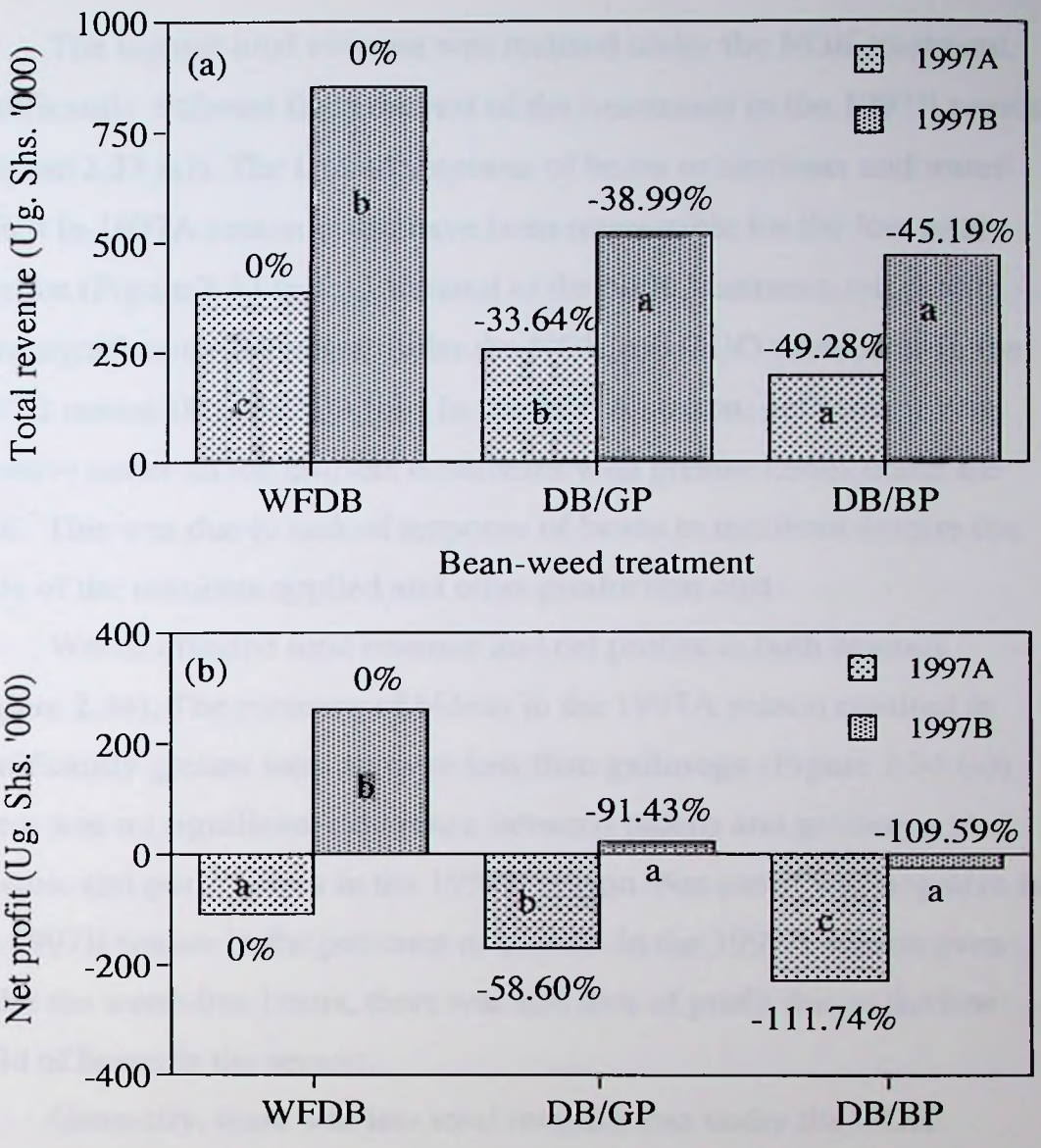


Figure 2.34 The effect of weeds on (a) total revenue and (b) net profit (US $ 1 equivalent to Uganda shillings 1,000) in the 1997A and B seasons. The average bean prices in the 1997A and B seasons were Ug. Shs. 1,500 and 800 per kg of beans, respectively. Note: WFDB = weed-free dry beans, DB/GP = dry beans grown with *G. parviflora* and DB/BP = dry beans grown with *B. pilosa*. Total revenue and net profit followed by the same letter on each graph each season are not significantly different at 5% level using LSD

The highest total revenue was realized under the NOK treatment significantly different from the rest of the treatments in the 1997B season (Figure 2.33 (a)). The lack of response of beans to nutrients and water deficit in 1997A season could have been responsible for the low total revenue (Figure 2.33 (a)). Compared to the NPK treatment, net profits were significantly increased under the NOK and OOO treatments in the 1997B season (Figure 2.33 (b)). In the 1997A season, net profits were negative under all the nutrient treatments with greater losses under the NPK. This was due to lack of response of beans to nutrients despite the costs of the nutrients applied and other production cost.

Weeds affected total revenue and net profits in both seasons (Figure 2.34). The presence of bidens in the 1997A season resulted in significantly greater total revenue loss than galinsoga (Figure 2.34 (a)). There was no significant difference between bidens and galinsoga in revenue and profit losses in the 1997B season. Net profit was negative in the 1997B season in the presence of bidens. In the 1997A season even under the weed-free beans, there was still loss of profit due to the low yield of beans in the season.

Generally, there was less total revenue loss under the NOK treatment compared to other treatments in the 1997B season. There was improved profit under the NOK and OOO treatments in the 1997B season. Under the bad weather conditions of 1997A season, bidens was more effective in reducing revenue and profit than galinsoga. Under the slightly better weather condition of 1997B season, both weeds were effective in reducing revenue and profit from beans.

DISCUSSION

Growth environments at Freeville Farm (Cornell University) and NAARI (Uganda)

Low response to nutrients was observed in Uganda in the 1997A and B seasons due to drought (Figure 2.1) and the relatively high nutrient contents of the soils used in the two seasons (Table 2.3). Plant analysis results in Uganda (Tables 2.15 and 2.16) also indicated no real N, P and K deficiency in the different treatments where nutrients were applied meaning that no response to added nutrients occurred. The significantly higher seed yield under the NOK than under NPK in the 1997B season (Table 2.24) supports the contention that no significant deficiency of P was occurring.

The environmental conditions at Freeville farm in the 1995 and 1996 growing seasons were more conducive for bean and weed growth than the conditions that existed in Uganda in both the 1997A and B seasons (Table 2.5). Rainfall was poorly distributed in 1995 but this was supplemented with irrigation when needed (Table 2.4) resulting in better bean growth. Rainfall was better distributed in the 1996 season (Table 2.5) allowing for vigorous growth of beans and weeds.

In Uganda, rainfall was poorly distributed in the 1997A season with the resultant drought 21-28 days after planting (Figure 2.1) resulting in poor bean and weed growth compared to Freeville farm plantings. In the 1997B season, there was too much rain immediately after planting which continued till harvest time (Figure 2.1). This resulted in better plant vegetative growth than in the 1997A season. Galinsoga weed was still not as vigorous as was observed in the 1996 season at Freeville farm.

The soil at Freeville farm was gravely loam soil of high pH, OM and friable soil structure (Tables 2.1 and 2.2). In Uganda, the field used had sandy clay soil of relatively low pH (Table 2.3). The soil had poor structure and during heavy rainfall was sticky and prone to compaction. During both the 1997A and B seasons, the site was plowed following heavy rain, possibly causing compaction of the soil providing environment less favorable for plant growth. These conditions could have resulted in the poor performance of the plants in Uganda compared to Freeville farm.

The effect of nutrient and bean-weed treatments on bean and weed nutrient uptake

In all seasons and across location, nutrients and weeds had no significant effect on bean nitrogen concentration (Tables 2.14, 2.15 and 2.16). Beans had slightly higher concentrations of N than the weeds. This indicates that beans had the ability to fix their own N (Table 2.7) or they were more efficient in utilizing N from soil organic matter (Tables 2.2 and 2.3) than the weeds. Our finding disagrees with the finding of Qasem (1992) who noted higher concentrations of N in a number of weeds including black nightshade when in competition with beans.

In all treatments where K was included, Mg concentration of beans was low under all bean-weed treatments (Figure 2.16). Murphy (1983) noted that added K decreased the uptake of Mg and Ca by barley and corn plants. From our results, it would be seen that beans were also poor accumulators of Mg when grown with nightshade in the absence of K. Beans grown with galinsoga in the absence of added nutrients (OOO) were also poorer accumulators of Mg than beans grown with nightshade.

This indicates that galinsoga may be more efficient in the uptake of Mg in the absence of added nutrients than nightshade when in competition with beans.

Beans were poor competitors for K and responded greatly to added K especially in the presence of galinsoga. This indicates that galinsoga became less competitive with beans when K was added. The addition of K also increased the competitive ability of nightshade against beans. This was indicated by the more marked height reduction, and canopy cover and LAI reduction of beans under the NPK treatment in the presence of nightshade than when grown with galinsoga (Figures 2.5, 2.9 and 2.14).

Weeds had nearly twice the concentration of K compared to beans in the absence of added K (Tables 2.14 and 2.15). This indicates that weeds are more efficient in the uptake of K than beans under limited supply of K. Nightshade was a better K accumulator than galinsoga when grown with beans (Figure 2.17). Our finding confirms the work of Qasem (1992) who noted that black nightshade accumulated more K than beans when supplied with full nutrients (N, P and K).

In Uganda in both seasons, averaged across nutrients, bidens was a better accumulator of N than galinsoga when grown with beans (Tables 2.15 and 2.16) indicating its ability to deplete soil of N better than galinsoga. Similarly, bidens was a better Ca and Mg accumulator than galinsoga when grown with beans (Figures 2.22 and 2.23). The better accumulation of nutrients by beans and weeds when grown together has implication for weed management in Uganda. The presence of weeds is likely to cause faster depletion of soil nutrients resulting in further reduction in bean yield (Di Tomaso, 1995). This was more pronounced in

the presence of N and P due to the better growth of the weeds. The situation is made worse by the fact that weeds are usually removed from the fields where crops are growing and are either burnt or placed in areas not likely to be used for cultivation. Similarly, beans are harvested by uprooting the whole plant and threshed at home and the residues are never returned to the fields from which they were removed. This further aggravates soil fertility problems under farmers' management conditions.

Due to the limited use of inorganic and organic fertilizers by farmers in Uganda, galinsoga, bidens and nightshade would be good sources of nutrients in perennial crops (coffee and bananas) when used as green manure. Therefore, proper management of these weeds for the supply of nutrients as green manure deserves further attention.

Effect of nutrients and weeds on bean growth and yield

Bean cultivars RAO 55 and BAT 25 displayed good bean growth characteristics (high canopy cover, PAR absorption, shoot dry weight) (Table 2.6) and produced more yield per unit area in 1995 (Table 2.20). In the absence of both P and K (NOO), BAT 25 produced significantly more pods m^{-2} while in the presence of K only (NPO), RAO 55 produced more pods and yield per unit area (Figures 2.24 and 2.25). This indicates that BAT 25 may be more adapted to both low P and K while RAO 55 is more adapted to low K. Work in Uganda indicated that BAT 25 was adapted to low N and P (Wortmann et al., 1995). Wortmann et al. (1995) also noted that RAO 55 was better adapted to low P and K in Uganda although it was not superior to K 131 under low P. This indicates that K 131 may be as efficient as RAO 55 in the use of P under stressful conditions of P. It also indicates that K 131 may be very efficient in the

use of N and K. Bean cultivar RAO 55 also had significantly higher seed yield than K 131 and BAT 25 in the absence of added nutrients (OOO) (Figure 2.24). This indicates that RAO 55 may be more adapted to low levels of all three nutrients together compared to the other two bean cultivars. Wortmann and coworkers (1995) concluded that RAO 55 was generally more adapted to multiple nutrient stresses compared to K 131, similar to our finding of cultivar performance in the absence of added nutrients (Figure 2.24).

Although cultivars BAT 25 and RAO 55 exhibited good performance for most growth parameters and yield, K 131 which is an indeterminate bush bean of type IIb growth habit was late maturing (Table 2.6) and had better survival to maturity (Table 2.20). These characteristics could provide K 131 with greater weed tolerance ability than the early maturing determinate bush of type I growth habit (RAO 55 and Bat 25). McWhorter and Hartwig (1972) and Callaway (1993) noted that late maturing cultivars of soybeans and dry beans, respectively, were more competitive against weeds than the early maturing cultivars. This was because early determinate cultivars ceased vegetative growth at flowering when weeds were still actively growing. A similar report was given by Malik et al. (1993) who noted that late bean varieties were more adapted to competition against weeds than early maturing bean cultivars. Bean cultivar K 131 also exhibited higher yield stability across environments than both BAT 25 and RAO 55 (Personal communication with the National Beans Program breeder in Uganda) leading to its selection for further bean-weed experimentation in 1996 and 1997.

It has been reported that bean seed yield reduction due to bidens was in part due to shading of beans by bidens (Carvalho, 1980, 1981). It is likely that the height advantage was in favor of bidens and galinsoga under the NPK and NPO treatments. Although beans were taller than the weeds under the two nutrients in the 1997B season (Figures 2.3 and 2.4), beyond 42 DAP or so the beans were more prostrate than erect. Therefore, the weeds overshadowed the beans possibly reducing light available to the beans in the NPK and NPO treatments contributing to reduced photosynthesis and seed yield in beans. Height advantage could have favored beans in the other treatments. Although the weeds were taller than the beans in the 1997A season, the difference in height and the vigor of the weeds and beans were too small to cause any significant effect on bean light absorption by shading.

The better performance of beans under the NPK, OPK, NOK and OOK treatments was a result of high canopy development and LAI (Tables 2.6, 2.8 and 2.12). This resulted in high absorption of PAR (Table 2.6), relatively high root dry weights to absorb high amount of nutrients (Table 2.10), and therefore, high shoot dry weights (Figures 2.10 and 2.11). This led to high bean seed harvest index and pods per unit area and eventually seed yield per unit area (Tables 2.20, 2.21, 2.22 and 2.24). It will be noted that the treatments that resulted in high bean seed yield all had K nutrient added. These treatments with K included also had relatively high organic matter (Table 2.2) which could have provided beans with the needed nutrients. This also indicates the importance of K in the nutrition of beans a finding similar to that of Evanylo and Zehnder (1989), and Murphy (1983) who noted that adequate K level increased

yield of barley, corn and Kentucky blue grass. Similarly, Thomas and Hungria (1988) observed that addition of K to beans in the presence of N stimulated the transport of nitrogenous compounds to the developing fruits. This induced greater partitioning of above ground N to the seeds thereby increasing bean seed yield. This indicates that there is more efficient use of N in the presence of K resulting in positive interaction between K and N for seed yield improvement.

Using the staining method for mycorrhiza infection detection (Koske and Gemma, 1989), we noted that there was a higher incidence of mycorrhiza infection under the NOK and OOK than the other nutrients at Freeville Farm in 1996. We also noted that bean cultivars under the OPK and OOK treatments had large nodules which were pink inside indicating they were effective (Table 2.7). Also due to the absence of added N, there could have been no inhibition of nodulation under the OPK and OOK treatments. Mycorrhizae could have provided the needed P while nodulation provided N to the beans both resulting in increased yield of beans (Tables 2.20, 2.21, 2.22 and 2.24). El-Ghandour et al. (1996) noted that faba bean dry matter yield and uptake of P, N and iron (Fe) significantly increased with mycorrhizal infection resulting in more faba bean yield. Similarly, Vejsadova et al. (1990) observed that mycorrhizae were more extensively developed in plant roots growing at deficient P concentrations (0.46 - 4.6 ppm) and at high N levels (8.8 - 17.6 ppm) which seems to explain why there was significantly high yield in all seasons in the absence of P (NOK). They also noted that in the presence of low P and N levels, mycorrhizae stimulated total N_2 fixation resulting in better growth of mycorrhizae and nodulating plants. This could explain

the better bean growth and yield observed in the OOK treatment in 1995 and 1996 (Tables 2.20 and 2.21). The weeds were also less active in the absence of P and N (NOK and OPK) which could have resulted in less competition with beans under these treatments.

The relatively late flowering and maturity in beans in the absence of P (NOK) (Tables 2.6 and 2.13) could have provided beans ample time to accumulate shoot dry matter, and to pass the highly competitive weed stage while still in the vegetative stage with later yield compensation. This seems to have resulted in increased yield of beans in the absence of P (NOK treatment) (Tables 2.22 and 2.24). The plants were also smaller compared to those in the NPK and OPK plots allowing plenty of air circulation possibly reducing white mold attack on the NOK and the other treatments (Table 2.7).

The absence of K (NPO) resulted in reduced yield of beans (Tables 2.20, 2.21, 2.22 and 2.24). Apart from the low yield due to lack of K, bean yield was further reduced due to the presence of weeds. The weeds were very vigorous in the presence of N and P and put on more shoot dry matter (Figure 2.10) increasing competition to beans resulting in low bean yields. This indicates the affinity these weeds have for N and P for their growth. Our finding confirms the finding of Sindel and Michael (1992) who noted that raising soil fertility through application of N and P increased growth of *Senecio madagascariensis* in a pasture with no potential benefit from K. The N and P fertilization increased the competitive ability of *S. madagascariensis* against other grasses. Similarly, Everaarts (1992) noted that N and P fertilizers stimulated the growth of weeds in a weed flora. Vanegas (1986) had earlier noted that

application of P in combination with N caused an increase in weed dry weights in unweeded bean crop. All these indicate that application of NPK and NPO nutrients may improve the competitive ability of the weeds more than improving the competitive ability of the beans especially when the nutrients are broadcast-applied.

The presence of weeds decreased bean shoot dry weight (Figure 2.11), LAI (Table 2.12) and pods per unit area in all seasons (Tables 2.22, 2.23 and 2.24). The effects on these growth parameters eventually determined seed yield per unit area. This is in accordance with Chikoye et al. (1995) finding that white bean LAI, above ground biomass and pods m^{-2} were negatively affected by ragweed interference. Similarly, Wortmann (1993) observed that bean LAI and leaf area accounted for 73% of the variations among bean genotypes for weed biomass suppression. Our finding also confirms the work of Evanylo and Zehnder (1989) who noted that low dry matter production in snap beans due to competition with common ragweed reduced snap bean yield by 75% in full season competition.

Weeds also significantly reduced bean seed yield in all seasons and across locations (Tables 2.22, 2.23 and 2.24). Galinsoga competition with beans resulted in 33 - 42% and bidens in 46 - 50% and nightshade in 29% reduction in bean yields. Other researchers have reported bean yield reductions of 13% (Blackshaw, 1991) and 10 - 22% (Chikoye et al., 1995) when 2 hairy nightshade and 1.5 ragweed per m row of bean, respectively, were used. Similarly, Fennimore et al. (1984) reported a 30 - 40% yield reduction in beans when in competition with black nightshade. Carvalho (1981) reported bean yield reduction of 33% when

bidens population of 222 plants per m^2 were in competition with beans. Although galinsoga in 1996 reduced bean seed more than nightshade, on the per weed dry matter basis, nightshade may be more competitive than galinsoga noting that nightshade was removed from the beans at 56 DAP. A relatively small nightshade dry matter per unit area compared to galinsoga resulted in a relatively large reduction in bean seed yield.

Therefore, relatively high bean shoot growth is required for better assimilate production to support the pods and seed yield per unit area. Any factor that increased bean shoot growth-related parameters resulted in increased bean seed yield per unit area. In all cases, the extent of weed effects on bean growth parameters, seed yield and yield components depended on the nutrients applied as well as weed dry matter yield.

CONCLUSION

Due to drought and the slightly high soil nutrient contents of the fields used in Uganda, the response to applied nutrients was very poor. In general, the following can be concluded from this research work:

• Bean cultivar RAO 55 is more adapted to a wide range of soil environments or multiple nutrient deficiencies. Bean cultivars BAT 25 and K 131 seem to be better adapted to low P and K, and N and K, respectively. Bean cultivar K 131 may also be more adapted to competition with weeds than RAO 55 and BAT 25 due to its late maturity and the type IIb growth habit.

• Beans competed very well for N with weeds with no significant effect of weeds on bean chlorophyll contents. Similarly, beans were more efficient in N accumulation than all the weeds, with no significant differences in bean shoot N concentration across nutrients and bean-weed

treatments in all seasons. Beans competed less for K in the presence of galinsoga than in the presence of nightshade and bidens but responded to added K.

• Nightshade was a better K accumulator and in the presence of K was more competitive with beans than galinsoga. Nightshade either grown with beans or as sole weed was more efficient in N acquisition than galinsoga.

• Bidens was a poorer competitor for N with beans than galinsoga and responded greatly to added N. Bidens was a better Mg accumulator than galinsoga when either grown with beans or as sole weed. Due to their high dry matter production compared to galinsoga in Uganda, bidens had higher contents of Ca per unit area than galinsoga.

• Galinsoga was a better accumulator of P, Ca and Mg when grown with beans than nightshade. Galinsoga was also a better Ca accumulator when grown together with beans in the absence of N than bidens.

• Since the combination of beans and weeds together overexploit the soil of nutrients, proper management of the weeds is important. The use of these weeds as green manure crops and crop residues as mulch should be encouraged in order to improve the nutrient status of the soils. Bidens, galinsoga and nightshade have all been shown to be good accumulators of various nutrients when in competition with beans or as sole weeds. They may be important in the supply of nutrients to poor soils under the Uganda conditions. Proper management of these weeds for the supply of nutrients needs further investigation.

• Broadcast application of N and P nutrients (NPK and NPO) without weed control is more likely to improve the competitive ability of weeds than beans, resulting in reduced bean yields.

• There is high possibility of improving the competitive ability of beans through the use of mycorrhizae in the absence of P (NOK) and using highly nodulating bean cultivars in the absence of N (OPK). Nutrient efficient cultivars would be good candidates. The use of K alone when banded in bean production using high nodulating cultivars combined with mycorrhizae is more likely to improve the competitive ability of beans over the weeds. Further research work needs to be done to test this suggestion.

• Galinsoga weed reduced bean yield by 33 - 42%, bidens by 46 - 50% and black nightshade by 29%. Although galinsoga reduced bean yield by higher percentage than nightshade, on per unit dry weight basis nightshade may be more competitive than galinsoga. A relatively small amount of nightshade dry weight resulted in the same amount of yield reduction caused by large amount of galinsoga dry matter.

CHAPTER THREE

PLANT GROWTH ANALYSIS IN THE SCREENHOUSE

INTRODUCTION

Competitive interactions between weeds and crops not only depend on population densities of the two crops and their arrangements but also on the intrinsic properties of the competing species. Growth characteristics are particularly important when plants are harvested before the reproductive stage. These characteristics are environmentally and genetically controlled and are a measure of the ability of a plant to harness resources and compete when grown with other plants. Therefore, there is need to examine crop and weed development under different conditions to establish differences in plant growth that may determine competition in the field. It is also important that the plant root system and its functions be fully understood before competition between plants can be fully evaluated. An effective weed management program should, therefore, consider crop-weed relationships and other growth attributes of the plants. We hope this study will give us an understanding of the growth strategies of dry beans (*Phaseolus vulgaris* L.), bidens or blackjack or beggarticks (*Bidens pilosa* L.) and galinsoga or gallant soldier (*Galinsoga parviflora* Cav.) in order to facilitate effective field management.

LITERATURE REVIEW

Plant growth and development

Galinsoga sp. is an annual weed in the Compositae family and occurs in open habitats. It is an important early colonizer of disturbed

areas such as cultivated fields, watersheds and roadsides (Rai and Tripathi, 1984). It occurs in agricultural lands throughout East Africa in all types of crops (Ivens, 1971; Terry and Michieka, 1987). The characteristics that make galinsoga an important weed are its vigorous growth, its prolific seed production and ability to germinate immediately (Ivens, 1971; Ivany and Sweet, 1973; Majek and Johnston, 1986). These factors enable it to be a serious weed especially in annual crops and therefore, present a major drawback in the production of crops such as beans.

Germination and survival of *G. parviflora* and *G. ciliata* have been observed to be adversely reduced by low light intensity with reduced leaf area ratio (Ivany and Sweet, 1973; Rai and Tripathi, 1986, 1987). Water stress also reduced the rate as well as total germination of *G. parviflora* and *G. ciliata* (Rai and Tripathi, 1983). The authors also noted in a greenhouse experiment that *G. parviflora* and *G. ciliata* showed enhanced germination with increased proportion of sand in the soil, with significantly greater seed production. They noted that the weeds when grown under good moisture condition, matured early.

Bidens sp. (blackjack or beggarticks or spanish needle) is in the Compositae (Asteraceae) family. It is a cosmopolitan weed of warmer areas and is of wide importance in all crops in East Africa and often associated with poor or exhausted soils (Ivens, 1971; Terry and Michieka, 1987). Reddy and Singh (1992) in a greenhouse experiment noted that hairy beggarticks (*B. pilosa*) had optimum temperature range for germination of 25/20° to 35/30° (day/night) under a 12/12 hour day/night with reduced germination below 15/10 °C or above 45/50 °C (day/night).

In Zimbabwe under greenhouse condition, Chivinge (1996) found that *B. pilosa* had optimum germination at 25 °C (range of 20° to 30 °C). Chivinge (1996) also noted that bidens germination was high under good moisture condition and soaking the seeds in water improved germination. Flooding, on the other hand even for a day reduced seedling emergence to 25% with further decrease in seedling emergence with days of flooding (Reddy and Singh, 1992). Bidens germinated more at depth less than 4 cm with more germination at soil surface (Reddy and Singh, 1992; Chivinge, 1996). Germination decreased with soil depth indicating the need for light and aeration for the seeds to emerge from the soil. Bidens also germinated at a range of pH (4 to 9) in a buffer solution indicating its wide adaptation to environment (Reddy and Singh, 1992). They concluded that well drained sandy soils with abundant moisture are particularly ideal for bidens germination and establishment.

It has generally been noted that the seed size difference between the crops and weeds give the crops a head start advantage over the weeds early in the season (Mohler, 1996). Therefore, the larger seeded crop plants initially have higher absolute growth rates (measured in units of grams per day). But Mohler (1996) noted that despite the large initial difference in the size of these plants, many weeds end up growing to larger sizes than crops over the course of the growing season. This has been attributed to the higher relative growth rates of the weeds and their slow growth rate decline with time compared to the large seeded crops (Grime and Hunt, 1975; Seibert and Peace, 1993). Chivinge and Schweppenhauser (1995) reported higher relative growth rate (RGR) in

pigweed (*Amaranthus hydridus* L.) and bidens (*Bidens pilosa* L.) growing together with soybeans.

Fennimore et al. (1984) noted that barnyard grass (*Echinochloa crus-gallis*) and black nightshade (*Solanum nigrum*) registered higher RGR than beans. They noted that the advantage imparted by larger seed size and early germination to the beans appeared to have been lost by their slower RGR. Chapin et al. (1989) explained that large seeded species tend to have a lower RGR because their seedlings are large. According to them, large plants have a greater proportion of non-photosynthetic structural materials, higher maintenance respiration, and more selfshading. For this reason, RGR tends to decline as a plant increases in size and since large seeded species begin larger, their RGR declines more rapidly (Grime and Hunt, 1975).

Nutrient effect on root distribution and root/shoot ratios

Greenwood et al. (1982) and Gregory (1988) reported that plant root density follows a similar trend to nutrient availability in the soil with rooting density decreasing with soil depth. Usually below 10-15 cm soil depth, root length per unit volume of soil decreases rapidly. Variation in nutrient and water supplies can substantially change this general pattern as well as the uptake of nutrients. Hoogenboom et al. (1988) noted that root length of bean variety "Porrillo sintetico" gradually decreased with soil depth under good moisture condition.

When the supply of mineral nutrients to plants is insufficient, Marschner (1986) noted that the roots become the more dominant sink for photosynthates and root growth is enhanced compared to shoot growth. Similarly, increasing N supply leads to increased shoot growth

than root growth which ultimately shifts the root/shoot ratio (Brouwer, 1962b). Cakmak et al. (1994) found out that K and Mg deficiency reduced root growth of beans (french beans) grown in nutrient solution for a period of 12 days. This increased shoot/root ratio while the ratio declined under P deficiency indicating the importance of P in root development. Brouwer (1962b) noted a similar finding where suboptimal supply of N led to reduced shoot growth compared to root growth increasing the root/shoot ratio. A large root system, according to Greenwood (1983) with fast rate of root replacement ensuring a high proportion of young roots could be of advantage where there is low supply of nutrients and water. Where there is good supply of water and nutrients, a plant may need only 10 - 20% of the root system to supply the required water and nutrients for the entire plant. In general, low nutrients result in relatively more root growth compared to shoot growth in order to increase uptake of water and nutrients resulting in increased root/shoot ratio.

Shading of plants can also cause a significant shift in root/shoot ratio. In one experiment, the transfer of barley plants from high light intensity to low light intensity reduced the supply of photosynthates to the roots resulting in reduced root/shoot ratio (Brouwer, 1962a; Minchin et al., 1994). The reduced photosynthesis resulted in an increase in growth of the shoots relative to the roots decreasing the root/shoot ratio. Low temperature on the other hand benefits the roots resulting in decrease in root/shoot ratio with increasing temperature (Brouwer, 1962a).

Water has also been noted as an important parameter in the distribution of root systems in the soil. Creelman et al., (1989) working with soybean noted that soybean roots continued to elongate when subjected to low water potential while shoot growth was inhibited leading to increased root/shoot ratio. Similar result was reported by Brouwer (1962a) where increased water supply promoted shoot growth of barley and maize at the expense of the roots resulting in reduced root/shoot ratio. This could have been attributed to the lowering of oxygen supply to the roots, therefore, reducing root growth among other factors.

Since many theories assume the uptake of water and nutrients from the soil to be a function of root length and other attributes of the roots, considerable effort is extended to determine plant root lengths and their distributions in the soil. Although there has been indication that bidens and galinsoga are shallow-rooted plants, there has been very little work carried out to determine root growth of these weeds under varied nutrients. Also the rates of weed root and shoot development either in the field or in the greenhouse as compared to beans have been less studied.

In order to evaluate the importance of the growth characteristics that may determine competition in the long run, we conducted screenhouse experiment. The objective was to determine the effects of NPK, NPO and NOK nutrients on beans, bidens and galinsoga growth characteristics and root morphologies. The 1996 results indicated that much weed growth was under the NPO and NPK treatments resulting in a lot of competition to beans and the least growth was under the NOK treatment. Therefore, it was necessary to find out what factors encouraged weed growth under the NPO and NPK treatments and why

growth was reduced under the NOK treatment. It was also necessary to find out why beans performed well when grown with weeds in the absence of P. This could lead to better manipulation of these nutrients for the management of these weeds in bean-weed association.

MATERIALS AND METHODS

Beans, bidens and galinsoga were grown in the screenhouse in black polyethylene tubes measuring 25 cm in diameter and 60 cm tall. Soil was filled up to 55 cm length of the tube. The soil used for the experiment was the red ferrallitic sandy clay soil (Harrop, 1970; FAO, 1993) and mixed with lake sand in the ratio of 1:3 (lake sand:soil) before use.

The screenhouse was covered with white plastic mesh that reduced light by 20 – 30% of the outside. Temperature in the screenhouse was higher compared to outside temperature. Temperatures inside the screenhouse ranged from 31.6 - 39 °C / 16.2 – 20 °C for day and night temperatures, respectively, and temperatures outside the screenhouse ranged from 24.2 – 29.15 °C / 14.6 – 15.6 °C for day and night temperatures, respectively, during the experiment runs.

Soil samples for laboratory analysis were taken from the field where soils were later collected for screenhouse experiment. Sampling was done by taking representative soil samples from 4 sites at depth of 20 cm. This depth was chosen based on the fact that the average plow layer is about 15 - 20 cm (Personal communication with soil scientists at Kawanda Agricultural Research Institute soil laboratory). The soil samples were air-dried and later analyzed for physical and chemical properties. Texture was determined by the hydrometer method (Gee and

Bauder, 1986), and exchangeable bases and P were extracted with excess of ammonium lactate solution at pH 3.8 (Foster, 1971). The exchangeable K^+ cation was determined by flame emission while calcium (Ca^{2+}) and magnesium (Mg^{2+}) were determined by Atomic Absorption Spectrophotometry (AAS). Total nitrogen (N) was determined by Micro-Kjeldahl technique. Organic carbon was determined by Walkley and Black (1934) method with chromic acid titration method with the value obtained multiplied by 1.729 to give percentage organic matter (OM). Soil pH was measured in a 1:2.5 soil:water ratio using a pH electrode (Okalebo et al., 1993). On average, the soil used had the following composition: sand 50 -56%, clay 37 - 46%, silt 4 - 7%, pH 5.1 - 5.2, OM 2.81 - 3.12%, available P 4.2 ppm, N 0.15%, K 30 - 70 mg kg^{-1} of soil, Ca 560 - 730 mg kg^{-1} of soil and Mg 144 - 192 mg kg^{-1} of soil.

In order to calculate the amount of nutrients to use in the polythene tubes, we based our calculation on soil surface area of the tube in relation to the rate applied in the field. The nutrient treatments were NPK, NPO and NOK (where N was applied as ammonium nitrate at the rate of 50 kg N ha^{-1}, P applied as triple superphosphate at the rate of 50 kg P ha^{-1} and K as muriate of potash at the rate of 60 kg K ha^{-1}). These were thoroughly mixed in the top 15 -20 cm soil depth in the polythene tubes. The treatments were combined in a 3 x 3 factorial (3 plant species and 3 nutrient combinations) replicated 3 times.

The plants were planted on 1 July, 23 August, and 10 November, 1997 at high density for the first, second and third run of the experiment, respectively. The plants were planted as monoculture plants with each tube containing only one species of the plant. They were thinned to a

population of 2, 5 and 8 beans, bidens and galinsoga plants per tube, respectively. Records were taken on the plants at 21, 35 and 49 days after planting (DAP). Records taken included plant height, plant shoot and root dry weight and root length. From these records we calculated crop growth rate (CGR or CR), relative growth rate (RGR) and specific root length. The results reported here are averages for the three plantings. The average temperatures in the screenhouse were 39/20°, 33.9/17.8° and 31.6/16.2 °C for day and night temperatures, respectively, for the 3 runs of the experiment.

In the screenhouse, the tubes were arranged on a wooden bench 0.75 m above the screenhouse floor. For each run of the experiment, a complete set of the treatments had 27 tubes (one replicate) randomly placed on the bench so that 9 tubes (each of the 3 plants grown under the NPK, NPO and NOK treatments) on each sampling date were destructively sampled and this was carried out at 21, 35 and 49 DAP. This was repeated in the second and third replicates. At planting, there was a fourth replicate or set of 27 tubes planted to the three plants under the three nutrients for replacement of any of the tubes in the three replicates in case any were destroyed by some factors during each sampling date. The tubes at planting were placed 10 cm apart. After first harvesting (21 DAP), the tubes were rearranged to 20 cm apart. After the second sampling, the tubes were separated by 50cm spacing. The tubes were shifted every one and half weeks to reduce edge or border effects.

Plant height was measured at 21, 35 and 49 DAP by using a meter ruler to measure the heights from soil surface to the tip of the growing point of each plant. The average was recorded per species per tube.

Measurements were taken on all the plants in each polythene tube before recording the average. Shoot dry matter determinations were also made at the time of plant height measurements. All plants were harvested by cutting at soil level from each tube and placed in marked paper bags for drying in the oven. The dry weights in grams per tube were recorded after 72 hours of drying at 70 °C.

In order to determine root dry weight with soil depth increase, the polythene tubes where the plants were growing were carefully cut into several horizontal layers of 10 cm each starting at soil level. The roots within each 10 cm cutting were carefully removed and washed in a large basin while placed on a thin 1-mm wiremesh container so that losses of small roots could be reduced. The same applied to the other sections of the cuttings till no roots were visible. These were then placed in separate labeled paper bags and dried in the oven for 72 hours at 70° C and dry weights were recorded.

Root length determinations in the screenhouse were made at 21, 35 and 49 DAP using the line intercept method based on Newman (1966) and Tennant (1975) methods as described in Tropical Soil Biology and Fertility: A Handbook of Methods (1993). Root lengths were estimated by counting the number of intersections between roots and sample lines. Roots were carefully removed from the polyethylene tubes and washed clean. Rotten roots and organic matter were removed from the samples. Clean roots were spread out with random orientation in a thin layer of water on a glass plate measuring 30 cm x 30 cm. Water was removed and a grid made from hard squared transparent (grid photocopied on transparencies from squared paper) was placed underneath the glass plate

on top of which the sample was placed. The grid size was 15 mm. Line by line all intersections of roots and grid lines were counted and added for both horizontal and vertical grid lines. Results for horizontal (H) and vertical (V) grid lines were added to form the number N. If the grid size was D (mm), root length, L (mm) was derived as:

$$L = \pi N D / 4$$

In order to count as many as possible of the smaller roots, a magnifying lens was used. The technique is time-consuming and destructive to soils and above ground crop. Use of other better automated methods which are non- destructive have been developed and proposed for use in Tropical Soil Biology and Fertility: A Handbook of methods (1993) such as the rhizoton method. The automated methods are quite expensive and not readily available.

From the dry weight measurements, calculations were carried out for crop growth rates (CGR or GR) and relative growth rates (RGR). Crop growth rate is the increase in plant material per unit time and was calculated using the formula (Radford, 1967):

$$\text{CGR or GR} = dw/dt$$

or

$$\text{CGR or GR} = \frac{w_2 - w_1}{t_2 - t_1}$$

where w_1 is the measure of plant material present (dry weight) at time period one (t_1) and w_2 is the measure of plant material present at time period two (t_2).

Relative growth rate is an increase of plant material per unit of plant material present per unit time and was calculated by (Radford, 1967):

$$RGR = \frac{\ln w_2 - \ln w_2}{t_2 - t_1}$$

where $\ln w_1$ and $\ln w_2$ are natural logs of the dry weights of plant materials at times t_1 and t_2, respectively.

The variables or data were subjected to analysis of variance (ANOVA) procedures after diagnosis for normality, constant error variance and zero error mean. The data which deviated from normality were transformed by either log or square root transformation. Means of the variables under the different treatments were seperated by the multiple mean comparison method of protected least significant difference (LSD) at 5% level of significance.

RESULTS

Beans on average germinated four days after planting. Bidens germinated on the same day as beans under the NPK and NPO treatments and a day after bean under the NOK treatment. Galinsoga emerged a day after beans under the NPK and NPO treatments and was delayed up to 2 days after beans emerged under the NOK treatment. All plants were

vigorous in the NPK and NPO treatments compared to the NOK treatment.

Plant height

At all the record dates and under all the nutrients, beans were significantly taller than the weeds and the weeds were significantly different from one another except at 35 DAP (Table 3.1). Better plant growth in terms of plant height was realized under the NPK and NPO treatments as compared to the NOK treatment (Table 3.1).

Shoot dry weight, growth rate (GR) and relative growth rate (RGR)

Shoot dry weight (gram/tube or gram/0.05 m^2) had a similar trend as plant height (Table 3.1). There was significantly more dry weight under the NPK and NPO treatments which were not significantly different from one another. Beans had significantly more shoot dry weight per tube than the weeds at all sampling dates. Bidens had significantly more shoot dry weight than galinsoga at 21 DAP with no significant differences between the weeds at 35 and 49 DAP (Table 3.1). Generally, plant shoot dry weight increased with time although at a decreasing rate for beans and at an increasing rate for the weeds.

There was significant nutrient by plant type treatment interaction for shoot dry weight at 21 DAP ($p = 0.0002$) (Figure 3.1). Under the NPK and NOK treatments, the plants were significantly different from one another with galinsoga having the lowest shoot dry weight. Under both these treatments, beans were significantly different from bidens and galinsoga ($p = 0.0001$ in either case), and bidens significantly different from galinsoga ($p = 0.0206$ and 0.0312, respectively). In the NPO

Table 3.1 The effect of nutrients on bean, galinsoga and bidens heights (cm) and shoot dry weights (g per tube) in the screenhouse

Treatment	Plant height (cm)			Shoot dry weight (g tube^{-1})		
	21 DAP	35 DAP	49 DAP	21 DAP	35 DAP	49 DAP
Nutrient treatment						
NPK	14.38 b	43.05 b	65.31 b	0.63 b	3.44 b	8.96 b
NPO (minus K)	14.70 b	44.67 b	62.37 b	0.63 b	3.69 b	9.26 b
NOK (minus P)	9.06 a	27.16 a	49.77 a	0.23 a	1.26 a	4.12 a
Plant type treatment						
Beans	24.49 c	103.04 b	109.14 c	1.68 c	7.15 b	12.80 b
B. pilosa	10.38 b	22.59 a	38.19 a	0.19 b	1.40 a	5.37 a
G. parviflora	7.55 a	22.39 a	45.50 b	0.11 a	1.09 a	4.71 a
Statistical significance[a]						
Nutrient treatment	****	****	***	****	****	****
Plant type treatment	****	****	****	****	****	****
Nutrient x plant type	ns	ns	ns	***	ns	ns
Coefficient of variation	4.23	4.10	3.54	9.07	14.60	14.27

Means in each column followed by the same letter for each treatment set are not significantly different at 5% alpha level using LSD, Plant height was log transformed and shoot dry weight was square root transformed and the back transformed means are reported,

[a] ***, **** or ns mean statistically significant at $p \leq 0.001$, 0.0001 or not significant, respectively.

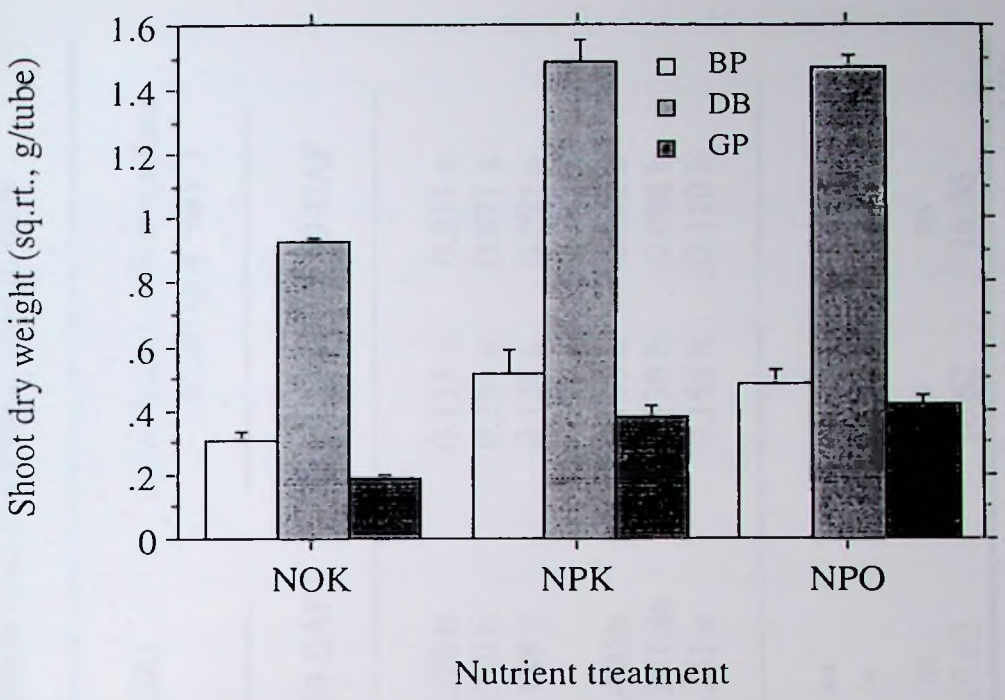


Figure 3.1 Nutrient by plant type treatment interaction effect on shoot dry weight (square root transformed, g/tube), 21 DAP where BP = *B. pilosa*, DB = dry beans and GP = *G. parviflora* (error bars are indicated on the graph)

treatment, beans were significantly different from bidens and galinsoga ($p = 0.0001$ in either case) with no significant difference between bidens and galinsoga (Figure 3.1).

Biweekly analysis of growth of young plants between 0 - 21, 21 - 35 and 35 - 49 DAP indicates that there was no significant difference between the plant growth rates under the NPK and NPO treatments at all record dates (Table 3.2). Plants under the NPK and NPO treatments had

Table 3.2 The effect of nutrients on bean and weed shoot growth rates and relative growth rates

Treatment	Shoot Growth Rate (GR) ($g\ day^{-1}$)			Shoot Relative Growth Rate (RGR) ($g\ g^{-1}\ day^{-1}$)	
	0-21 DAP	21-35 DAP	35-49 DAP	21-35 DAP	35-49 DAP
Nutrient treatment					
NPK	0.0303 b	0.197 b	0.376 b	0.133 a	0.074 a
NPO (minus K)	0.0299 b	0.215 b	0.380 b	0.134 a	0.071 a
NOK (minus P)	0.0082 a	0.073 a	0.188 a	0.128 a	0.095 a
Plant type treatment					
Beans	0.0053 c	0.387 b	0.400 b	0.103 a	0.042 a
B. pilosa	0.0092 b	0.086 a	0.281 ab	0.139 b	0.096 b
G. parviflora	0.0053 a	0.070 a	0.251 a	0.156 b	0.110 b
Statistical significance[a]					
Nutrient treatment	****	****	**	ns	ns
Plant type treatment	****	****	*	*	****
Nutrient x plant type	***	ns	ns	ns	ns
Coefficient of variation	9.10	18.10	19.62	10.62	16.06

Means in each column followed by the same letter for each treatment set are not significantly different at 5% alpha level using LSD, All the variables were square root transformed and the back transformed means are reported,

[a] *, **, ***, **** or ns mean statistically significant at $p \leq 0.05, 0.01, 0.001, 0.0001$ or not significant, respectively.

significantly higher shoot growth rates than plants under the NOK treatment. Growth rate was drastically reduced at all dates under the NOK treatment.

Between 0 - 21 DAP, all plants had significantly different shoot growth rates with beans significantly higher than bidens and galinsoga, and bidens significantly higher than galinsoga (Table 3.2). Between 21 and 35 DAP, bean had significantly higher shoot growth rate than both weeds. There was no significant difference between the weeds in their growth rates.

Between 35 and 49 DAP, there were no significant differences between bean and bidens shoot growth rates, and bidens and galinsoga shoot growth rates (Table 3.2). Bidens at this stage was producing as much shoot dry weight per day as beans. There was significant difference between bean and galinsoga shoot growth rates.

Shoot relative growth rate (RGR) had the opposite trend to CGR (Table 3.2). Nutrients had no significant effect on RGR. Weeds had significantly more RGR than beans although there was no significant difference between the weeds. Although the amount of dry matter produced by the weeds per day compared to beans was low, the amount of dry matter produced per gram of available dry matter per day was much higher.

Although there was a significant nutrient by plant type interaction for shoot growth rate between 0 - 21 DAP (Table 3.2), the explanation for the interaction is similar to shoot dry weight at 21 DAP (Figure 3.1). This is because, shoot dry weights at 21 DAP were divided by 21 days for all

values therefore, maintaining a constant ratio to shoot dry weights as well as significant interactions.

Root dry weight, growth rate and relative growth rate

Nutrients had significant effect on plant root dry weights (Table 3.3). At 21 DAP, plant root dry weights were significantly different under the different nutrient treatments. At all other measurement dates, there were no significant differences between the NPK and NPO treatments. All were significantly different from the NOK treatment.

At all sampling dates, beans had significantly more root dry weights than the weeds except at 49 DAP where there were no significant differences between beans and bidens (Table 3.3). Plant root dry weights increased progressively with time for all plants. The increase in weed root dry weights was at increasing rate with increase in time. Bean root dry weight increased at a decreasing rate with time. Root dry weight decreased with increasing soil depth but the bulk of the roots were within 0-10 cm soil depth.

Root growth rate was similar to shoot growth rate (Table 3.4). Between 0 - 21 DAP, nutrients significantly affected root growth rate. The highest and the lowest root GRs were observed under the NPK and NOK treatments, respectively. Root growth rates at this time were all significantly different from one another.

Between 21 - 35 DAP and 35 - 49 DAP, there were no significant differences in root GR between the NPK and NPO treatments but both were significantly different from the NOK treatment (Table 3.4).

Weeds on the other hand had significantly lower root GR than beans between 0 - 21 and 21 - 35 DAP (Table 3.4). Between 35 - 49

Table 3.3 The effect of nutrients on bean, bidens and galinsoga total root dry weights (0-20 cm soil depth) in the screenhouse

Treatment	21 DAP	35 DAP	49 DAP
Nutrient treatment			
NPK	0.135 c	0.598 b	1.774 b
NPO (minus K)	0.110 b	0.599 b	1.566 b
NOK (minus P)	0.060 a	0.219 a	0.623 a
Plant type treatment			
Beans	0.326 b	1.016 c	1.452 b
B. pilosa	0.038 a	0.322 b	1.618 b
G. parviflora	0.032 a	0.195 a	0.801 a
Statistical significance[a]			
Nutrient treatment	****	****	**
Plant type treatment	****	****	*
Nutrient x plant type	ns	ns	ns
Coefficient of variation	10.00	18.09	24.35

Means in each column followed by the same latter for each treatment set are not significantly different at 5% level using LSD,
The data were square root transformed and the back transformed means are reported,
[a] *, **, **** or ns mean statistically significant at $p \leq 0.05, 0.01, 0.0001$ or not significant, respectively.

DAP, there was no significant difference between galinsoga and bean root GRs. Bidens had significantly higher root growth rates than beans and galinsoga between 35 and 49 DAP. In all, weed root growth rates increased at increasing rates and bean root growth rates increased at decreasing rates with time. This is the period when bidens is exhibiting high shoot GR as well as shoot RGR and root dry weights.

Nutrient Table 3.4 The effect of nutrients on bean and weed root growth rates and root relative growth rates

Treatment	Root Growth Rate (GR) ($g\ day^{-1}$)			Root Relative Growth Rate (RGR) ($g\ g^{-1}\ day^{-1}$)	
	0-21 DAP	21-35 DAP	35-49 DAP	21-35 DAP	35-49 DAP
Nutrient treatment					
NPK	0.0064 c	0.032 b	0.094 b	0.117 ab	0.077 a
NPO (minus K)	0.0053 b	0.035 b	0.059 b	0.130 b	0.065 a
NOK (minus P)	0.0028 a	0.011 a	0.028 a	0.092 a	0.094 a
Plant type treatment					
Beans	0.0156 b	0.048 b	0.034 a	0.076 a	0.029 a
B. pilosa	0.0018 a	0.020 a	0.091 b	0.146 b	0.111 b
G. parviflora	0.0015 a	0.011 a	0.048 a	0.120 b	0.106 b
Statistical significance[a]					
treatment	****	***	*	*	ns
Plant type treatment	****	****	*	***	**
Nutrient x plant type	ns	ns	ns	ns	ns
Coefficient of variation	10.04	24.36	43.39	12.31	40.07

Means in each column followed by the same letter for each treatment set are not significantly different at 5% alpha level using LSD,
All the variables were square root transformed and the back transformed means are reported,
[a] *, **, ***, **** or ns mean statistically significant at $p \leq 0.05, 0.01, 0.001, 0.0001$ or not significant, respectively.

In terms of the amount of root dry weight per unit dry weight available per day (RGR) at 21 - 35 DAP, roots under the NPO and NPK treatments had significantly higher RGR (Table 3.4). There were significant differences between the NPO and NOK treatments and no significant differences between the NPK and NPO, and the NPK and NOK treatments (Table 3.4). Between 35 and 49 DAP, nutrients had no significant effect on root RGR. Weed roots had a similar response as shoot RGR with weeds exhibiting significantly higher root RGRs than beans with no significant differences between the weeds at both 21 - 35 and 35 - 49 DAP (Table 3.4).

Root/shoot ratio

Nutrients had significant effect on root/shoot ratio only at 21 DAP where minus P (NOK) increased root/shoot ratio significantly compared to the NPO and NPK treatments (Table 3.5). The weeds on the other hand exhibited higher root/shoot ratios than beans (Table 3.5). At 21 DAP, galinsoga had significantly higher root/shoot ratio than both beans and bidens with no significant differences between beans and bidens (Table 3.5). At 35 DAP, both bidens and galinsoga had significantly higher root/shoot ratios than beans. At 49 DAP, only bidens had significantly higher root/shoot ratios than both beans and galinsoga with no significant differences between beans and galinsoga (Table 3.5). The relatively higher root/shoot ratios for the weeds could be an added advantage for the weeds in the field to secure more soil resources than beans under these nutrient conditions.

Table 3.5 The effect of nutrients on bean, bidens and galinsoga root/shoot ratios in the screenhouse

Treatment	21 DAP	35 DAP	49 DAP
Nutrient treatment			
NPK	0.23 a	0.19 a	0.20 a
NPO (minus K)	0.19 a	0.19 a	0.18 a
NOK (minus P)	0.30 b	0.19 a	0.16 a
Plant type treatment			
Beans	0.20 a	0.14 a	0.11 a
B. pilosa	0.20 a	0.22 b	0.29 b
G. parviflora	0.32 b	0.19 b	0.17 a
Statistical significance[a]			
Nutrient treatment	**	ns	ns
Plant type treatment	***	**	***
Nutrient x plant type	ns	ns	ns
Coefficient of variation	10.83	11.17	18.28

Means in each column followed by the same latter for each treatment set are not significantly different at 5% level using LSD,
All variables were square root transformed and the back transformed means are reported,
[a]**, *** or ns mean statistically significant at $p \leq 0.01$, 0.001 or not significant, respectively.

Plant root length and root elongation rate

Plant root length followed a similar trend as root dry matter for both weeds and beans (Figure 3.2). Under all the nutrients, bean root length increased at a decreasing rate with time with eventual leveling-off after just 35 DAP (Figure 3.2). This could have been due to death of some of the roots as well as slow elongation of bean roots at this stage (Table 3.6). Galinsoga had a progressive increase in root length with time under the NOK nutrient but at a decreasing rate of increase after 35 DAP

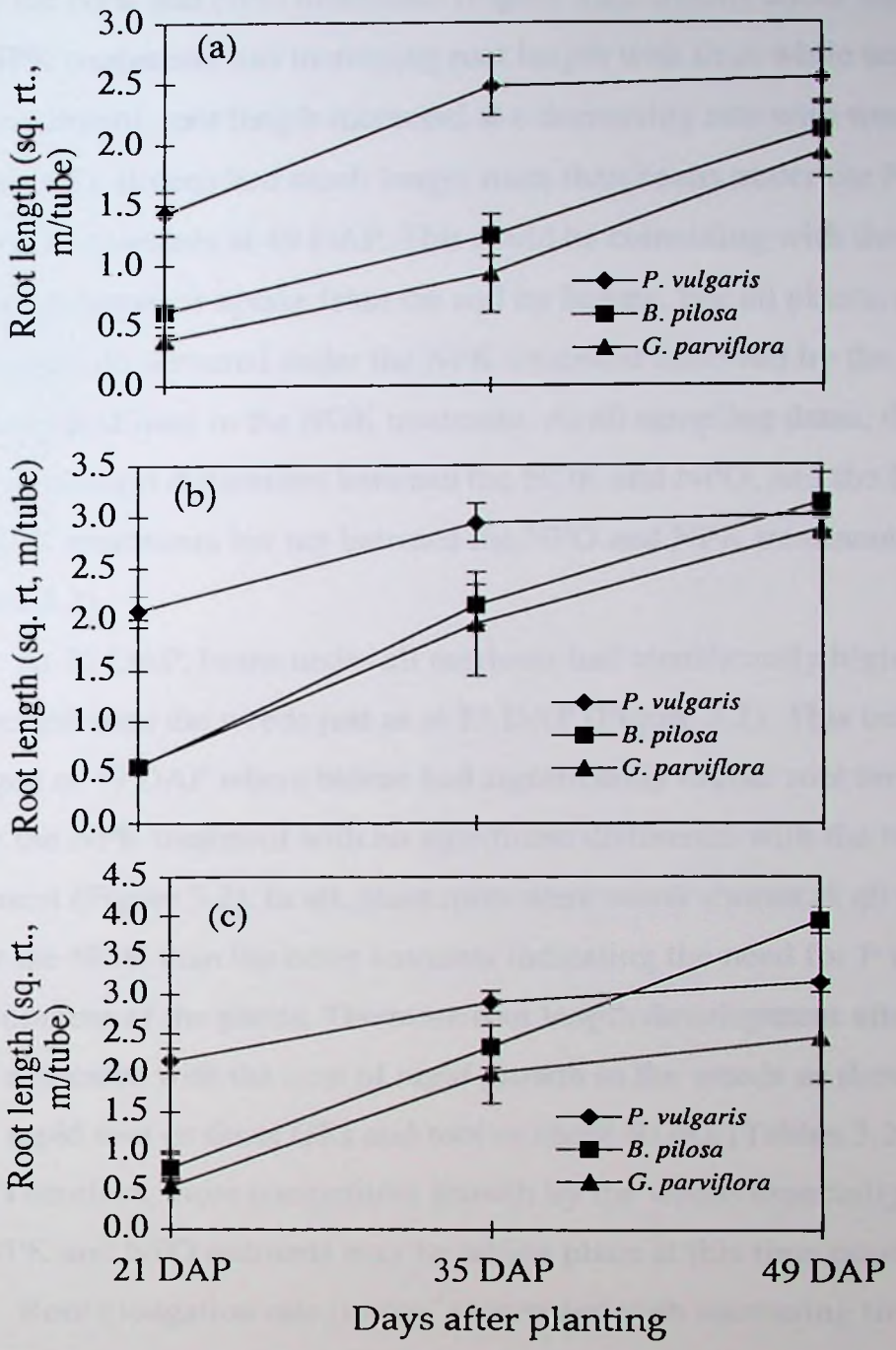


Figure 3.2 The effect of nutrients on plant root lengths (square root transformed, m/tube) where (a) NOK, (b) NPO and (c) NPK nutrient treatments (on the graphs are error bars)

under the NPK and NPO treatments (Figure 3.2). Bidens under the NOK and NPK treatments had increasing root length with time while under the NPO treatment, root length increased at a decreasing rate with time (Figure 3.2). Bidens had much longer roots than beans under the NPK and NPO treatments at 49 DAP. This could be coinciding with the time of maximum resource uptake from the soil by bidens. For all plants, more root extension occurred under the NPK treatment followed by the NPO treatment and least in the NOK treatment. At all sampling dates, there were significant differences between the NOK and NPO, and the NOK and NPK treatments but not between the NPO and NPK treatments (Figure 3.2).

At 35 DAP, beans under all nutrients had significantly higher total root length than the weeds just as at 21 DAP (Figure 3.2). This trend was changed at 49 DAP where bidens had significantly higher root length under the NPK treatment with no significant difference with the NPO treatment (Figure 3.2). In all, plant roots were much shorter at all dates under the NOK than the other nutrients indicating the need for P in root development of the plants. The more root length development after 35 DAP coincides with the time of rapid growth in the weeds as shown by more rapid root or shoot GRs and root or shoot RGRs (Tables 3.2 and 3.4). Therefore, more competitive growth by the weeds especially under the NPK and NPO nutrients may be taking place at this time period.

Root elongation rate (m day^{-1}) increased with increasing time under the different nutrients (Table 3.6). Nutrients had significant effect on root elongation rates with no significant differences between the NPK and NPO nutrients. These were all significantly different from the NOK

Table 3.6 The effect of nutrients on bean, bidens and galinsoga root elongation rates (m day^{-1}) in the screenhouse

Treatment	0-21 DAP	21-35 DAP	35-49 DAP
Nutrient treatment			
NPK	0.065 b	0.278 b	0.312 b
NPO (minus K)	0.054 b	0.278 b	0.331 b
NOK (minus P)	0.031 a	0.120 a	0.194 a
Plant type treatment			
Beans	0.170 b	0.270 a	0.132 a
B. pilosa	0.020 a	0.223 a	0.396 c
G. parviflora	0.012 a	0.167 a	0.283 b
Statistical significance[a]			
Nutrient treatment	**	**	**
Plant type treatment	****	ns	****
Nutrient x plant type	ns	ns	*
Coefficient of variation	17.41	24.68	37.97

Means in each column followed by the same latter for each treatment set are not significantly different at 5% level using LSD,
All variables were square root transformed and the back transformed means are reported,
[a] *, **, **** or ns mean statistically significant at $p \leq 0.05, 0.01, 0.0001$ or not significant, respectively.

treatment at all record dates (Table 3.6). The least elongation rate was observed under the NOK treatment.

Between 0 – 21 DAP, beans had significantly higher root elongation rates than galinsoga and bidens (Table 3.6). There were no significant differences between root elongation rates of the weeds. Beans

had nearly 9 and 14 times elongation rates than bidens and galinsoga, respectively (Table 3.6).

Between 21 - 35 DAP, the weeds had reached similar root elongation rates as the beans, with no significant difference between them (Table 3.6). Between 35 - 49 DAP, weed roots were elongating at much higher rates than beans (Table 3.6). At this stage, galinsoga and bidens were having root elongation rates of 2 and 3 times that of beans, respectively. Bidens root elongation rates were significantly higher than that of galinsoga and beans, and galinsoga significantly higher than that of beans (Table 3.6). Beans between 35-49 DAP compared to 21-35 DAP had drastically reduced root elongation rates by almost half which could be attributed to death of the roots and more increase in size than in length of the roots beyond 35 DAP. The higher root elongation rates exhibited by the weeds could be one of the ways in which the weeds compete for nutrients. It might also help weeds survive under low nutrient situations.

Between 35 and 49 DAP, there was a significant nutrient by plant type treatment interaction for root elongation rate ($p = 0.0183$) (Figure 3.3). Under the NPK treatment, bidens had significantly higher root elongation rates than galinsoga ($p = 0.0035$) and beans ($p = 0.0001$). At the same time, galinsoga had significantly higher root elongation rate than beans ($p = 0.0015$). Under the NPO treatment, galinsoga and bidens had significantly higher root elongation rates than beans ($p = 0.0021$ and 0.0017) with no significant differences between the weeds. There were no significant differences in root elongation rates of the plants under the NOK treatment.

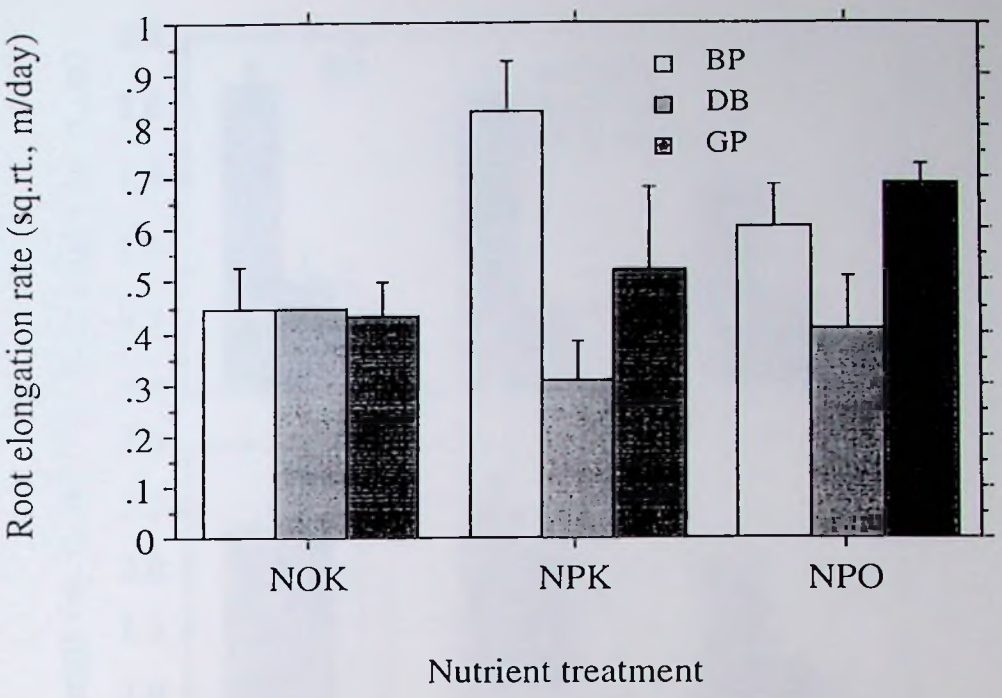


Figure 3.3 Nutrient by plant type treatment interaction effect on plant root elongation rate (square root transformed, m day^{-1}) between 35 -49 DAP where DB = dry beans, BP = *Bidens pilosa*, and GP = *Galinsoga paviflora* (error bars are as indicated on the graph)

At 21 DAP, all plant roots were within 0-10 cm soil depth although beans under all nutrient treatments had significantly greater root lengths than the weeds (Figure 3.4 (a)). There were no significant differences between the weeds at this time. At 35 DAP, although beans had the bulk of their roots in the 0-10 cm soil depth (Figure 3.4 (b)), they had penetrated beyond the 10cm soil depth under all the nutrient treatments (Figure 3.5 (a)). Bidens roots were within the 10 - 20 cm soil depth under

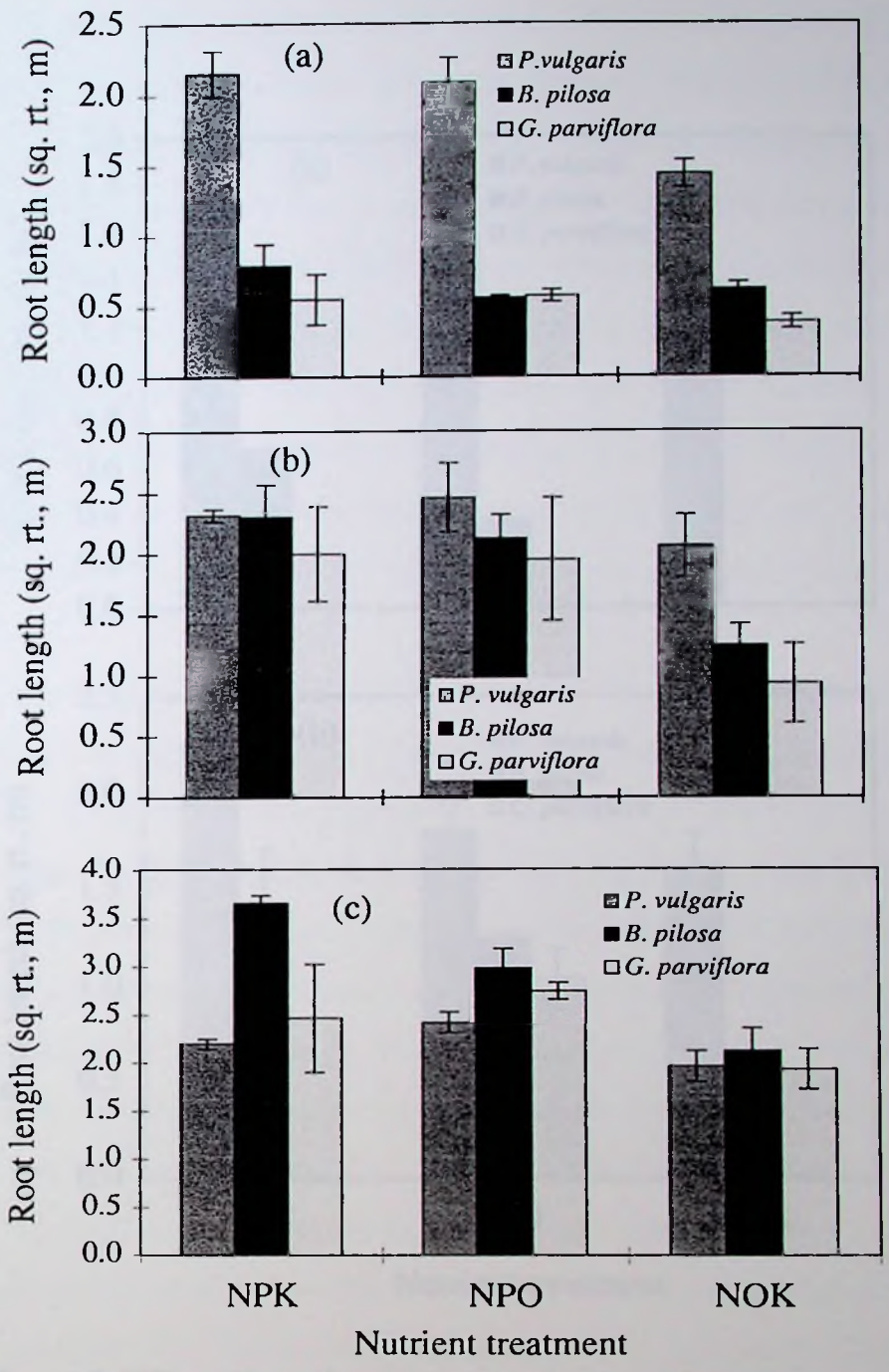


Figure 3.4 The effect of nutrients on plant root lengths (square root transformed, m) at 0-10 cm soil depth at (a) 21 DAP, (b) 35 DAP and (c) 49 DAP (on the graphs are error bars)

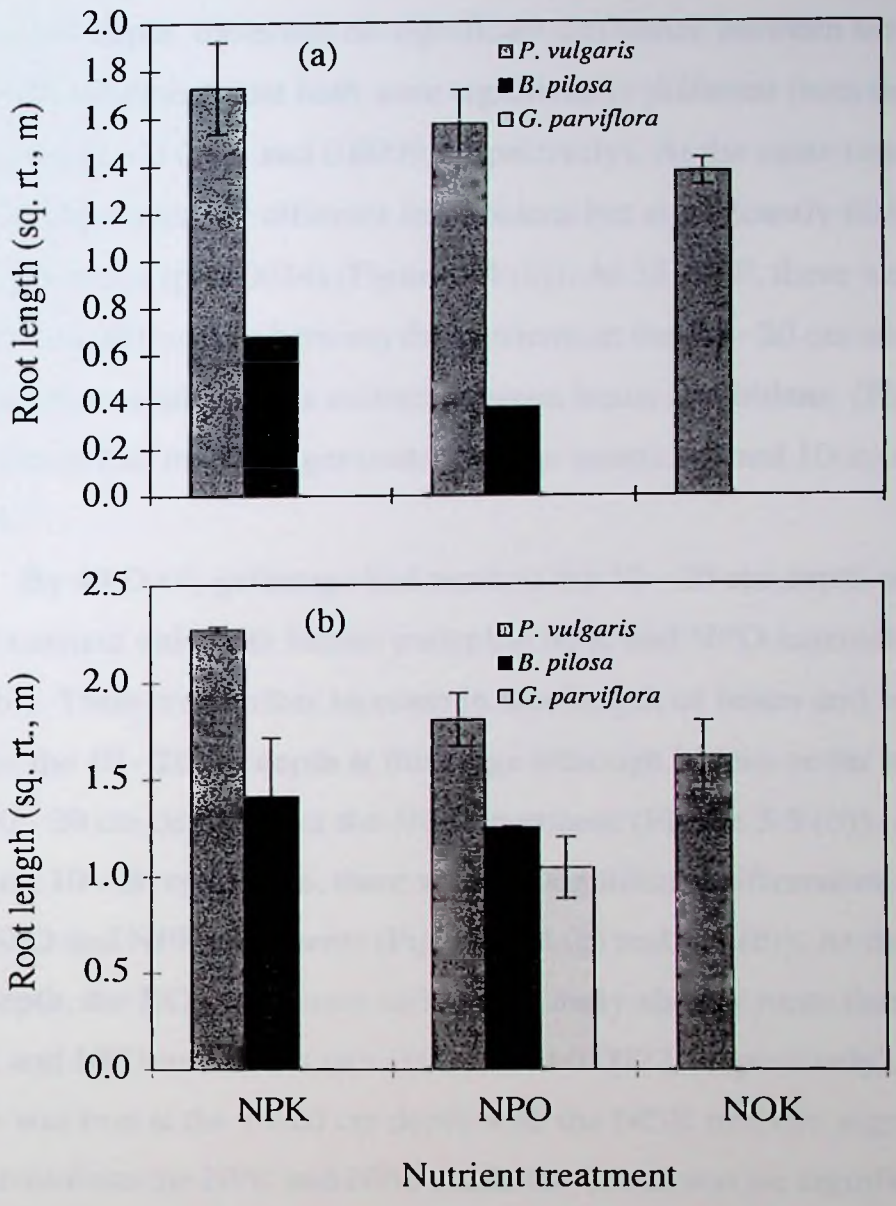


Figure 3.5 The effect of nutrients on plant root lengths (square root transformed, m) at 10-20 cm soil depth at (a) 35 DAP and (b) 49 DAP (on the graphs are error bars)

the NPK and NPO treatments only (Figure 3.5 (a)) while galinsoga remained within the 0 -10 cm soil depth (Figure 3.4 (b)). Within the 0 - 10 cm soil depth, there was no significant difference between the NPO and NPK treatments but both were significantly different from the NOK treatment ($p = 0.0007$ and 0.0009, respectively). At the same time, beans were not significantly different from bidens but significantly different from galinsoga ($p=0.0034$) (Figure 3.4 (b)). At 35 DAP, there were no significant differences between the nutrients at the 10 - 20 cm soil depth but significant differences existed between beans and bidens (Figure 3.5 (a)). Beans had much longer roots than the weeds beyond 10cm soil depth.

By 49 DAP, galinsoga had reached the 10 - 20 cm depth under the NPO nutrient only with bidens under the NPK and NPO nutrients (Figure 3.5 (b)). There was further increase in root length of beans and bidens within the 10 - 20 cm depth at this stage although bidens never reached the 10 - 20 cm depth under the NOK treatment (Figure 3.5 (b)). At both 0 -10 and 10 - 20 cm depths, there were no significant differences between the NPO and NPK treatments (Figures 3.4 (c) and 3.5 (b)). At the 0 -10 cm depth, the NOK treatment had significantly shorter roots than the NPK and NPO treatments ($p = 0.0018$ and 0.0022, respectively). The same was true at the 10-20 cm depth with the NOK nutrient significantly different from the NPK and NPO nutrients. There was no significant difference between beans and galinsoga at 0-10 cm depth but both were significantly different from bidens ($p = 0.0027$ and 0.0185, respectively) (Figure 3.4 (c)). Bidens had the highest root length in the 0-10 cm depth

especially under the NPK and NPO treatments. It should also be noted that the nutrients applied were mixed in the top 15 - 20 cm of the soil.

Averaged over all nutrient treatments at 10 - 20 cm depth, beans had significantly higher total root length than bidens and galinsoga. There were also significant differences between bidens and galinsoga at the 10 - 20 cm soil depth with higher root length in bidens than galinsoga. In all, by 49 DAP, the weeds had as much roots as possible within the 0 - 10 cm soil depth which seems to be where most of our available nutrients are for most soils in Uganda. This, therefore, seems to favor better growth of the weeds for more intense competition against the crops.

Specific root length

Total specific root length (root length in meters per unit root dry weight) decreased with time (Table 3.7). At all dates, nutrients and plant types had no effect on total specific root lengths (0 - 20 cm soil depth).

At 35 DAP within the 0 - 10 cm soil depth, nutrients had no significant effect on specific root length (Table 3.7). At the 10 - 20 cm soil depth, the NOK treatment had significantly higher specific root length indicating the presence of smaller sized roots compared to its dry weight or very low root dry weight. Nutrients had no significant effect on specific root length at 49 DAP within the 0 - 10 cm and 10 - 20 cm soil depth (Table 3.7).

The weeds at 35 DAP within the 0 - 10 cm depth had no significant differences for specific root length but were significantly different from beans (Table 3.7). At 49 DAP, galinsoga at both the 0 - 10 and 10 - 20 soil depths had significantly higher specific root lengths than beans and bidens with no significant differences with bidens at 35 DAP (Table 3.7).

Table 3.7 The effect of nutrients on bean and weed specific root lengths (m g^{-1}) in the screenhouse

Treatment	21 DAP	35 DAP			49 DAP		
	0-10 cm	Total 0-20 cm	0- 10 cm	10- 20 cm	Total 0-20 cm	0-10 cm	10-20 cm
Nutrient treatment							
NPK	9.12 a	10.09 a	9.27 a	15.07 a	6.12 a	5.09 a	12.11 a
NPO (minus K)	9.04 a	9.68 a	9.02 a	12.79 a	5.93 a	5.26 a	16.26 a
NOK (minus P)	11.27 a	11.51 a	10.67 a	23.01 b	8.20 a	7.36 a	16.67 a
Plant type treatment							
Beans	10.67 a	7.83 a	6.22 a	16.23 a	5.93 a	4.14 a	14.09 a
Bidens pilosa	11.09 a	11.53 a	11.51 b	14.72 a	6.17 a	6.01 ab	10.76 a
Galinsoga parviflora	9.66 a	12.45 a	12.45 b	-	8.13 a	7.93 b	37.41 b
Statistical significance[a]							
Nutrient combination	ns	ns	ns	*	ns	ns	ns
Plant type treatment	ns	ns	**	ns	ns	**	**
Nutrient x plantytpe	ns	ns	ns	ns	ns	ns	ns
Coefficient of variation	20.45	19.81	23.23	9.88	19.50	25.36	17.08

Means in each column followed by the same letter for each treatment set are not significantly different at 5% alpha level using LSD,
All variables were log transformed and the back transformed means are reported,
[a] *, **, or ns mean statistically significant at $p \leq 0.05, 0.01$, or not significant, respectively.

This could indicate that the weeds have much finer roots than beans which could be very effective in acquisition of resources from the soil making them more competitive with beans.

DISCUSSION

The evaluation of beans and the weeds under the monocrop situation may not necessarily reflect their competitive abilities when grown in mixtures or may not predict the outcome of competition under field conditions when grown in mixtures. But still it gives us a lot of clues and ideas of the behavior of the weeds and beans under the different nutrients and how their behavior in the screenhouse may possibly relate to field conditions.

Beans could have maintained height advantage over the weeds for the entire period of the experiment (Table 3.1) and secured more light resources than the weeds. This bean variety (K 131) although tall had the tendency to become prostrate with time while the weeds remained erect during the whole growth period (K 131 is indeterminate bush of type IIb growth habit, erect stem and branches with guides and ability to climb). In our experimentation, beans under the NPK and NPO treatments although taller than weeds became prostrate just after 28 DAP. Beans under the NOK nutrient remained erect up to 42 DAP. It was also noted that development under the NOK treatment was delayed compared to other nutrients as was noticed in the field. The height advantage, therefore, under the NPK and NPO nutrients is not likely to be realized by beans in competition with weeds. The weeds end up shading the beans when they become prostrate trapping light resource and continuing to put on more growth. The advantage of height is more likely to be realized

under P deficit condition (NOK) where beans remain erect for long intercepting more light. This was similarly observed in the field. The height advantage under the NOK nutrient could have contributed to the yield advantage realized under the NOK treatment in the field.

Beans had more shoot dry weight and higher shoot growth rates than the weeds at all dates, especially under the NPK and NPO treatments (Tables 3.1 and 3.2). But between 35 and 49 DAP, bidens showed no significant difference with beans in terms of shoot growth rates (Table 3.2). The weeds had the advantage to increase their shoot dry matter production fast due to their significantly higher RGRs than beans. This greatly improved shoot growth rates of bidens between 35 and 49 DAP. The big seed size advantage of beans and its early emergence could have been overshadowed by the relatively high shoot and root RGR of the weeds. This was similar to the finding of Fennimore et al. (1984). They observed that the lower RGRs for beans compared to barnyard grass and black nightshade greatly reduced beans advantage of emerging 3 and 5 days before barnyard grass and black nightshade, respectively, and its large initial seed size. Similarly, Chivinge and Schweppenhauser (1995) reported higher RGRs in bidens and pigweed (*Amaranthus hybridus* L.) growing together with soybean leading to yield reduction in soybeans.

Judging from Table 3.2, shoot RGR of weeds declined with time more slowly than that of beans. This indicates that over a longer period of time, weeds had the advantage to more greatly add to their shoot dry matter than beans. This finding supports the findings of Seibert and Pearce (1993), Chapin III et al. (1989) and Grime and Hunt (1975). They all recognized that the ability of weeds to reach and eventually surpass

the crop in size arises because a number of small seeded weed species tend to have higher RGR which declines less quickly as the weeds grow compared to big seeded crops. Seibert and Peace (1993) also noted that the small seeded weeds devoted more biomass percentage to leaf area resulting into higher RGR.

The weeds initially had lower root dry weight (Table 3.3) and root lengths (Figure 3.2) which increased with time especially for bidens between 35 and 49 DAP under the NPK and NPO treatments. By 35 DAP, the higher root dry weights and root lengths of beans were increasing slowly and weeds were taking over especially bidens under the NPK and NPO treatments. This was due to the relatively high weed root growth rates, root elongation rates and root RGR under the NPK and NPO nutrient treatments. Root RGR and elongation rates declined less drastically for weeds compared to those of beans (Tables 3.4 and 3.6). This could have allowed the weeds more time to reach larger soil volume for better uptake of soil resources than beans. Our result, therefore, indicates that P is very essential for root development in weeds as well as bean as root development remained low under the NOK treatment (Figures 3.4 and 3.6). The result also suggests that the soil used was deficient in P and K. Soil analysis results of the soil used in the mix had 4.2 ppm of P, 0.15% N and 30-70 mg K per kg of soil. The values were low for all nutrients and for N the recommended lower critical level is 0.2% and low for P where the recommended lower critical level is 5 ppm (Recommendations by the Soil Science Laboratory at Kawanda Agricultural Research Institure for soils in Uganda). The level of K in the

mixture was low. The recommended value for K is in the range of 150 (low value) to 500 (high value) mg per kg of soil.

The high root dry weights as well as root lengths of the weeds under the NPK and NPO treatments (Figure 3.2) suggests that weeds, and especially bidens, under adequate N and P conditions could be in better position to take advantage of their relatively faster root growth to trap more resources than beans. This may make them more competitive and allow them to suppress bean growth, beginning between 35 - 49 DAP. Galinsoga may become strongly competitive with beans at a later time than bidens. Burnside et al. (1998) reported that the critical period for annual weed control in beans was between 21 and 42 DAP for common lambsquarters (*Chenopodium album* L.), common ragweed (*Ambrosia artemisiifolia*), foxtails (*Setaria* spp.), hairy nightshade (*Solanum sarrachoides*), redroot pigweed (*Amaranthus retroflexus* L.), and wild buckwheat (*Polygonum convolvulus* L.).

The results also suggest that bidens and galinsoga could be suppressed by beans in the absence of P as was indicated by the weeds' generally low development under the NOK nutrient. This was also observed in the field where both weed species caused less yield reduction to beans under the NOK nutrient compared to other nutrients.

Generally, root lengths decreased with increasing soil depth and weeds in general and bidens in particular maintained high root lengths in the upper 10 cm soil depth even at 49 DAP (Figures 3.4 and 3.5). Greenwood et al. (1982), Marschner (1986), and Gregory (1988) similarly reported this where the levels of nutrients in the top soil and root density decreased with increasing soil depth. Noting that most of our

soil nutrients are within 10-15 cm soil depth, having a relatively high root length and most probably root surface area within that soil depth could be an advantage. Our nutrients in the screenhouse were also mixed in the top 15 – 20 cm soil depth. This could aid the weeds in securing larger nutrient resources from the soil and compete with beans. Only beans had roots below 10cm soil depth under the NOK treatment. This could have offered beans advantage under field condition to secure more of the immobile P from a wider soil volume under the NOK treatment, improving their competitiveness against the weeds with less yield reduction under field conditions compared to adequate P treatments. This may have been what happened under the NOK treatment in the field.

Root/shoot dry weight ratio was not affected by nutrients except at 21 DAP where the NOK treatment had a significantly higher ratio (Table 3.5). This could have been an adaptation by the plants to have more root dry weight under the NOK nutrient in relation to shoot dry weight in order to secure the more needed P for plant growth. The low root/shoot dry weight ratios under the NPK and NPO treatments compared to the NOK treatment confirms the work of Cakmak et al. (1994). They noted that K deficiency reduced root growth of french beans leading to reduced root/shoot ratio. They also observed that lack of P increased root/shoot ratio confirming the importance of P in root nutrition and development. Under good supply of nutrients and water, usually shoot growth is more favored than root growth shifting the root/shoot ratio (Brouwer, 1962b) as was observed under the NPK treatment.

Higher specific root lengths for weeds compared to beans (Table 3.6) may mean an increase in weed root surface area for absorption of

resources from the soil. This is particularly so within the 0-10 cm soil depth where most nutrients occur as noted by Greenwood et al. (1982), Marschner (1986) and Gregory (1988). The presence of high specific root lengths in the top soil could have resulted in weeds gaining advantage over beans under the NPK and NPO treatments as was observed in the field.

CONCLUSION

Weeds may be very competitive with beans under adequate N and P conditions but less competitive under P deficit conditions. Relatively high shoot and root RGRs, and high root elongation and growth rates of the weeds contribute to their competitiveness especially with adequate N and P.

Intense competition between these weeds and beans could begin sometime between 35 and 49 DAP under the present conditions. This time period coincides with maximum root development, RGRs, higher root/shoot ratios and root elongation rates for the weeds.

Beans are more competitive under P deficit conditions due to early emergence, erect growth for a longer time, and more root volume compared to the weeds. Therefore, under P deficit condition, beans are more likely to be competitive than the weeds so long as there are ample N and K nutrients in the soil.

CHAPTER FOUR

ENVIRONMENTAL FACTORS AFFECTING WEED DISTRIBUTION AND ABUNDANCE IN FARMERS' FIELDS IN UGANDA

INTRODUCTION

Weeds differ in abundance and composition according to different geographical regions, and man's activities on land including his choice of agronomic practices, crops, fertilizer use (organic or inorganic), and soil cultivation methods. These activities shift weed composition and abundance leading to adaptation of different weeds to different environmental conditions. Soil, weather and cropping system related factors are important in determining weed abundance

The main method of weed control among peasant farmers in Uganda is mechanical or by cultural means with no or limited use of herbicides. Weeds are one of the main agents affecting crop production and determination of factors affecting their abundance and distribution in Uganda on farmers' fields is essential as a stepping stone to better weed control strategies.

LITERATURE REVIEW

Economic importance of weeds

Weeds have been reported to cause both direct and indirect losses to crops most importantly by reducing crop value (Zimdahl, 1980; Aldrich, 1984). Weeds have also been acknowledged to be poisonous to farm animals and humans (Tiley, 1970; Ivens, 1971; Terry and Michieka, 1987; Rwiza, 1991; Ceha et al., 1997) while some have been used as

foods for both humans and animals (Tiley, 1970; Ivens, 1971; Terry and Michieka, 1987; Zimdahl, 1993; Pandey and Parmar, 1994), and for soil conservation purposes (Tiley, 1970; Pandey and Parmar, 1994).

A number of researchers have observed the importance of weeds for their medicinal values. Richmond (1993) noted that the aborigines of Australia used a number of weedy desert shrubs to cure diseases ranging from fever, headache, rheumatism and scabies to initiation of mothers' milk after childbirth. *Bidens pilosa* has been used in the Amazon region of Brazil for the cure of malaria fever and liver disorders (Brandao et al., 1997). Brandao et al. (1997) found that the crude ethanol extracts of the whole plant (leaves and roots) and the chloroform and butanol extracts from *B. pilosa* at concentrations of 50 mu-g ml^{-1} caused up to 90% inhibition of *Plasmodium falciparum* growth in vitro. In South Africa, crude extracts from 21 medicinal plants including *B. pilosa* which are traditionally used for the cure of infectious or septic wounds were screened for antibacterial activity and most extracts of the methanol group of *B. pilosa* inhibited the growth of *Escherichia coli* (Rabe and Staden, 1997). Similar findings of weeds being used to treat headache and inflammatory diseases have been reported by many researchers and the chemicals responsible for the antibacterial activities have been examined (Christensen et al., 1990; Jager et al., 1996; Wang et al., 1997).

Factors affecting weed composition and abundance

Weeds under arable farming are constantly affected by environmental factors to which they are subjected (Chancellor, 1985; Salonen, 1993). Research has shown that farmers' choice of management practices can significantly shift the weed flora under arable farming.

These factors include soil cultivation methods, weed control methods, choice of crops, crop rotations and previous crop history of the fields; and other environmental factors like soil properties (texture, drainage, soil pH, soil moisture and soil nutrients) and climatic (weather) variables (rainfall, temperature etc.) (Mukula et al., 1969; Hume, 1982; Saavedra et al., 1990; Andreasen et al., 1991; Hume et al., 1991; McIntyre et al., 1991; Dale et al., 1992; Salonen, 1993; Derksen et al., 1994; Ervio et al., 1994; Andersson and Milberg, 1998).

Hume (1982) noted that the fertilizer application and rotation system in a wheat-based system after 22 years had significant effect on weed flora. His result and others showed that continuous cropping increased total weed densities with similar composition as the crop-fallow system especially those weeds with short dormancy periods. Densities of some species such as lambsquarters (*Chenopodium album*) increased under fallow (Hume, 1982; Derksen et al., 1994). Hume et al. (1991) reported a similar finding, where continuous tillage led to increased green foxtail (*Setaria viridis* (L.) Beauv) population under continuous wheat and wheat-fallow rotations.

Frick and Thomas (1992) working in southern Ontario under different tillage systems found that annual weeds were at higher densities and perennial weeds at lower densities in reduced tillage than in conventional tillage, supporting the earlier findings of Hume (1982). The highest total density of weeds was however found in fields with no tillage. Some researchers have noted that increased tillage reduced weed seedling densities or the number of seeds in the soil for some weed species (Robert and Dawkins, 1967; Wilson, 1978). On the other hand,

Andersson and Milberg (1998) in a 6-year crop rotation in southern Sweden found no effect of crop rotation on weed flora composition.

Weed control practices through the use of herbicides also lead to weed flora shift in favor or against particular weeds depending on their tolerance or susceptibility to the herbicides and the crop cultivated (Mukula et al., 1969; Ervio and Salonen, 1987; Thomas and Ivany, 1990; Dale et al., 1992; Salonen, 1993; Derksen et al., 1994; Thomas et al., 1994; Van-Male et al., 1996). Constant application of MCPA in a spring cereal field in Finland decreased the population of susceptible weed species like *Chenopodium album*, *Erysimum cheiranthoides* and *Galeopsis* sp. while the population of resistant weed species like *Agropyron repens*, *Galium vaillantii*, *Lamium* sp., *Lapsana communis* and *Myosotis arvensis* increased (Mukula et al., 1969). Ervio and Salonen (1987) later confirmed this finding in spring cereals.

Van-Male et al. (1996) observed that *Echinochloa crus-galli* was abundant in fields where high inputs of herbicides (MCPA and propanil) and fertilizer were used in the dry and intermediate zone rice fields in Sri Lanka. They noted that *E. crus-galli* was positively correlated with propanil use while *E. frumentacea* and *E. stragnina* were more frequent in fields where no or little herbicides were used. *Echinochloa crus-galli* was more resistant to the herbicides while the other 2 species were susceptible to the herbicides used by the farmers. Salonen (1993) also observed that *Galium* sp., *Lamium* sp. and *Triplerospermum inodorum* were widespread under heavy herbicide application in spring cereals indicating the creation of resistance to these herbicides after continuous use.

Combine harvesting on farms has been noted to influence weed flora composition (Mukula et al., 1969; Ervio and Salonen, 1987). They noted that repeated use of combine harvesters favored some weed species like *Sonchus arvensis*, *Chenopodium album* and *Galeopsis* sp. Farmers in Australia recognized that weed species in a rice-based system were associated with the methods of crop establishment (McIntyre et al., 1991). Farmers noted that aerial sowing of rice favored establishment of *Cyperus difformis* and *Damasonium minus* but suppressed *Echinochloa crus-galli*. On the other hand, combine harvesting and sod sowing favored the establishment of *E. crus-galli* but suppressed *C. difformis* and *D. minus* which they related to tolerance of the weeds to flooding and the timing of permanent flood.

Soil physical and chemical properties such as soil types, texture, soil moisture, soil pH and soil nutrients also affect weed flora distribution (Mukula et al., 1969; Ervio and Salonen, 1987; Saavedra et al., 1990; Andreasen et al., 1991; Dale et al., 1992; Salonen, 1993; Derksen et al., 1994; Ervio et al., 1994; Scheldeman et al., 1995; Andersson and Miberg, 1998). In their investigations of weed flora in spring cereals, Mukula et al. (1969), Salonen (1993) and Ervio et al. (1994) noted that soil type, soil texture and soil moisture conditions significantly affected weed community composition. Weed density increased or decreased depending on the soil types and texture. Under sandy soils, *Elymus repens*, *Erysimum cheiranthoides* , *Myosotis arvensis* , *Lapsana communis* , and *Poa annua* L., populations increased (Mukula et al., 1969; Salonen, 1993; Ervio et al., 1994). On the other hand, under clay soils *Chenopodium album* , *Fallopia convolvulus*, *Fumaria officinalis*, *Lamium* sp., *Sochus*

arvensis and *Thlaspi arvense,* and under humus soils *Achillea ptarmico*, *Polygonum lapathifolium*, *Ranunculus repens, Rumex* sp. and *Spergula arvensis* populations increased. Similar findings in variation of weed densities in relation to soil types were reported by other researchers (Ervio and Salonen, 1987; Saavedra et al., 1990; Andreasen et al., 1991; Scheldeman et al., 1995; Andersson and Milberg, 1998). In all cases, soil texture was very important in determining weed flora composition.

Soil chemical properties like soil pH and soil nutrients including inorganic and organic fertilizers also affect weed distribution (Hume, 1982; Ervio and Salonen, 1987; Saavedra et al., 1990; Andreasen et al., 1991; Pysek and Leps, 1991; Salonen, 1993; Ervio et al., 1994; Scheldeman et al., 1995). Increasing soil pH decreased the population of *C. album* while the populations of *Lamium* sp. and *Myosotis* sp. increased (Ervio and Salonen, 1987; Andreasen et al., 1991; Ervio et al., 1994).

Fertilization has been particularly important in weed community composition. Fertilization may affect the composition of particular weeds by increasing their abundance (increasing germination of dormant seeds from the soil) (Hume, 1982). It may also increase the competitive nature of the crops with resultant decrease in weed species diversity as was noted in a barley field when supplied with N fertilizer (Pyseck and Leps, 1991). Pyseck and Leps (1991) noted that weeds responded to both fertilizer types and dose with a change in weed composition. Fertilizer application either reduced or increased the competitive nature or germination ability of the weeds. Similarly, the effect of farmyard manure (FYM) had been observed on some weeds. The use of FYM in spring cereals in Finland increased the population of *Chenopodium*

album, *Myosotis arvensis*, *Polygonum convolvulus* and *Stellaria media* (Mukula et al., 1969).

Andreasen et al. (1991) noted that increase in available P favored the occurrence of *Solanum nigrum* and *Viola tricolor* while increase in K level decreased *Anagallis arvensis* and *Solanum nigrum* but increased *Stellaria media*. They also noted that serious weeds like *Chenopodium album*, *Elymus repens* and *Poa annua* were unaffected by changes in K and Mn nutrients indicating their wide adaptability to environmental conditions. Ervio and Salonen (1987) had earlier on reported varied response of weeds to K and N. Although soil chemical properties affected weed distribution, Saavedra et al. (1990) observed that the effects of soil pH and carbonate contents were less important than soil texture in Spain. After studying weed distribution in cereal and vegetable fields, Ervio et al. (1994) concluded that soil physical properties (soil porosity, aeration, water-holding capacity and humus content) had much more marked influence on weed abundance than do soil chemical properties.

Climatic or weather variables (rainfall, temperature and humidity) also affect weed composition (Mukula et al., 1969; Pysek and Leps, 1991; Dale et al., 1992; Salonen, 1993). Saavedra et al. (1990) observed that in Guadalquivir Valley (Spain), climate did not have marked influence on the weed flora found in the crops. Similarly, Ervio and Salonen (1987) observed no climatic effect on weed occurrence in spring cereals. Dale et al. (1992) on the other hand noted that specific weeds were adapted to a specific temperature range in spring seeded crops in Saskatchewan. They found *Medicago lupulina*, *Gallium spurium*, *Neslia paniculata* and *Stellaria media* to be adapted to low temperature regions

while *Kochia scoparia*, *Euphorbia serpyllifolia*, *Malva rotundifolia* and *Amaranthus graecizans* to be adapted to lowland regions which are very humid and warm.

Although weeds have been known to be a big problem in Uganda, no work has been documented on the factors that affect weed abundance and distribution especially in cultivated crops. Widespread labor shortage could easily cause a shift in weed population with resultant shortage in food supply. Therefore, determination of which factors affect weed abundance and distribution in Uganda may be very important as a stepping stone to a more economical solution to weed problems in Uganda. This survey was, therefore, undertaken to determine which environmental, agronomic and soil factors affect the abundance and distribution of weeds in Uganda under farmers' management conditions.

MATERIALS AND METHODS

Weed surveys were conducted in central (Mpigi District) and eastern (Iganga, Kamuli and Pallisa districts) regions of Uganda (Figure 4.1) in July and August of 1997 just at the start of first season crop harvest and in the middle of the second rain season of 1997 (October/November). This part of Uganda is north of the equator and characterized by forest/savanna mosaic vegetation comprising of elephant grass with forest remnants (Iganga, Kamuli and Mpigi districts) or *Hyparrahenia rufa* with forest remnants (Pallisa District) (Langdale-Brown, 1970). The soils are mostly Ferrasols (Ferrallitic soils) which are extremely weathered soils characterized by dominance of kaolinite clays and residual accumulation of iron and aluminum oxides and hydroxides (Harrop, 1970; FAO, 1993). These soils are red in color and



Figure 4.1 The map of Uganda showing the 4 districts (Mpigi, Iganga, Pallisa and Kamuli) where the surveys were carried out in 1997

undifferentiated sandy clay loam (Mpigi District) or sandy loam (Iganga and Kamuli districts) or yellowish-brown in color and differentiated on loose sandy sediments (Pallisa District). Both vegetation and soils in these districts have been changing over time due to man's activities leading to less forested areas and great extension of infertile soils. The region surveyed lies within an altitude of 1100m - 1250m with an annual rainfall ranging from 1000 - 1500 mm (Meteorological Department Data for 1997).

The fields surveyed were previously surveyed for a nutrient flux study in 1996 and were under varied crops and cropping systems. A total of 63 fields was surveyed and farmers who own these fields were interviewed with the help of a structured questionnaire (Appendix B, Table B1). Other farmers whose fields were not surveyed were also interviewed for more information on weeds. A total of 126 farmers was involved in the survey. Weed assessment was made on two plots of 3 m x 4 m in each field where weeds falling along the diagonal lines of each plot area were counted (each diagonal line measured 5m long). A string of more than 5 m length was used to aid in the counting of the weeds along the diagonals. The string was marked every 5 cm and the predetermined 18 weeds falling at these 5 cm points on the 5 m string were counted. All weeds were counted along a distance of 10 m in each sample plot and 20 m in two sample plots giving total weed number per field surveyed (4 diagonals each of 5m). The 18 predetermined weeds counted (10 broadleaf and 8 grasses) were *Bidens pilosa, Galinsoga parviflora, Amaranthus* sp., *Datura stramonium, Solanum nigrum, Portulaca oleracea, Euphorbia* sp., *Oxalis latifolia, Commelina* sp.,

Ageratum conyzoides, Cynodon dactylon, Digitaria sp., *Setaria* sp., *Panicum maximum, Eleusine indica, Sorghum halepense, Cyperus* sp. and *Imperata cylindrica*. These weeds were conceived to be the most important and most common weeds in cultivated fields. Observations were also made on other weeds that happened to be common in these areas but not included among the 18 listed weeds.

Farmers were requested to evaluate the economic importance of the weeds and discuss the various factors affecting weed distribution and abundance. Weeds that could not be identified were collected and taken for identification to Makerere University, Faculty of Science, Botany Department (Herbarium section). Other information collected during the survey included topographic information (field slope) and land drainage. Climatic factors in most districts were not properly documented and were not included in the analysis. Soil depth was determined and soil samples were collected for soil pH analysis during the survey (soil pH reported in the results). Soil samples were earlier collected in late 1996 and analyzed for organic carbon, total N, total P, total K, and also exchangeable K, Mg, Ca and Oslen P by the methods described in chapter 2 under materials and methods. These are the soil chemical properties used in this report

Statistical Analysis

Frequency of each weed species was determined as the proportion of the fields infested by a weed species expressed as percentage of the total number of surveyed fields. The frequency of mention of weed species by farmers denotes the proportion of responses by farmers of weeds that were cited as most prevalent expressed as proportion (percentage) of the total responses by the farmers. Mean weed density

was obtained by summing the number of a particular weed species for all plots surveyed and dividing by the number of plots surveyed.

Data on factors involved in the distribution of weeds in each field were collected either by observing and measuring weed incidence or by interviewing the farmers. The environmental data collected were either quantitative or qualitative. In order to describe the relationship between weed species abundance (using weed densities that we counted in the sampled plots) and the environmental factors, multivariate analysis and analysis of variance were carried out on the data. Simple descriptive statistics of the weed and environmental data were also gathered. The multivariate analysis techniques used were the canonical ordination technique and multiple regression analysis. Canonical ordination technique is designed to detect the patterns of variations in the weed species data that can be "best" explained by the observed environmental variables (ter Braak, 1995). The resulting ordination diagram expresses not only a pattern of variation in weed species composition but also the main relations between the weed species and each of the environmental variables. The canonical ordination also combines the features of regression analysis and species-environment interactions (ter Braak, 1995, 1996).

The canonical ordination method used for the weed species - environment analysis was the "canonical correspondence analysis" (CCA) (ter Braak, 1986, 1987; ter Braak and Prentice, 1988). The CCA is a direct gradient analysis method also known as constrained ordination method where the ordination axes are linear combinations of the environmental variables (ter Braak, 1987; ter Braak and Prentice, 1988).

The CCA fits the unimodal curve to the species-environment data using weighted averaging estimation (ter Braak, 1996).

The reasons for multivariate analysis using the CCA ordination technique were (ter Braak, 1987):

(a) Vegetation data are often qualitative or when quantitative contain many zero values for the plots at which a species is absent. In neither case do the data satisfy the assumption of a normal error distribution that is implicit in ordinary multiple regression,

(b) Relationships between species and environmental variables are generally non-linear. Species abundance is often a single-peaked (bell-shaped) function of the environmental variables, and

(c) Environmental variables are often highly correlated, and it can be impossible to separate their independent effects.

The CCA ordination analysis was performed with the CANOCO 4 program (ter Braak and Smilauer, 1998). Ordination diagrams (weed species-environment biplots) were drawn with the CANODRAW 3.0 program (Smilauer, 1992) and CANOPOST 1.0 program (ter Braak and Smilauer, 1998). The relationship between weed species abundance and environmental variables is displayed with the first two canonical ordination axes. Canonical axis is an ordination axis that is constrained to be a linear combination of environmental variables (Gauch, 1982). Eigenvalue (an importance measure of an ordination axis) is the variance accounted for by that axis (Gauch, 1982). The axes are ranked by their eigenvalues, and the first axis has the greatest value followed by the next axis. The bulk of the original total variance is extracted in the early eigenvalues, and later eigenvalues will be small or zero. The first two

eigenvalues may account for 40 to 90% of the total variance. Weighted correlation (it uses weighted means) between environmental variables and the first four ordination axes with their respective eigenvalues are also reported.

Results of multiple regression analysis of the weed species – environment relationship are also reported. Except for *B. pilosa* and *S. halepense*, the multiple regression analysis models reported were derived from the original data. *Bidens pilosa* and *S. halepense* models were derived from estimated weed abundance data using Additive Main Effect and Multiplicative Interaction (AMMI) model (Gauch, 1988) as described in Appendix B (Table B2). The estimated weed abundance data did not improve the prediction power of the other weed species models compared to the original data.

RESULTS

Weed occurrence and weed densities

The weeds surveyed for their occurrence and abundance belong to 9 families out of which 11 annual weeds were from 6 families and 7 perennial weeds were from 4 families (Table 4.1). The weeds with high frequencies of occurrence were also the weeds that had high overall densities. The 7 most frequently occurring weeds with their densities during the survey were *Bidens pilosa*, *Digitaria* sp., *Ageratum conyzoides*, *Commelina* sp., *Galinsoga parviflora*, *Euphorbia* sp., and *Cyperus* sp. Although *Oxalis latifolia* occurred less frequently, it had relatively high mean weed number (Table 4.1). Other less frequently occurring weeds are included in Table 4.1. *Solanum nigrum*, *Datura*

Table 4.1 Family name, scientific name, common name, life cycle, frequency of occurrence and density of weed species surveyed in farmers' fields in 1997

Family	Scientific name	Common name	Life cycle	Frequency[a] (%)	Mean density[b] (No./plot)	SE of the mean[c]
Compositae	*Bidens pilosa* L.	Blackjack, Beggarticks	Annual	90.48	15.6	2.84
Gramineae	*Digitaria* sp.	Couch grass	Perennial	87.30	25.4	3.26
Compositae	*Ageratum conyzoides* L.	Goat weed	Annual	85.71	18.4	2.26
Commelinaceae	*Commelina* sp.	Wondering Jew	Perennial	77.78	14.6	2.18
Compositae	*Galinsoga parviflora* Cav.	Gallant soldier	Annual	76.19	14.7	1.99
Euphorbiaceae	*Euphorbia* sp.	Asthma or Blue weed	Annual	76.19	11.2	2.25
Cyperaceae	*Cyperus* sp.	Nutsedge, Nutgrass	Perennial	60.32	9.3	2.28
Oxalidaceae	*Oxalis latifolia* H. B. K.	Oxalis	Perennial	26.98	7.0	1.86
Gramineae	*Sorghum halepense*	Wild sorghum	Annual	25.40	1.7	0.47
Gramineae	*Eleusine indica* L.	Wild finger millet	Annual	23.81	1.4	0.46
Amaranthaceae	*Amaranthus* sp.	Pig weed	Annual	22.22	1.6	0.68
Gramineae	*Panicum maximum* Jacq.	Guinea grass	Perennial	19.05	0.6	0.22
Gramineae	*Cynodon dactylon* L.	Star or Bermuda grass	Perennial	7.94	0.6	0.34
Portulaceae	*Portulaca oleracea* L.	Purslane	Annual	1.59	0.1	0.11

[a] Frequency for each weed species was determined as the proportion of the fields infested by a weed species expressed as percentage of the total number of surveyed fields,

[b] Mean weed density was obtained by summing the number of a particular weed species for all all plots and dividing by the total number of plots surveyed,

[c] SE is the standard error of the mean density.

stramonium, *Setaria* sp., and *Imperata cylindrica* were not encountered in the sampled areas or spots although they were available in the fields in the surveyed districts.

All weeds showed no significant difference in their abundance across the districts except for *Oxalis latifolia* ($p = 0.0001$) and *Cyperus* sp. ($p = 0.004$). *Oxalis latifolia* was significantly more abundant in Mpigi district (mean of 24.27) in central Uganda compared to Kamuli (6.53), Iganga (2.87) and Pallisa (0.33) districts in eastern Uganda (Figure 1). On the other hand, *Cyperus* sp. was significantly more plentiful in Pallisa district (mean of 21.72), compared to Kamuli (6.16), Mpigi (3.91) and Iganga (2.13) districts. There were no significant differences between the other districts for both *O. latifolia* and *Cyperus* sp. The rest of the weeds were equally distributed in all the four districts.

The weeds that were commonly encountered during the survey were also the weeds that farmers cited as the most prevalent and serious weeds in the regions (Table 4.2). These weeds belong to 10 families of which 13 are annual weeds from 6 families and 12 are perennials from 7 families. Five weeds although frequently found in the survey as the most common weeds in the regions were never recognized by farmers as the most common weeds namely *Eleusine indica*, *Amaranthus* sp., *Panicum maximum*, *Solanum nigrum* and *Setaria* sp. (Tables 4.1 and 4.2). The importance attached to these species locally for other purposes could have overshadowed their importance as weeds. Some species of *Amaranthus* and *Solanum nigrum* are used as vegetables and less regarded as weeds. *Panicum maximum* seems to be important for use as brooms economically important to a number of rural families. In addition

Table 4.2 Weeds cited by farmers as most serious and prevalent in the surveyed areas in farmers' fields with their frequency of mention

Family	Scientific name	Common name	Life cycle	Frequency[a]
Compositae	*Bidens pilosa* L.	Blackjack, Beggar ticks	Annual	96.83
Gramineae	*Digitaria* sp.	Couch grass	Perennial	90.48
Compositae	*Galinsoga parviflora* Cav.	Gallant soldier	Annual	63.49
Euphorbiaceae	*Euphorbia* sp.	Asthma or Blue weed	Annual	60.32
Compositae	*Ageratum conyzoides* L.	Goat weed	Annual	49.21
Commelinaceae	*Commelina* sp.	Wondering Jew	Perennial	46.03
Cyperaceae	*Cyperus* sp.	Nutsedge, Nutgrass	Perennial	25.40
Oxalidaceae	*Oxalis latifolia* H. B. K.	Oxalis	Perennial	17.46
Compositae	*Acanthospermum hispidum* DC.	Starbur	Annual	15.87
Compositae	*Conyza floribunda* H. B. & K.	Fleabane	Annual	14.29
Verbenaceae	*Lantana camara* L.	Tick-berry, curse of India	Perennial	7.94
Compositae	*Senecio* sp.	Ragwort, groundsel	Annual	6.35
Malvaceae	*Abutilon mauritianum* (Jacq.) Medic.		Perennial	4.76
Gramineae	*Sorghum halepense*	Wild sorghum or johnson grass	Annual	4.76
Compositae	*Aspilia africana* (Pers.) C. D. Adams	Haemorrhage weed	Perennial	4.76
Gramineae	*Cynodon dactylon* L.	Star grass, Bermuda grass	Perennial	4.76
Solanaceae	*Datura stramonium* L.	Thorn apple, Jimson weed	Annual	4.76
Gramineae	*Imperata cylindrica* (L.) Raeuscher	Sword grass	Perennial	4.76
Compositae	*Launaea cornuta* (Oliv. & Hiern) C. Jeffrey	Wild lettuce	Perennial	4.76
Labiatae	*Leonotis nepetifolia* (L.) Ait.f.	Lion's ear, Lion's tail	Annual	4.76
Portulaceae	*Portulaca oleracea* L.	Purslane	Annual	4.76
Gramineae	*Rottboellia exaltata* L.f	Itch grass, Guinea fowl grass	Annual	4.76
Gramineae	*Brachiaria* spa.		Annual/Perennial	3.17
Gramineae	*Panicum maximum* Jacq.	Guinea grass	Perennial	3.17

[a]Frequency (%) of mention of weeds by farmers denotes the proportion of responses by farmers of weeds that were cited as most prevalent expressed as proportion of the total responses by the farmers

to the weeds surveyed and counted, farmers also mentioned other weeds which commonly occurred in their fields including *Acanthospermum hispidum*, *Conyza floribunda*, *Lantana camara*, *Senecio* sp., *Abutilon mauritianum*, *Aspilia africana*, *Launaea cornuta*, *Leonutis nepetifolia*, *Rottboellia exaltata* and *Brachiaria* sp. (Table 4.2).

Other weeds which were observed in farmers fields but which were not mentioned by farmers as important were identified and noted (Table 4.3). They included some of the most serious weeds like *Striga asiatica* and *Striga hermonthica*, common in cereal-based farming systems especially sorghum and millet systems in eastern Uganda. The weeds that were observed and identified belonged to 11 families out of which 12 annual weeds were from 9 families and 5 perennials were from 3 families. All the weeds encountered (Tables 4.1, 4.2 and 4.3) indicate the wide variation in the weed flora found in farmers' fields. These are only a few of the weeds found in farmers' fields but they form the majority of the troublesome and most serious weeds of crops in the surveyed areas.

Annual and perennial crops which were encountered in the surveyed plots are included in Table 4.4. Most of the crops were being grown as intercrops of two or more crops. The reason advanced by farmers for the intercrops included labor shortage, land shortage, risk avoidance due to climatic factors, pests and diseases.

Economic importance of weeds (bidens, galinsoga and nightshade)

The economic importance of the 3 annual weeds namely *B. pilosa*, *G. parviflora* and *S. nigrum* was documented by the farmers. According to the farmers interviewed, 36.5% observed that *B. pilosa* was an

Table 4.3 Other weeds not cited by farmers but observed in farmers' fields as widespread and abundant

Family	Common name	Scientific name	Life cycle
Papaveraceae	*Argemone mexicana* L.	Mexican poppy/thistle	Annual
Acanthaceae	*Asystasia schimperi* T. Anders.		Annual
Papilionaceae	*Crotolaria* sp.	Rattle pod	Annual
Gramineae	*Dactyloctenium aegyptium* (L.) Willd.	Crows-foot grass	Annual
Fabaceae	*Desmodium* sp.	Beggarweed	Perennial
Capparaceae	*Gynadropsis gynandra* (L.) Briq	Spider flower	Annual
Polygonaceae	*Oxygonum sinuatum* (Meisn.) Dammer	Double thorn	Annual
Gramineae	*Pennisetum clandestinum* Chiov.	Kikuyu grass	Perennial
Solanaceae	*Physalis* sp.	Purple/wild cape gooseberry	Annual
Gramineae	*Rhynchelytrum repens* (Willd.) C. E. Hubbard	Blanket grass	Annual
Gramineae	*Setaria* sp.	Love grass, fox tail grass	Annual
Malvaceae	*Sida* sp.	Broom weed	Perennial
Solanaceae	*Solanum incanum* L.	Sodom apple	Perennial
Gramineae	*Sporobulus pyramidalis* P. Beauv.	Cat's tail grass	Perennial
Scrophulariaceae	*Striga asiatica* (L.) Kuntza	Striga, red witch weed	Annual
Scrophulariaceae	*Striga hermonthica* (Del.) Benth	Striga, purple witch weed	Annual
Compositae	*Tagetes minuta* L.	Mexican marigold	Annual

Table 4.4 Lists of annual and perennial crops encountered in the surveyed areas in farmers' fields

Family Name	Scientific name	Common name	Life cycle
Gramineae	*Zea mays* L.	Maize	Annual
Gramineae	*Sorghum bicolor* (L.) Moench	Sorghum	Annual
Gramineae	*Eleusine coracana* Gaerth	Finger millet	Annual
Leguminosae	*Glysine max* (L.)	Soybeans	Annual
Leguminosae	*Phaseolus vulgaris* L.	Dry beans	Annual
Leguminosae	*Vigna unguiculata*	Cowpeas	Annual
Leguminosae	*Pisum sativum* L.	Field peas	Annual
Leguminosae	*Arachis hypogaea* L.	Groundnuts	Annual
Malvaceae	*Gossypium hirsutum* L.	Cotton	Annual
Convolvulaceae	*Ipomoea batata* Poir.	Sweet potato	Annual
Euphorbiaceae	*Manihot utilissima* Crantz.	Cassava	Perennial
Musaceae	*Musa* sp.	Bananas	Perennial
Bromeliaceae	*Ananas comosus* (L.) Merr.	Pineapples	Perennial
Compositae	*Helianthus annuus* L.	Sunflower	Annual
Pedaliacea	*Sesamum indicum* L.	Simsim/sesame	Annual
Solanaceae	*Lycopersicum esculentum* Mil.	Tomato	Annual
Rubiaceae	*Coffee robusta* L.	Robusta coffee	Perennial
Passifloraceae	*Passiflora edulis* Sims.	Passion fruit	Perennial
Caricaceae	*Carica papaya* L.	Pawpaw/papaya	Perennial
Lauraceae	*Persea americana* L.	Avocado	Perennial
Anacardiaceae	*Mangifera indica* L.	Mango	Perennial
Moraceae	*Artocarpus heterophylla* Lam.	Jackfruit	Perennial
Myrtaceae	*Psidium guajava* L.	Guava	Perennial

extremely serious weed in reducing crop yield, especially bean yield while 44.4% considered it a very serious weed and only 19.1% noted it as a serious weed (Table 4.5). Farmers indicated that total yield loss (100% loss) was possible if no weeding was done especially if combined with poor initial land preparation or if the land the previous season had heavy bidens population. Farmers also noted that *B. pilosa* was very important for medicinal purposes with many rural families using the dried seed

Table 4.5 Rating of weeds' competitiveness (*B. pilosa*, *G. parviflora*, and *S. nigrum*) with crops by farmers

Weed species	ES	VS	S	NE
B. pilosa	36.5	44.4	19.1	0.0
G. parviflora	0.0	38.1	61.9	0.0
S. nigrum	0.0	0.0	34.9	65.1

Measured in terms of output reduction from the crops e.g. 10 bags of produce without weed competition, yield reduction of over 60% was noted as extremely serious (ES), 30-60% as very serious (VS), 10-30% as serious (S) and less than 10% as having little or no effect (NE).

when burnt to ashes for treatment of cough. The sap from the fresh leaves is used for treating fresh wounds and ringworm, while the sap from the fresh roots is used for treatment of eye diseases. Farmers also observed that immature *B. pilosa* are cheap sources of nutrients as green manure, especially in banana and coffee plantations, and should be turned in the soil before they produce seeds.

Galinsoga parviflora was also observed to cause great yield reduction in beans and other annual crops especially under good soil fertility. Farmers indicated *G. parviflora* to be a very serious weed (38.1% of the farmers) while 61.9% observed it as a serious weed in reducing crop yield (Table 4.5). Farmers also noted that *G. parviflora* was a cheap source of food for rabbits and pigs, important in improving soil fertility when used as green manure, especially in banana or coffee plantations, and can also be used as cover crop to retain moisture in

banana-coffee systems. Farmers use fresh galinsoga during delivery of women to hasten the excretion of the placenta.

Solanum nigrum was observed by farmers as an important source of green vegetable, especially during poor cropping seasons. Most farmers observed *S. nigrum* to have no effect on crop yield (65.1%) and only 34.9% observed that it was a serious weed in bean crop (Table 4.5). The "no effect" consensus is due to the fact that *S. nigrum* is an important food crop for families with low income and food scarcity. Medically, farmers in the region use *Solanum nigrum* to reduce and in some cases completely cure patients of high blood pressure and diabetes. The sap from the fresh leaves is used in the treatment of fresh wounds and in combination with other herbs is used for treating eye problems.

In general, farmers consider *B. pilosa* to be the most dangerous weed in crop production followed by *Galinsoga parviflora* and *S. nigrum* as the least serious weed due to the fact that it can be used as food apart from competing with crops.

Weed species abundance-environment relations

Farmers in the surveyed districts identified six main factors responsible for weed abundance and distribution, namely soil fertility, soil depth, cropping system, land drainage, soil texture and soil acidity (Table 4.6). Soil fertility (overall effect of soil nutrients), soil depth and cropping systems were the most commonly mentioned factors by farmers as affecting weed flora composition and distribution. Farmers also indicated that deep fertile soils might have many weed species or a few but weeds of more biomass than less fertile soils which may also have many or a few weeds but less vigorous weeds. According to farmers,

Table 4.6 Frequencies (as percentages) of mention of factors by farmers which affect weed distribution and abundance

Factors	Frequency				
	Iganga	Kamuli	Mpigi	Pallisa	Over all
Soil fertility	100.0	100.0	100.0	100.0	100.0
Soil depth	100.0	84.2	90.9	100.0	93.8
Cropping system	100.0	52.6	100.0	83.3	84.0
Land drainage	60.0	26.3	0.0	50.0	34.1
Soil texture	0.0	15.8	27.3	0.0	10.8
Soil acidity	0.0	0.0	9.1	0.0	2.3
Over all mention of factors affecting weed distribution	60.0	46.5	54.6	55.6	54.2

acidic soils usually have few weed species which may be many in number.

Analytical nutrient results for soil factors affecting weed abundance averaged across all sites and location (district) are indicated in Table 4.7. The high variance inflation factor (VIF) for soil clay and sand contents indicates that the two factors are highly correlated. In general, the standard errors for most of the variables were low (Table 4.7).

Considering the different locations, there were significant differences among the locations for soil pH, soil carbon, soil N and K, soil depth and soil clay (Table 4.7). Soil pH was significantly high in Mpigi and Iganga districts, and soil carbon content and soil N in Kamuli,

Table 4.7 Means and variance inflation factors (VIF) for the soil environmental variables averaged across sites for all locations and across sites per location (district)

Soil environmental variables	Weighted mean	SE of the mean	VIF	Location				
				Pallisa	Kamuli	Iganga	Mpigi	Stat. signif.[a]
Soil pH	5.45	0.06	1.81	5.28 a	5.33 a	5.59 ab	5.75 b	*
Carbon (%)	2.37	0.08	8.10	1.92 a	2.59 bc	2.31 ab	2.82 c	***
Total N (ppm)	1357.00	43.60	6.91	1172.80 a	1485.30 b	1391.30 b	1390.00 b	*
Total K (ppm)	1606.20	90.90	2.92	2089.90 b	1318.10 a	1702.90 ab	1180.20 a	***
Total P (ppm)	490.80	32.10	3.01	441.40 a	560.50 a	397.90 a	577.80 a	ns
Calcium (ppm)	6.81	0.55	1.95	7.46 a	7.40 a	5.70 a	6.22 a	ns
Magnesium (ppm)	1.70	0.09	4.52	1.87 a	1.77 a	1.37 a	1.74 a	ns
K meq/100 gm	0.72	0.07	2.76	0.58 a	0.75 a	0.87 a	0.71 a	ns
Oslen P	26.66	6.57	3.78	15.39 a	39.79 a	27.94 a	20.67 a	ns
Soil depth (cm)	32.21	1.22	1.45	36.08 c	34.26 bc	29.00 ab	26.73 a	*
Clay soil content (%)	22.51	0.98	42.57	22.72 a	18.68 a	22.80 ab	28.36 b	**
Silt soil content (%)	13.44	0.52	12.71	13.56 a	12.95 a	14.87 a	12.18 a	ns
Sand soil content (%)	64.27	1.05	45.49	64.44 abc	68.37 c	62.40 ab	59.46 a	ns

[a] Statistical significance where means followed by the same letter across locations are not significantly different at 5% level using LSD, *, **, ***, ns means statistically significant at $p \leq 0.05, 0.01, 0.001$ or not significant, respectively.

Iganga and Mpigi districts. Soil K was significantly high in Pallisa and Iganga districts. The sample site distribution in relation to soil environment in a triplot diagram indicates that most sites in Pallisa district had relatively deep soils and slightly high soil K but low soil N and carbon (Appendix B, Figure B1). Sample sites in Mpigi district had relatively high soil carbon and soil pH. The rest of the nutrients did not show any particular trend to locations as per the triplot diagram. This is because particular weeds heavily affected some of the fields while others were less prevalent. This is indicated by the scattered distribution of the sample sites with no clear pattern in a particular soil environment for a particular location (Appendix B, Figure B1). This is confirmed by the non-significant differences between all weed species across locations except for *O. latifolia* and *Cyperus* sp.

Both canonical correspondence analysis (CCA) and multiple regression analysis (MRA) were used to analyze the weed species abundance-environment relationship. The CCA results indicate that the eigenvalues were high for the first two CCA ordination axes (Table 4.8). The eigenvalue denotes the dispersion (maximized) of the species scores along the ordination axis, and is thus a measure of importance of the ordination axis (ter Braak, 1995). The eigenvalues of the first two axes were, therefore, used to display the biologically relevant information. The weed species-soil or cropping system environment correlation at each axis was relatively high for the first two axes (Table 4.8). The first two ordination axes accounted for 49.8 and 62.6% of the variances of the weed species-soil and cropping system environment relationships, respectively. The Monte Carlo permutation test for the first canonical

Table 4.8 Eigenvalues, correlation and cumulative variances corresponding to the first 4 ordination axes and the Monte Carlo permutation test for the CCA ordination axes

Factors/variables	Axis 1	Axis 2	Axis 3	Axis 4
Soil environmental variables:				
Eigenvalues (λ)	0.142	0.113	0.073	0.061
Weed species - environment correlation	0.752	0.612	0.665	0.561
Cumulative variances (%)				
- of weed species data	8.4	15.1	19.4	23.0
- of weed species-environment relation	27.8	49.8	64.2	76.1
Cropping system environmental variables:				
Eigenvalues (λ)	0.123	0.113	0.058	0.036
Weed species - environment correlation	0.677	0.633	0.583	0.476
Cumulative variances (%)				
- of weed species data	7.3	14.0	17.4	19.6
- of weed species-environment relation	32.7	62.6	78.1	87.6

Monte Carlo permutation test: [a]	Soil environments	Cropping system
Test of significance of the 1st canonical axis:	ns	*
Test of significance of all canonical axes:	**	**

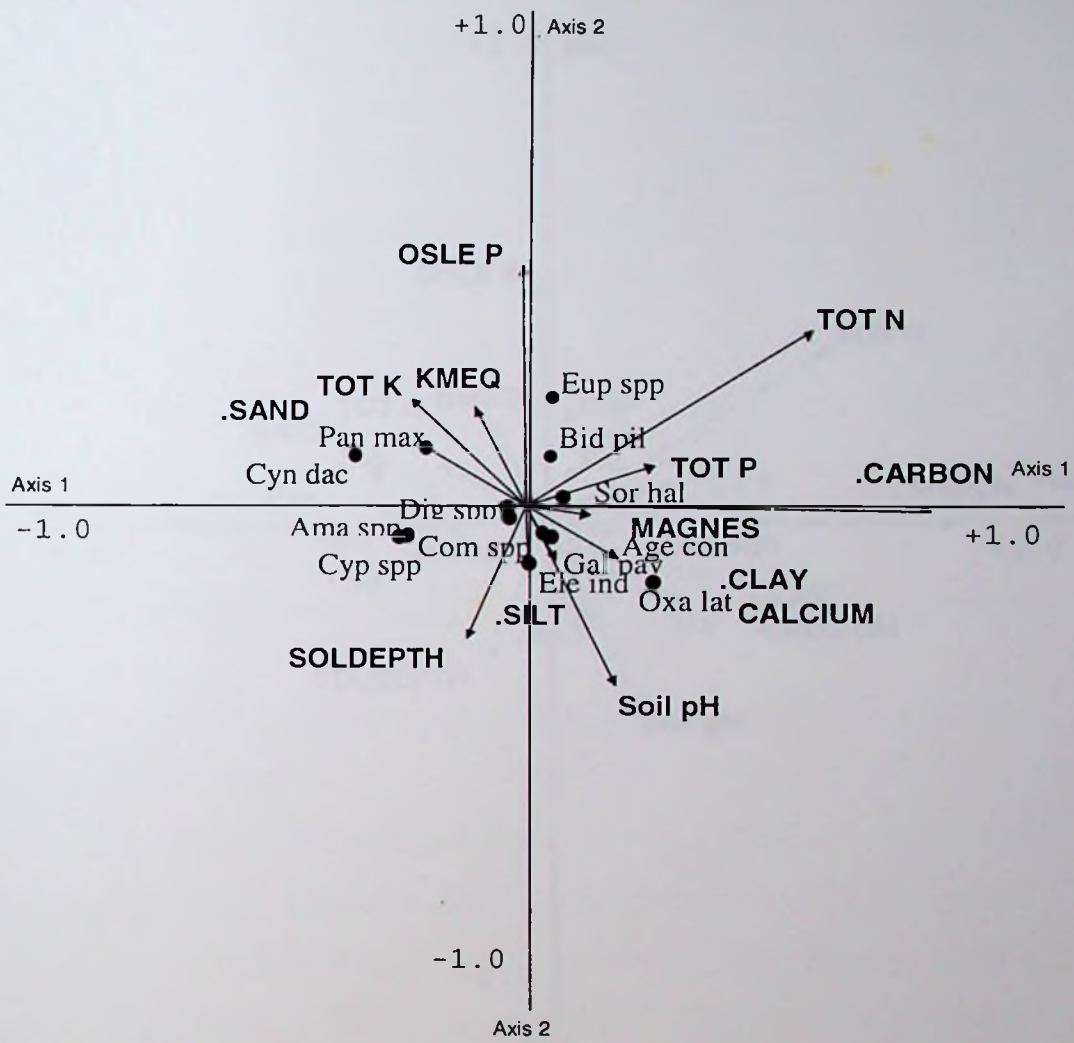
[a] *, **, ns statistically significant at $p \leq 0.05$, 0.01 or nor significant, respectively.

axis indicated that the weed species abundance was significantly related to the cropping system environmental variables ($p = 0.04$). The permutation test for all canonical axes showed that the weed species abundance was significantly related to both soil and cropping system environmental variables ($p = 0.005$ each) (Table 4.8).

Weed species-soil environment relations

The distribution of weed species on the first and second CCA axes are shown in relation to soil chemical and physical environmental factors (Figure 4.2). The first canonical axis extracted by CCA was closely related to percent carbon and total N as indicated by the long vectors (Figure 4.2) and by the high correlation with the axis (Table 4.9). *Galinsoga parviflora*, *Digitaria* sp., *Commelina* sp., *A. conyzoides*, and *B. pilosa*, were found in soils of relatively low N while *B. pilosa* was positively related to soil P. *Sorghum halepense* was also associated with slightly more soil P. *Euphorbia* sp. was found in relatively high soil P and slightly medium soil N. *Galinsoga parviflora*, *Ageratum conyzoides*, *Sorghum halepense, Digitaria* sp., *Commelina* sp. and *B. pilosa* were associated with soils of relatively low carbon content. *Amaranthus* sp., *Cynodon dactylon*, *P. maximum*, *Cyperus* sp., and *Commelina* sp., were negatively associated with soil N, carbon and P and were mostly found in soils of very low N, C and P. *Oxalis latifolia* was frequently found in soils of relatively high N and C and its number increased with increase in the levels of the two nutrients. Analysis of variance (ANOVA) indicated that *Cynodon dactylon* abundance decreased with increasing soil N level ($p = 0.038$). *Digitaria* sp. and *Eleusine indica* densities were both high at

Figure 4.2 Biplot based on canonical correspondence analysis of weed species abundance (mean density per plot) with respect to 13 soil environmental variables in cultivated fields in Uganda. Abbreviations of the environmental variables: TOT N = total soil N (ppm), TOT K = total soil K (ppm), TOT P = total soil P (ppm), MAGNES = exchangeable magnesium (ppm), CALCIUM = exchangeable calcium (ppm), OSLEN P = soil P by Oslen method (ppm), KMEQ = exchangeable potassium as meq/100gm, Soil pH = soil pH, SOLDEPTH = soil depth (cm), CLAY = soil clay content (%), SILT = soil silt content (%) and SAND = soil sand content (%). Abbreviations of weed species: Bid pil = *B. pilosa*, Dig spp = *Digitaria* sp., Age con = *A. conyzoides*, Com spp = *Commelina* sp., Gal pav = *G. parviflora*, Eup spp = *Euphorbia* sp., Cyp spp = *Cyperus* sp., Oxa lat = *O. latifolia*, Sor hal = *S. halepense*, Ele ind = *E. indica*, Ama spp = *Amaranthus* sp., Pan max = *P. maximum*, and Cyn dac = *C. dactylon*. Zero values are near the centroid and increasing values or numbers are towards the arrow tips for all soil variables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TOT N
TOT K
KMEQ
Eup spp
.SAND
Pan max
Bid pil
Cyn dac
TOT P
.CARBON
Axis 1
Axis 1
Sor hal
Dig spp
-1.0
Ama spp
MAGNES
+1.0
Com spp
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Cyp spp
Gal pav
Ele ind
.CLAY
Oxa lat
CALCIUM
.SILT
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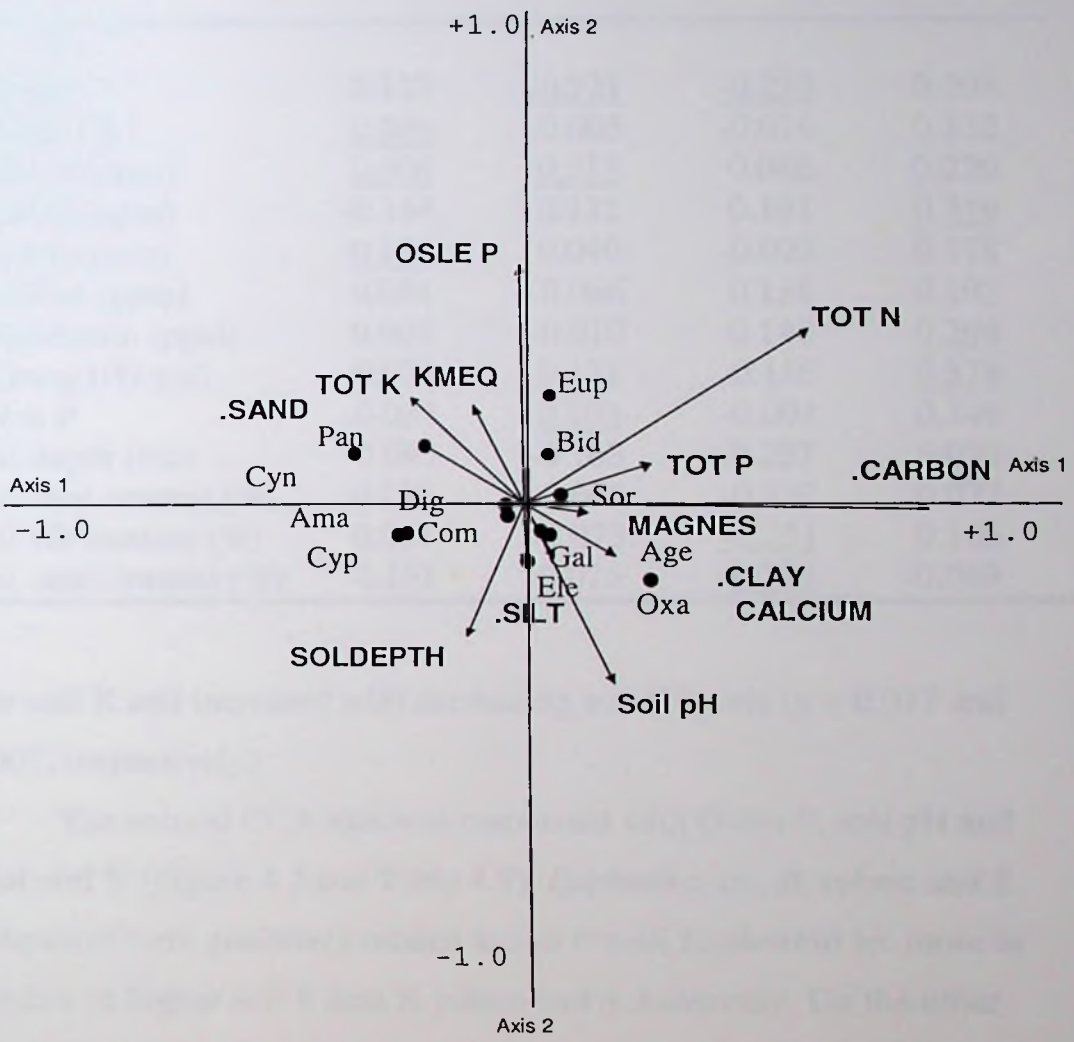
Soil pH
-1.0
Axis 2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CALCIUM
.SILT
SOLDEPTH
Soil pH
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Axis 2

Table 4.9 Weighted correlation between soil environmental variables and the first 4 ordination axes from CCA for weed abundance (the three highest values of each axis are underlined)

Soil environments	Axis 1	Axis 2	Axis 3	Axis 4
Soil pH	0.127	-0.221	-0.253	0.208
Carbon (%)	0.569	-0.005	-0.016	0.132
Total N (ppm)	0.406	0.213	0.046	0.220
Total K (ppm)	-0.164	0.132	0.191	0.319
Total P (ppm)	0.181	0.049	-0.023	0.178
Calcium (ppm)	0.044	-0.066	0.138	0.195
Magnesium (ppm)	0.092	-0.010	0.146	0.294
K (meq/100 gm)	-0.072	0.121	-0.150	0.378
Oslen P	-0.007	0.293	-0.094	0.249
Soil depth (cm)	-0.085	-0.163	0.237	0.023
Soil clay content (%)	0.130	-0.065	-0.232	0.072
Soil silt content (%)	0.001	-0.073	-0.251	0.166
Soil sand content (%)	-0.151	0.075	0.389	-0.099

low soil K and increased with decreasing soil K levels ($p = 0.017$ and 0.001, respectively).

The second CCA axis was associated with Oslen P, soil pH and total soil N (Figure 4.2 and Table 4.9). *Euphorbia* sp., *B. pilosa* and *S. halepense* were positively related to soil P with *Euphorbia* sp. more in number at higher soil P than *B. pilosa* and *S. halepense*. On the other hand, *Euphorbia* sp. was negatively associated with soil pH, soil depth and soil silt content and to some extent *B. pilosa*. They were mostly found in soils of pH near 5.0 and few at pH beyond 6.0. *Oxalis latifolia* was in great number in soils of high pH (pH above 6.0), high calcium and clay and silt contents. Similarly, *Ageratum conyzoides*, *G. parviflora* and

E. indica were found in moderately low pH soils, moderately deep soils and soils of moderately low clay and silt contents. They were negatively associated with soil K contents (Figure 4.2). This was similar to farmers' observations where they indicated that *B. pilosa*, *G. parviflora*, *Commelina* sp. and *Digitaria* sp. were found both in deep and shallow soils. In general, weeds that were more common in deep soils according to farmers were *Pennisetum purpureum*, *Ageratum conyzoides*, *Cyperus* sp., *Imperata cylindrica* and *Conyza floribunda*. In shallow soils they recognized that *Sporobulus pyrimidalis*, *Striga* sp., *Euphorbia* sp., *O. latifolia*, *Dactyloctenium aegyptium*, *Cynodon dactylon*, *Launeae cornuta* and *Oxygonum sinuatum* weeds were more common. Farmers noted that all weeds could be found in deep soils as long as the right nutrients are available except their densities might vary.

Panicum maximum, *Cynodon dactylon* and *Euphorbia* sp. were positively associated with soil K and sand contents of the soils (Figure 4.2). They were found in high numbers in high K and sandy soils and less in high Ca, pH and clay soils. *Sorghum halepense*, *O. latifolia*, *G. parviflora* and *A. conyzoides* were also positively associated with soil Mg. *Digitaria* sp., *G. parviflora*, *S. halepense*, *A. conyzoides* and *B. pilosa* and *Commelina* sp. which were more near the centroid were less affected by the soil environments indicating their wide adaptability despite the nature of the soils.

The third CCA axis was related more closely to soil pH, sand and silt contents of the soil, and the fourth axis was associated with soil K and magnesium contents (Table 4.9).

After so many years of experience, farmers observed that *B. pilosa*, *Euphorbia* sp. and *Digitaria* sp. were found in both high and low fertility soils indicating their wide distribution. They also observed that under high soil fertility, the most common and dominant weeds were *G. parviflora*, *Commelina* sp., *Tagetes minuta*, *Gynadropsis gynandra*, *Amaranthus* sp., *Cynodon dactylon*, *Asystasia schimperi*, *Panicum maximum* and *Pennisetum purpureum*. On the other hand under low soil fertility, the most common weeds noted were *Striga* sp., *Imperata cylindrica*, *Ageratum conyzoides*, *Cyperus* sp., *Senecio vulgaris*, *Rottboellia exaltata*, *Sorghum halepense*, *Conyza floribunda*, *Oxygonum sinuatum* and *Acanthospermum hispidum*. Where the soil is poor, both *B. pilosa* and *Digitaria* sp. are found together. Farmers concluded that all weeds may be found on fertile soils except that those mentioned become more dominant and outcompete others.

Farmers also observed that application of farm yard manure (FYM) increased weed density and flora. They thought this could be due to FYM stimulating dormant weed seeds in the soil to germinate and thereby increasing the weed flora or that weed seeds were being distributed with application of FYM. The weeds most believed by farmers to be distributed by FYM are *Cynodon dactylon*, *Physalis philadelphia*, *Amaranthus* sp. and *Digitaria* sp. Farmers would prefer to use compost manure which according to them reduces weed growth compared to fresh FYM and that is why most farmers would prefer to leave FYM to dry before applying in the fields. Farm yard manure was also noted to encourage the growth of broadleaf weeds more than grasses and to lead to toppling of banana crops when surface applied. Surface application of

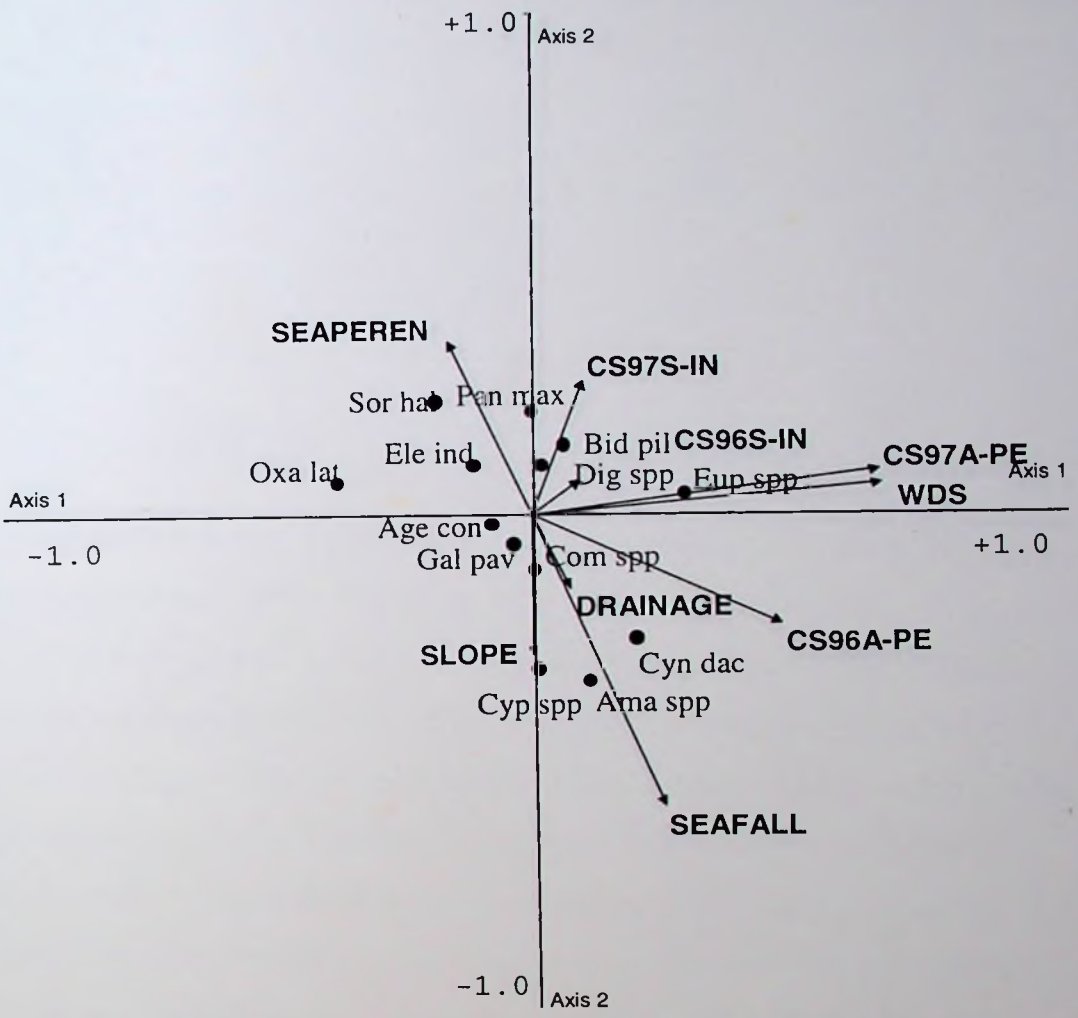
FYM encourages banana roots to grow towards the soil surface where the manure is which may cause banana to topple easily in windy situations. Manure use by farmers is of little economic benefit at present due to the high labor involved in application of the manure and the occurrence of the extra weeds that come with application of the manure.

Weed species-cropping system environment relations

The first canonical axis extracted by CCA ordination was closely associated with the number of weedings and whether the crop grown in the 1996B and 1997A seasons was an annual or a perennial as indicated by the long arrows and the high correlation (Figure 4.3, Table 4.10). *Euphorbia* sp. was highly associated with perennial crops and increased in number with increase in the frequency of weeding. Analysis of variance results indicated that *Euphorbia* sp. was found significantly more in perennials than annual crops ($p = 0.024$). On the other hand, *O. latifolia* was negatively associated with the number of weedings but was more related to annual crops grown in the 1997A season.

Sorghum halepense, *O. latifolia* and *E. indica* were associated with annual crops in the 1996B and 1997A seasons and were more in number where few or no weedings were carried out (Figure 4.3). Similarly, *A. conyzoides* and *G. parviflora* were more in non-weeded or fields weeded only a few times. *Bidens pilosa*, *Digitaria* sp., *Panicum maximum*, *Amaranthus* sp., *G. parviflora*, *C. dactylon*, *Cyperus* sp. and *Commelina* sp. showed no preference to annual or perennial crops in the 1997A season (Figure 4.3). *Panicum maximum*, *B. pilosa* and *Digitaria* sp. were associated with intercrops in the 1996B season. *Panicum maximum* was

Figure 4.3 Biplot based on canonical correspondence analysis of weed species abundance (mean density per plot) with respect to 9 cropping system environmental variables in cultivated fields in Uganda. Abbreviations of environmental variables: CS96A-PE and CS97A-PE = annual or perennial crop in the 1996B and 1997A seasons, respectively (where annual crop = 0 and perennial crop = 1), CS96S-IN and CS97S-IN = crops grown in sole or intercrop system in the 1996B and 1997A seasons, respectively (where sole crop = 0 and intercrop = 1), SLOPE = topographical position of the field (where 1 = hill top, 2 = upper slope, 3 = mid slope, 4 = lower slope, 5 = upper valley and 6 = valley), WDS = frequency of weeding (weeded 0, 1, 2, 3, 4, 5 times), DRAINAGE = soil drainage class (where 1 = well drained, 2 = fairly drained and 3 = poorly drained), SEAFALL = seasons since the field was fallow and SEAPEREN = seasons since perennial crop was grown (where 1 = continuous perennial crop, 2 = 1-10 seasons ago, 3 = 11-20 seasons ago, 4 = 21-30 seasons ago, 5 = 31-40 seasons ago, 6 = over 40 seasons ago or continuous annual crops). Zeros are near the centroids and increasing numbers are towards the arrow tips for all cases. Weed species abbreviation meanings as for Figure 4.2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SEAPEREN
CS97S-IN
Sor hal
Pan max
Bid pil
CS96S-IN
CS97A-PE
Ele ind
Oxa lat
Dig spp
Eup spp
Axis 1
WDS
Axis 1
Age con
-1.0
+1.0
Gal pav
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DRAINAGE
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SLOPE
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Cyp spp
Ama spp
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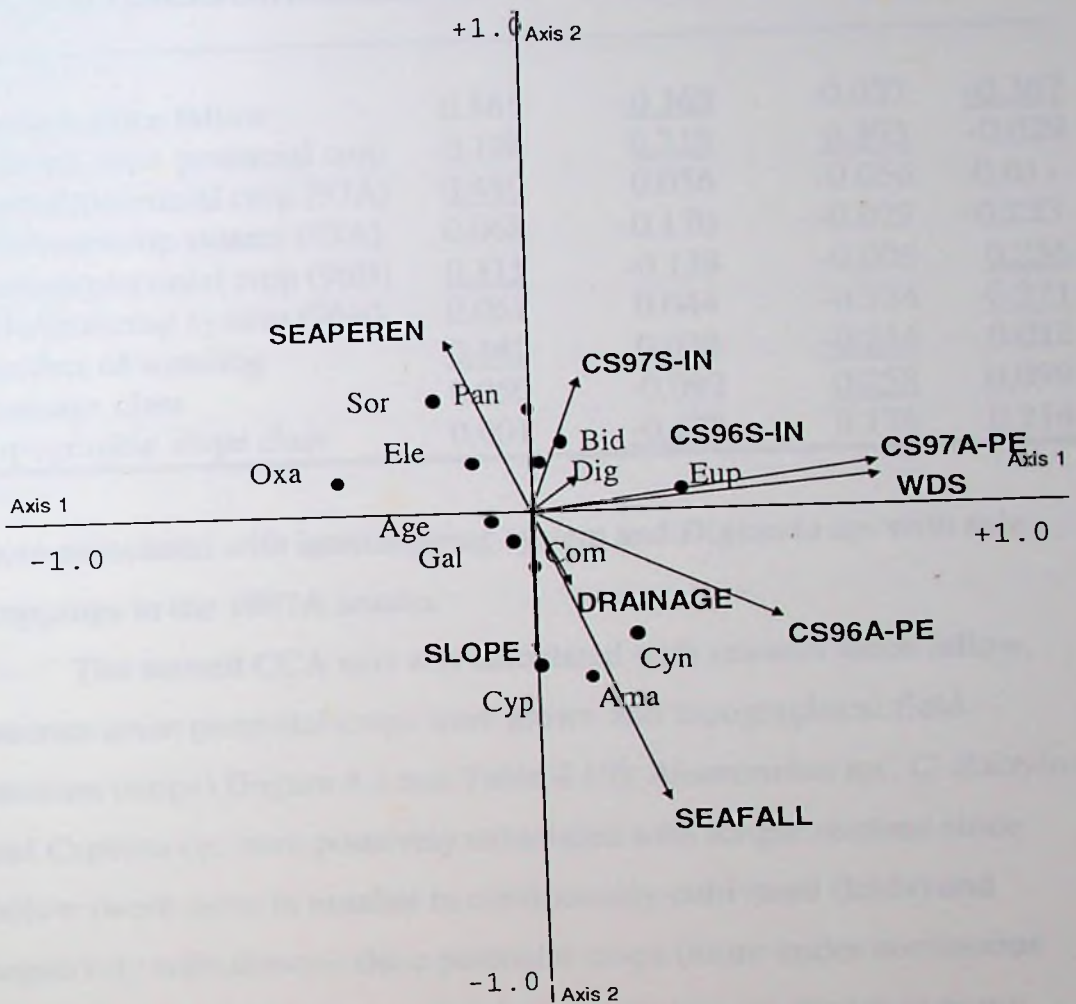
Axis 2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Axis 1
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Dig
Eup
WDS
Oxa
Axis 1
-1.0
+1.0
Age
Gal
Com
DRAINAGE
CS96A-PE
SLOPE
Cyn
Cyp
Ama
SEAFALL
-1.0
Axis 2

Table 4.10 Weighted correlation between cropping system environmental variables and the first 4 ordination axes from CCA for weed abundance (the three highest values of each axis are underlined)

Cropping systems environments	Axis 1	Axis 2	Axis 3	Axis 4
Seasons since fallow	0.165	-0.369	0.027	-0.307
Seasons since perennial crop	-0.108	0.218	0.395	-0.029
Annual/perennial crop (97A)	0.440	0.056	-0.056	-0.011
Sole/intercrop system (97A)	0.068	0.170	-0.027	-0.223
Annual/perennial crop (96B)	0.315	-0.138	-0.005	0.236
Sole/intercrop system (96B)	0.061	0.044	-0.134	0.271
Number of weeding	0.442	0.038	-0.216	0.012
Drainage class	0.050	-0.092	0.258	0.099
Topographic slope class	0.001	-0.178	0.176	0.214

more associated with intercropping system and *Digitaria* sp. with sole croppings in the 1997A season.

The second CCA axis was associated with seasons since fallow, seasons since perennial crops were grown and topographical field position (slope) (Figure 4.3 and Table 4.10). *Amaranthus* sp., *C. dactylon* and *Cyperus* sp. were positively associated with longer seasons since fallow (were more in number in continuously cultivated fields) and negatively with seasons since perennial crops (more under continuous perennial crop cultivation than if the perennials were grown so many seasons back). On the other hand, *S. halepense*, *P. maximum*, *Digitaria* sp., *E. indica* and *O. latifolia* were more common in fields that had just been under fallow or are currently under fallow (Figure 4.3). They were also more common in fields that were under continuous cultivation with annual crops or fields that were under perennial crops so many seasons

back. *Cyperus* sp., *Amaranthus* sp. and *C. dactylon* were mostly found in the upper valley to the valley bottom fields. These were relatively poorly drained fields. *Ageratum conyzoides*, *G. parviflora* and *Commelina* sp. were mostly in the upper to lower slope fields with some in the upper valleys. *Sorghum halepense*, *P. maximum* and *E. indica* where mostly in hill top and upper slope fields. *Bidens pilosa* was indifferent to either sole or intercropping systems.

The third CCA axis was mostly associated with seasons since fallow, soil drainage class and frequency of weeding (Table 4.10). The fourth CCA axis was associated with seasons since fallow, sole or intercropping system in the 1996B and 1997A seasons, the crop grown in the 1996B season whether annual or perennial crop and topographical position of the field (slope class) (Table 4.10).

The distribution of the sample fields per location did not show any particular trend with particular cropping system as shown by the scattered points in the triplot diagram (Appendix B, Figure B2). No particular location showed dominance of particular cropping system with weed abundance. Similarly, soil environmental variables did not show any clearly defined association with the cropping system as all the points were near the centroid except for Oslen P (Appendix B, Figure B3). Oslen P was positively associated with perennial crops grown in the 96B and 97A seasons and that was why *Euphorbia* sp. that was more associated with Oslen P was also associated with perennial crops.

According to farmers, intercrops usually have fewer weeds than sole crops and tall sole crops tend to have more weeds than short sole crops. Leafy crops like sweet potatoes, beans and soybeans tend to have

fewer weeds as they cover the ground better than cassava. Farmers have observed over the years that where sweet potatoes are grown, there is usually very low density of *B. pilosa* and *G. parviflora*. Perennial crops on the other hand encourage the growth of weeds because weeding is less frequently done. This allows weeds to reach maturity leading to more seed production and dissemination to other places.

Farmers indicated that almost all weeds will perform well under good drainage but specific weeds will tend to dominate under poorly drained conditions. Weeds which were recognized by farmers as very common in poorly drained areas were *Cyperus* sp., *Digitaria* sp., *Oxalis* sp., *B. pilosa*, *Fimbristylis* sp., *Fuirena* sp., *Kyllinga* sp., *Echinochloa* sp., *Panicum* sp. and *Paspalum* sp.

Multiple regression analysis (MRA) was also used to analyze and explain the relationship between weed abundance and environmental variables. The finding using multiple regression analysis was similar to CCA. Multiple regression analysis showed that by including all the environmental variables in the model, this explained only between 34.5 to 52.7% of the variation in abundance of the different weed species (Table 4.11). Weed species whose variation in abundance was explained well by the models when all environmental variables were included were *B. pilosa*, *Euphorbia* sp., *Commelina* sp., *O. latifolia*, *Amaranthus* sp., *Cyperus* sp., *C. dactylon* and *E. indica* as indicated by the R^2 values greater than 40% (Table 4.11). Environmental variables accounted for less of the variation in weed abundance of *G. parviflora*, *A. conyzoides*, *sorghum halepense*, *Digitaria* sp., and *P. maximum*. This may indicate the wide adaptability of these weeds to varied environmental conditions.

Table 4.11 Multiple regression analysis models for the best 5 environmental variables to explain the weed abundance-environment relationship in cultivated fields in Uganda

Weed species	Multiple regression analysis R models for the best 5 variables as selected by the best Subsets regression technique	R^2 for the best five variables	R^2 when 10 - 20 variables are in the model
1. *B. pilosa*	y = 13.7 – 0.008 TOT N + 0.03 OSL P + 0.169 DEP + 0.228 CLAY – 2.71 97S/IN	R^2 = 26.7	41.5
2. *G. parviflora*	y = -28.9 + 11.4 pH – 5.47 KMEQ – 5.74 97S/IN – 2.31 SSP – 6.08 97A/P	R^2 = 24.4	38.0
3. *Euphorbia* sp.	y = 11.5 - 7.89 KMEQ + 0.154 OSL P - 0.871 SILT + 6.40 WDN + 6.15 97A/P	R^2 = 36.7	48.7
4. *Commelina* sp.	y = 23.8 - 0.007 TOT K + 1.06 SILT + 0.178 SSF - 3.29 SSP - 10.0 97A/P	R^2 = 28.2	42.2
5. *A. conyzoides*	y = -407 + 0.605 DEP + 4.60 CLAY + 3.65 SILT + 4.04 SAND -9.32 97S/IN	R^2 = 23.3	36.4
6. *O. latifolia*	y = -53.0 + 0.022 TOT N + 10.6 pH + 17.8 C - 0.916 Ca - 9.47 97A/P	R^2 = 39.0	51.1
7. *Amaranthus* sp.	y = 24.7 + 0.145 DEP - 2.29 C - 0.336 SAND - 4.12 97S/IN + 4.16 96A/P	R^2 = 29.8	44.5
8. *Digitaria* sp.	y = 75.3 - 0.033 TOT N - 0.165 SSF + 1.62 SSP + 9.20 97S/IN - 1.04 SILT	R^2 = 26.3	35.5
9. *Cyperus* sp.	y = 32.9 + 0.304 DEP - 10.7 C - 4.07 WDN + 0.245 SSF - 1.52 SSP	R^2 = 36.7	49.6
10. *C. dactylon*	y = 1.27 - 2.15 C + 2.60 KMEQ + 0.140 CLAY - 1.68 97S/IN + 1.09 96S/IN	R^2 = 36.2	49.7
11. *E. indica*	y = -129 + 0.001 TOT K + 0.113 DEP + 1.28 CLAY + 1.27 SILT + 1.23 SAND	R^2 = 41.1	52.7
12. *P. maximum*	y = 8.03 - 0.338 C - 1.07 pH + 0.006 OSL P - 0.825 WDN + 1.04 97A/P	R^2 = 25.4	34.5
13. *S. halepense*	y = 11.0 – 0.004 TOT N – 0.001 TOT K + 0.024 OSL P – 3.07 96A/P – 0.469 SSP	R^2 = 25.3	38.5

Abbreviations for the variables: CLAY, SILT and SAND = soil clay, silt and sand contents (%), respectively, C = soil carbon content (%), TOT N = total soil nitrogen (ppm), TOT K = total soil potassium (ppm), Ca = soil calcium (ppm), Mg = exchangeable magnesium (ppm), KMEQ = exchangeable potassium (meq/100gm), OSL P = Olsen phosphorus (ppm), pH = soil pH, DEP = soil depth (cm), 96A/P and 97A/P = annual or perennial crop in the 1996B and 1997A seasons, respectively, 96S/IN and 97S/IN = crops grown in sole or intercrop systems in 1996B and 1997A seasons, respectively, SSF = seasons since land was last fallow, and SSP = seasons since land was last used for perennial crops (where 1 = continuous perennial cropping, 2 = 1-10 seasons ago, 3 = 11-20 seasons ago, 4 = 21-30 seasons ago, 5 = 31-40 seasons ago and 6 = over 40 seasons ago or continuous annual crops), and WDN = frequency of weeding from 0 - 5 times.

In the case of *Euphorbia* sp., Oslen P alone accounted for 17.1% of the variation in weed abundance while the frequency of weeding accounted for 12.9% and both factors combined accounted for 26.9% of the variation. Therefore, the weed species responded differently to the different environments in which they were surviving. *Eleusine indica* showed great response to soil structure and soil depth while *O. latifolia* increased in number with increasing soil pH, carbon and calcium content of the soil (Table 4.11). Both soil and cropping system environmental factors were very important in determining weed species abundance.

Euphorbia sp., *Amaranthus* sp., and *P. maximum* were associated with perennials while *Digitaria* sp. was more in intercrops and A. conyzoides, *B. pilosa*, *C. dactylon* and *Amaranthus* sp. were associated with sole cropping (Table 4.11). *Ageratum conyzoides*, *Amaranthus* sp., *Cyperus* sp., and *E. indica* were positively associated with soil depth. Most weeds showed general tendency to increase in number with increasing soil P and clay content of the soil and decrease in number with increasing soil N, C and K.

In general, weed flora composition and abundance were affected more by soil P, soil carbon content, soil N and to a moderate extent by soil pH, soil K, soil sand content and soil depth and to a lesser extent by soil clay and silt contents, soil magnesium and calcium (Figure 4.2 and Table 4.11). On the other hand, weed composition and abundance were more affected by seasons since fallow, frequency of weeding, and crops grown whether annual or perennial (Figure 4.3 and Table 4.11). Whether the crops were grown as sole crops or in intercropping system and the

topographic field position (slope) had less effect on weed abundance. The effect of cropping system seems to be more pronounced than the effect of soil chemical and physical factors indicating that weeds are in position to survive under varied soil environments but their species composition is shifted more by man's action of producing food.

DISCUSSION

The most frequently occurring weeds discovered during the survey with high mean densities were *B. pilosa*, *Digitaria* sp., *A. conyzoides*, *Commelina* sp., *G. parviflora*, *Euphorbia* sp., *Cyperus* and *O. latifolia* (Table 4.1). These weeds were also mentioned by farmers as the most prevalent and serious weeds in their fields (Table 4.2). Although *Cyperus* sp. and *O. latifolia* had slightly high mean densities, their low frequencies of citation by farmers was due to the fact that they were concentrated in specific regions of the survey. *Oxalis latifolia* was mainly found in Mpigi district of central Uganda where its mean density was significantly different from the other districts ($p = 0.0001$). It is believed that this weed was introduced to Uganda in the 1920's from Kenya as a cover crop in coffee plantations (Tiley, 1970). This was first in central Uganda where coffee was important which included Mpigi district. Since then it has spread from the areas of introduction to cover the entire country. The weed is also positively associated with soil pH, soil calcium and clay contents and soil depth which all seem to be relatively high in Mpigi district compared to other districts (Table 4.7).

Cyperus species was less frequently cited as prevalent by farmers during the survey although we found it in 60% of the fields surveyed.

This was because the weed was frequently found in fields near swampy areas (Figure 4.3) that were less frequently cultivated for annual crops except in Pallisa district. The population density was significantly higher in Pallisa than in other districts ($p = 0.004$). The rest of the weeds were widely distributed in all districts.

Solanum nigrum and *Amaranthus* sp. were found important as food for human beings and were less encountered in the cultivated fields. Their not being found in cultivated fields was because they were constantly removed during weeding and used as spinach. The dry spell in the 1997A season and heavy rainfall in the 1997B season resulted in poor crop growth and yield creating the need for alternative source of food. These "weeds" were the more suitable alternative to allow survival. Although they may reduce crop yield, their biomass yield is considered part of crop yield and less as competing weed species with crop plants (they are in fact labelled "crops" in most areas although they are not intentionally grown by farmers).

Apart from causing yield reduction and being used as food, some of the weeds are important source of medicine for cure of varied diseases as also reported in other countries (Brandao et al., 1997; Rabe and Staden, 1997). Due to poor health facilities in rural areas and the high costs of modern or western medicines, farmers are willing to preserve some of these weeds in specific areas for medical purposes.

Farmers in their several years of field cultivation have come to associate weed abundance with six main factors namely soil fertility, soil depth, cropping system, land drainage, soil texture and soil acidity (soil

pH) (Table 4.6). These can be grouped into two main factors as soil chemical and physical factors and cropping system-related factors. Results from multivariate analysis of canonical correspondence analysis or CCA and multiple regression analysis (MRA) were similar and indicated that both soil and cropping system environments affected weed species abundance in the surveyed areas. *Euphorbia* sp. was commonly found in soils of relatively high P and N and *B. pilosa* and *S. halepense* were relatively many in soils of low N and C (Figure 4.2) and increased in number with increasing soil P and N, respectively (Table 4.11). This confirms our field experiment finding that *B. pilosa* was most likely to be a problem to crops under moderate soil N and relatively high soil P as indicated by the high dry matter (Figure 2.10) and eventually yield reduction (Table 2.24). *Bidens pilosa*, *S. halepense* and *Euphorbia* sp. abundance declined with increasing soil pH, soil depth and soil silt content (Figure 4.2). At higher pH, there is possibility that P in the presence of Ca was fixed in the soil becoming unavailable to the weeds resulting in lower density (Tisdale et al., 1993). *Galinsoga parviflora*, *A. conyzoides*, and *B. pilosa* plants were numerous in low carbon and N soils. *Oxalis latifolia* was most often found in high pH and carbon soils and soils of high Ca content.

Both canonical correspondence analysis and multiple regression analysis indicated that soil N, P, K and C contents and soil pH explained much of the variation in weed abundance. This was similarly reported by other authors (Saavedra et al., 1990; Pysek and Leps, 1991; Ervio et al., 1994). Weeds like *Digitaria* sp., *Commelina* sp., *S. halepense*, *G.*

parviflora and *A. conyzoides* and to some extent *B. pilosa* and *E. indica* which were near the centroid (Figure 4.2) were less affected by soil environments indicating their wide adaptability to a range of soil environments. The farmers also noted this by the mention of these weeds as the most frequently occurring despite variation in soil fertility and cropping systems (Table 4.2). *Cynodon dactylon* was mostly found in fields near livestock (cattle) kraals or near swampy areas or valley bottoms, which are in most cases grazing sites to livestock. This may confirm the theory advanced by farmers that livestock distributes weed seeds.

Cropping system also had profound effects on weed abundance. This has also been observed by other researchers (Hume, 1982; Ervio and Salonen, 1987; Ervio et al., 1994; Andersson and Milbergs, 1998). The presence of either perennial or annual crops, the frequency of weeding, the seasons since the field was fallow and seasons since the field was used for perennial crop and the topographical field position greatly affected weed abundance (Table 4.10 and Figure 4.3). These variables were closely correlated with the first and second axes of the CCA ordination (Table 4.10). This was also supported by the significance of the axes as performed by Monte Carlo permutation test in explaining the weed-environment interaction (Table 4.8). *Euphorbia* sp. was more common in perennial crops (coffee, banana and cassava) and increased in number with frequency of weeding. Weeding each time probably exposed the dormant seeds or deep buried seeds to favorable environment resulting in high germination rate and abundance. On the other hand,

Oxalis latifolia was associated with annual crops and negatively with weeding frequency. This could have been due to the fact that the first season of 1997 was very dry and the frequent weeding could have exposed the bulbs to dry condition resulting in low germination rate and therefore, low abundance. In perennial crops, their density was high. Perennial crops (banana, coffee and cassava) could have provided shady condition allowing survival of the weed during the dry season experienced in 1997A season. This could have similarly applied to *Euphorbia* sp. under perennial cropping resulting in their increased abundance.

Sorghum halepense and *E. indica* were more common in cereal fields or fields which were grown to cereal crops especially sorghum, maize and millet in the previous season. *Sorghum halepense* is more closely related to sorghum and *E. indica* closely related to millet and at the early stages of growth are very difficult to distinguish. They often escape weeding and reach maturity resulting in more seeds in those particularly fields the following season. *Bidens pilosa*, *Digitaria* sp., *P. maximum*, *G. parviflora*, *Amaranthus* sp., *C. dactylon*, *Cyperus* sp., and *Commelina* sp. were found as frequently in annual and perennial crops in the 1997A season.

Sorghum halepense , *E. indica*, *Digitaria* sp., and *P. maximum* were more in fallow fields or fields that have just come out of fallow. During the fallow period, they produce seeds which continue to germinate increasing abundance. During the first few weedings, the seeds are exposed to favorable environments resulting in high germination and

abundance. With frequent cultivation and weeding, these weeds are not allowed to reach maturity, greatly reducing their abundance. This indicates the seriousness of these weeds especially in cereal crops.

Bidens pilosa, was found in similar frequency in sole and intercropping systems while *Digitaria* sp. and *E. indica* were more common in sole crops than intercrops of cereals in the 1997A season. *Panicum maximum* and *S. halepense* were more in intercrops than sole cropping in the 1997A season (Figure 4.3). Most weeds were found in mid slope fields where cultivation is more commonly carried out.

Regression analysis showed that the abundance of weeds like *Digitaria* sp., *A. conyzoides* and *G. parviflora* were not well explained by the environmental variables used, as indicated by their low R^2 values (Table 4.11). Other weeds had their abundance variation well explained by the environmental variables with R^2 up to over 40%. In the regression models, both soil and cropping system environments were important in determining weed abundance.

Although MRA provided models to explain weed abundance, the CCA provided simple diagrams that expressed the pattern in variation of weed abundance and the relationship between weed species and each of the environmental variables. The diagramming using CCA makes explanation of weed species abundance - environment relationship easy.

CONCLUSION

Due to many factors involved in weed composition and abundance, drawing definite conclusions from the survey data may be limited due to the complex cropping history and interactions of factors. The relatively

high eigenvalues in the third and fourth axes (Table 4.9 and 4.10) and the low regression coefficients (Table 4.11) still indicate the complex nature of the weed abundance in this area, which may be difficult to explain with the few environmental variables used. Other environmental data such as weather data and data collected over several seasons could be important. More detailed information on crop history, crop rotation, crop association (multiple cropping), crop growth habits, land preparation methods and weed control methods are needed to effectively explain weed abundance in this area.

From the results, it can still be concluded that weed abundance varied with cropping systems more than with soil properties. In general weed abundance was more responsive to soil P, N, C, and pH, frequency of weeding, seasons since fallow, whether the crop grown was annual or perennial and seasons since perennial crop was grown in the field. To a lesser extent, soil K and the nature of cropping whether sole cropping or intercropping affected weed abundance. Weeds responded differently to different environmental variables. For example, *Euphorbia* sp. responded significantly to soil P. A number of the weeds showed low response to the environments indicating their wide adaptability. Most weeds had tendency to increase in number with increasing soil P and decrease in number with increasing soil N, C and K and this confirms the importance of P in the nutrition of the weeds.

Results from the analyses (both CCA and MRA) confirm the observations made by the farmers. Both observations and analysis indicate that *B. pilosa*, *G. parviflora*, *A. conyzoides*, *Digitaria* sp., and

Commelina sp. are widely adapted to environmental conditions across locations as confirmed by their frequencies of mention by the farmers and their high densities encountered in the fields. They may also be the major troublesome weeds causing great yield reduction in farmers' fields. Some of the weeds were found in large numbers in particular areas where environmental conditions allowed their survival and multiplication such as *O. latifolia* and *Cyperus* sp. in Mpigi and Pallisa districts, respectively, confirming the effects of environment on weed distribution and abundance.

Both MRA and CCA were similar in explaining the weed-abundance relationship that was observed in the fields in Uganda in 1997. It should be noted that these are weed numbers (abundance) which may not necessarily reflect yield reduction in crops. To correlate with crop yield losses, weed biomass weights should also be considered in addition to yields of the crops.

CHAPTER FIVE
GENERAL DISCUSSION

Weeds are of major concern in crop production among the resource-poor farmers in Uganda. According to farmers and our own observations, *B. pilosa*, *Digitaria* sp., *A. conyzoides*, *Commelina* sp., *G. parviflora*, *Euphorbia* sp., and *Cyperus* sp. were the most frequently encountered weeds on farmers' fields (Tables 4.1 and 4.2). These weeds had high mean densities, were widely distributed and seem to be some of the most troublesome weeds in crop production. They are adapted to a wide range of environmental conditions across locations and are more likely to cause great losses to crops if not properly managed. Many researchers have reported bean yield reduction due to competition from weeds ranging from as low as 2% to nearly 100% depending on the weed in question, its density and other growth factors (Fennimore et al., 1984; Blackshaw, 1991; Zollinger and Kells, 1992, Malik et al., 1993; Wilson, 1993; Chikoye et al., 1995).

Another factor of concern in bean production in Uganda is low soil fertility especially N, P and K interacting with Al and Mn toxicity (Wortmann and Allen, 1994). Farmers in Uganda usually grow beans without fertilization or inoculation yet most of our soils are low in soil fertility. In addition to the low soil fertility, most of the available bean varieties grown by farmers are poor nodulators. Research has shown that bean response to inoculation has been varied with most local cultivars showing low response to inoculation under our production condition in

Uganda (Jjemba and Male-Kayiwa, 1993). Therefore, proper nutrient management is important for better bean production.

Not all weeds were considered by farmers as bad plants. Nightshade is an important weed in bean production in the United States and Canada (Ogg and Rogers, 1989; Fennimore et al., 1984), yet it is not considered a weed of major importance in Uganda (Table 4.5). Black nightshade is considered a vegetable by farmers in most places in Uganda and is a source of income in urban places. Galinsoga and bidens were observed by farmers as serious weeds in crop production (Table 4.5) and are of economic importance. All three weeds (galinsoga, bidens and black nightshade) were found to be sources of medicines for the cure of various diseases ranging from headache to the cure of patients with high blood pressure and diabetes.

Our results indicate that bean yields were significantly better under the NPK, OPK, NOK and OOK nutrients in 1995 and 1996 (Tables 2.20, 2.21 and 2.22) and only under the NOK in the 1997B season (Table 2.24). The better yields of beans under these nutrient treatments was related to their better canopy covers (Tables 2.6 and 2.8), LAI (Table 2.12) and shoot dry weights (Figures 2.10 and 2.11). This eventually resulted in high pod and seed yield per unit area. Other factors that could have played important roles in improving bean yield could have been the presence of mycorrhizal infection in the NOK and OOK treatments and the slightly better nodulation of beans in the OPK and OOK nutrients (Table 2.7). El-Ghandour et al. (1996) observed that faba-bean yield improved with mycorrhizal infection. Similarly, Vejsadova et al. (1990)

indicated that the presence of low levels of P and N improved plant root infection with mycorrhizae. The presence of mycorrhiza infection also improved N-fixation resulting in improved growth of the nodulating plants. All these point to the fact that mycorrhizae may play a very important role in the nutrition of beans and therefore, bean-weed association.

As pointed out earlier, weeds have played significant negative roles in bean production. The presence of weeds (galinsoga, bidens and black nightshade) resulted in significant bean yield reduction especially under the NPK and NPO treatments (Tables 2.22, 2.23 and 2.24). Weeds in the absence of P (NOK) were less competitive with beans due to their low shoot dry weights (Figure 2.10). Weeds in the presence of NPK and NPO were very vigorous resulting in much shoot dry matter production (Figure 2.10) creating more competition against beans. Screenhouse experiments indicated that beans and the weeds (galinsoga and bidens) all had high shoot and root growth rates under the NPK and NPO treatments (Tables 3.2 and 3.4). Beans had significantly higher growth rates than the weeds at the early stages of growth. Later in the growth period (between 35 and 49 DAP), bidens had the same shoot growth rate as beans (Table 3.2) and both weeds had higher root growth rates than the beans (Table 3.4). Both galinsoga and bidens had significantly higher shoot and root relative growth rates, nearly 4 times that of beans (Tables 3.2 and 3.4). This indicates that although weeds may start growth at a slow pace, they are more likely to catch up with the crops due to their high RGRs (Mohler, 1996) and outcompete the crops. Fennimore et al. (1984) reported higher

RGRs in black nightshade and barnyard grass than in beans. They observed that the large bean seed size and early germination were masked by the slow RGR of beans giving the weeds competitive advantage over the beans.

Our finding also indicates that the RGRs of bidens and galinsoga declined much more slowly than that of beans (Tables 3.2 and 3.4) as the plant increased in size. This was explained by Grime and Hunt (1975) and Chapin et al. (1989) to be due to the greater proportion of non-photosynthetic structural materials, higher maintenance respiration and more selfshading in large plants resulting in large plants. This leads to faster decline in RGR in large seeded species as they increase in size.

Similarly, by 35 to 49 DAP in the screenhouse, weeds had high root/shoot ratios (Table 3.5), root length (Figure 3.2) and significantly higher root elongation rate (Table 3.6) than beans. Galinsoga and bidens had root elongation rates of 2 and 3 times that of dry beans, respectively (Table 3.6). This could have aided weeds in absorption of nutrients in the field resulting in better weed growth with improved competitive ability under the N and P nutrients. The weeds also had most of their roots and high specific root length within the top 10 cm soil depth in the screenhouse (Figures 3.4 and 3.5, Table 3.7). The high specific root length indicates the presence of numerous small weed roots within the 10-cm soil depth increasing the root surface area for more nutrient absorption. Greenwood et al. (1982) and Gregory (1988) reported high plant rooting density within the top 10-15 cm under field conditions. It also happens that most soil nutrients are within the 10-15 cm soil depth

(Marschner, 1986). By having most of the roots within the upper soil layer gives the weeds more advantage and access to the nutrients. This was also manifested by the fact that the nutrients were broadcast applied and thinly mixed in the upper 15-20 cm soil layer. This could have been of advantage to the weeds under the field situation increasing the competitive ability of weeds against beans especially under the NPO and NPK treatments. Better root growth could have resulted in more efficient uptake of K, Ca and Mg nutrients by weeds in the field compared to beans (Table 2.14, 2.15 and 2.16). This was similar to the finding of Qasem (1992) who noted that a number of weeds growing with beans had significantly higher shoot concentrations of P, K, Ca and Mg than beans. They noted that this could have been due to better translocation of nutrients from the roots to the shoots. Similar processes could have taken place in our field experimentation.

Beans both in the field and in the screenhouse in the absence of P (NOK) had relatively better growth than the weeds. Beans had higher root dry weights in 1996 (Table 2.10) and shoot dry weights in all seasons than the weeds (Figure 2.10). In the screenhouse, beans had higher root lengths than the weeds within the top 10 cm soil depth for the first 21 DAP (Figure 3.4) and significantly higher root length at deeper soil depth than the weeds (Figure 3.5). In the absence of P, the greater bean root length at higher soil depth and the larger soil volume occupied by bean roots could have been of advantage to beans to absorb more of the immobile P from the soil than the weeds. This could have given beans more advantage to secure the little available P under field conditions

improving their competitive ability against the weeds. The slightly late emergence of weeds in the NOK treatment could have also given beans advantage over the weeds with better initial head start. The slightly late maturity of beans in the absence of P gave beans more time to accumulate more dry matter and outcompete the weeds. All these seem to have positively affected beans resulting in improved bean yield in the absence of P.

Both field and screenhouse experiments support the fact that weeds are most likely to become very competitive in the presence of N and P. This in the screenhouse seems to be due to faster growth rates of the weeds giving the weeds more access to nutrients and other growth factors thus improving their competitive abilities against beans. It was also observed in farmers' fields that bidens was positively associated with soil P and increased in number with increasing P level (Figure 4.2). Bidens was also slightly positively associated with N nutrient confirming our field observation. Our field results indicate that bidens was a better N accumulator than galinsoga when grown with beans. Farmers' observations also indicated that both bidens and galinsoga were very vigorous at high soil fertility and were most likely to cause more damage to beans under the high soil fertility status.

Our results also indicate that beans were better accumulators of N than the weeds as indicated by the high bean shoot N concentration under all nutrient and weed treatments across locations (Tables 2.14, 2.15 and 2.16). This may indicate that beans are more efficient in the utilization of N from soil organic matter as the plots used had relatively high organic

matter (Tables 2.2 and 2.3). It may also indicate that beans are in position to supply their own N through N fixation (Table 2.7). Black nightshade was a better accumulator of N and K than galinsoga but galinsoga was a better accumulator of Ca than nightshade (Figure 2.20). This was similarly observed in farmers' fields where galinsoga was more associated with soil Mg and Ca (Figure 4.2) with increased abundance with increasing levels of Ca and Mg. The indication by farmers of using young succulent bidens and black nightshade as green manure crops in banana plantation seem to indicate the need for K by bananas (Hegde and Srinivas, 1991). Our finding indicates that these weeds were rich in nutrients and could supply crops with the needed nutrients when used as green manure crops. Bidens was found to be a good Mg accumulator. The three weeds if properly managed are most likely to be of importance in acidic soils since liming is not common among farmers yet our soils are becoming more acidic. Therefore, proper management of these weeds is important if their benefits are to be realized as green manure crops.

In general, galinsoga may be more widely adapted to a wide range of soil environments than bidens (Figure 4.2) but bidens is more likely to perform well and be more competitive with beans in the presence of N and P. Both field and screenhouse experiments and the survey results seem to indicate that in the presence of N and P, these weeds are likely to be very competitive with beans. In the absence of N and P nutrients, weeds are likely to perform poorly and give beans competitive advantage over the weeds.

CHAPTER SIX
SUMMARY AND CONCLUSION

Beans are the major grain legumes in Uganda. Their production is constrained by both low soil fertility including Mn and Al toxicity and weed competition. Among resource-poor farmers (RPF), labor is a major problem and the use of energy-saving technologies is limited. Due to the need to get better alternatives of weed management, we decided to carry out this research to investigate nutrient use in bean-weed association. The understanding of nutrient use in the association may allow for better management of nutrient in the system to the advantage of beans rather than the weeds.

This research was aimed at determining bean cultivar response to nutrients and analyzing competition between beans and weeds (galinsoga, bidens and black nightshade) as affected by low soil fertility. The research was also aimed at determining the effects of nutrients on growth rates of weeds and beans. The idea was to find out which particular nutrients favored beans when in competition with weeds and which nutrients favored weeds when in competition with beans. To have these findings more useful to the situation on-farm, it was necessary to get more information on how the abundance and distribution of these weeds and other weeds are affected by soil and other environmental factors in farmers' fields in Uganda. Having a thorough knowledge of bean-weed association could help in designing a much more effective weed

management strategies for resource poor farmers through better nutrient management strategies.

Our results indicate that bean cultivars differed in their response to nutrients with some cultivars more adapted to lower levels of soil fertility. Bean cultivar RAO 55 was found to be more adapted to multiple nutrient deficiencies while BAT 25 was more adapted to low P and K. Bean cultivar K 131 was better adapted to low N and K. Bean cultivar K 131 may also be more suitable for competition with weeds due to its late maturity and type II growth habit (indeterminate bush) compared to BAT 25 and RAO 55 which are early maturing and of type I growth habit.

The results also indicate that beans had good performance in the NPK, OPK, NOK and OOK treatments. The good performance of beans under these nutrients was related to good canopy covers, LAI, root dry weights and high PAR absorption, with high shoot dry weights and eventually pod and seed yield per unit area. The better development of beans in the absence of P or N, or both, and possibly involvement of mycorrhizae gives promise for more manipulation of nutrients for better weed management.

The presence of weeds significantly reduced bean seed yield and this was more emphasized in the NPK and NPO nutrients resulting in greater loss of income. This was due to the relatively high weed growth rate (shoot and root relative growth rates, root length and root elongation rate) in the presence of N and P when applied together. Since the performance of these weeds is more encouraged by N and P when they

are applied together, beans are more likely to be more competitive than the weeds in the absence of the two nutrients.

It was also noted that nightshade was a better N and K accumulator and may be a better competitor in the presence of K than galinsoga. Bidens was a better Ca and Mg accumulator while galinsoga was a better Ca accumulator. Beans were found to be better competitors for N than the weeds as was indicated by the lack of significant effect of nutrients and weeds on bean shoot N concentration. Also there was no significant effect of weeds on bean leaf chlorophyll contents still indicating that beans are more efficient in utilizing available N than the weeds or are able to manufacture their own nitrogen. Bidens was noted to be more competitive with beans than galinsoga in the presence of N and P applied together and is likely to be more competitive at high soil fertility. Similarly, in farmers' fields, bidens was associated with P and slightly with N.

Due to the heavy mining of nutrients by these weeds, the presence of these weeds is likely to cause further soil depletion. The weeds are also likely to be suitable candidates for use as green manure crops as they accumulate high amount of nutrients. Therefore, with good management of the nutrients, beans are likely to be more competitive than the weeds resulting in less bean yield reduction in the presence of these weeds.

Nutrient management to improve bean competitive ability

The following are suggestions which are likely to improve the competitive ability of beans when in competition with weeds (galinsoga, bidens and black nightshade). Most of these suggestions have been made

by many researchers either covering crops or weeds in general in books or as reviews. The suggestions being made now is as a result of our finding using beans and is specifically towards managing the three weeds (bidens, black nightshade and galinsoga) when in competition with beans. It may or may not apply to all weeds and all crops.

The following measures are most likely to improve the competitive ability of beans against galinsoga, black nightshade and bidens. According to our findings, the exclusion of P (NOK) and N (OPK) had less negative effects on beans than on the weeds resulting in relatively high bean yield (Tables 2.22 and 2.24). By using mycorrhizae in the absence of P (NOK) or N (OPK) and high nodulating bean cultivars in the absence of N (OPK) could greatly improve the competitive ability of beans against weeds. It had been noted that all three weeds can be infected by mycorrhizae (Gerdemann, 1968) although their infection rates when grown with beans have not been indicated. Stejskalova (1990) observed that mycorrhizal infection increased significantly in maize by 29% in the presence of *G. parviflora* compared to monoculture maize when both plants were inoculated with mycorrhizae. At the same time, mycorrhizal infection on *G. parviflora* increased in the presence of maize. This may indicate some form of mutual benefit that both plants derive from the association when grown together with mycorrhizal infection. This needs to be researched in bean-weed system in more detail.

The use of mycorrhizae in the absence of P (NOK) and highly nodulating bean cultivars in the absence of N (OPK) would even be more

effective if the nutrients are made unavailable to the weeds through banding. Our findings of better bean performance under minus P and N have been through broadcast application of the nutrients. Banding of these nutrients to bean rows so that they are more available to the beans would further improve beans' efficiency in utilizing these nutrients resulting in improved beans' competitive ability against the weeds. If the beans could be given nutrients by banding to further accelerate growth as weed emergence is delayed in the absence of P, the beans could quickly over top the weeds. This then could allow weeds be in check long enough for the crops to form canopy over the weeds making weed management easy. Farmers then can afford to delay weeding in case there are other pressing activities without losing bean yields. Otabbong et al. (1991) observed that banding of phosphorus 7 cm deep along the bean rows in bean-weed trial greatly lowered weed populations compared to broadcast application and increased bean seed yield. Similarly, Maynard (1992) indicated a great drop in bean yield in competition with velvetleaf (*Abutilon theophrasti*) only when velvetleaf had access to P and K. By banding P and K, bean competitive ability against velvetleaf was improved.

In order to improve nutrient use efficiency and yield of beans, the use of bean cultivars more adapted to low soil nutrients would be of advantage. A variety like K 131 of type II growth habit and slightly late maturing especially in the absence of P would be of more advantage in competition with weeds than BAT 25 and RAO 55.

A nutrient treatment that may best be used for improved bean yield is the application of K nutrient only (OOK) in a soil of relatively high organic matter. Our result had shown very high bean yield under OOK nutrient in the absence of weeds. But since these weeds tend to perform well in the presence of N and P, there is high probability that a highly nodulating late maturing bean cultivar (type II growth habit) in combination with mycorrhizae would be useful in bean-weed management system. Research is needed to test this under field condition to ascertain how much yield reduction can be due to weeds. Situations of low soil nutrients are common in Uganda and a better way to manipulate nutrients and other means to achieve high bean yield in the face of competing weed species with lack of labor is very important.

Future research needs

In the future, research may need to focus more on nutrient management in bean-weed system in order to improve the competitive ability of beans when in competition with weeds. This needs to be extended to include other weeds apart from the three weeds we looked at in our current research. It is also important that a combination of the weeds be looked at when in competition with beans. The following areas of research are suggested for further investigation:

(a) The role of mycorrhizae in bean-weed (galinsoga, nightshade and bidens) association in the absence of P (NOK), or both N and P (OOK). It is also important that the role of mycorrhizae be considered in the interaction between beans and these weeds when the weeds are in combination than singly.

(b) There is need to test whether the use of highly nodulating bean cultivars would greatly influence the relationship between beans and weeds in the absence of added N to the extent that bean yield would be maintained at relatively high level.

(c) A study to combine the effect of both mycorrhizae and high nodulating bean cultivars in bean-weed association needs attention.

(d) Similar research activities in (a), (b) and (c) need to be extended to other weeds than the three weeds considered in this research. It will be important to carry out the three above activities when natural weed population in dry beans is considered.

In all the above cases (a, b and c), the nutrients should be banded rather than broadcast applied to make them more available to the beans than the weeds.

(e) Lastly, weed surveys need to be conducted to cover more areas of Uganda and these should also relate weed biomass yield to crop yield. Other factors like weather variables and detail histories of the fields, crops planted and their association in the field and crop rotations should be considered during the survey. It may be important to carry out the survey over several seasons in order to come up with a good approximation of weed abundance, distribution and the effects on crop production. Surveys should also relate weeds as indicators of fertilizer (nutrient) needs of the soils for diagnosis purposes.

APPENDIX A
(ADDITIONAL TABLES FOR CHAPTER 2)

Table A1 The costs of bean production at farm level in Uganda in 1997 (average cost of production in the suburb of Kampala)

Activities	Amount per ha[1] in Uganda shillings
1. Land preperation	
(a) Slashing	15,000.00
(b) Plowing	50,000.00
(c) Harrowing	50,000.00
Sub-total	115.000.00
2. Seeds for planting at 30 kg seeds per ha[1]	27,000.00
3. Planting	
30 people/day/ha x 1,500=/person/day	45,000.00
4. Fertilizer costs	
(a) Muriate of potash at 18,000=/bag of Kcl applied at 60 kg K/ha	43,200.00
(b) Ammonium nitrate (NH4NO3) at 25,000= per bag applied at 50 kg N/ha	75,000.00
(c) Triple superphosphate at 18,000= per bag applied at 50 kg P/ha	90,000.00
(d) Transport coct at 2,000= per bag of fertilizer (2,000=/bag x 10.4 bags)	20,800.00
Sub-total	244,000.00
5. Weeding	
40 people/ha x 1,500=/person	60,000.00
6. Costs of pesticides	
(a) Insecticide (Ambush) (1997A) at 10,000=/ha and application cost of 15,000=/ha	25,000.00

Table 1A (Continued)

(b) Fingicide (Dithane M45) (1997B) at 15,000=/ha and application cost of 15,000=/ha	30,000.00
(c) Fungicide (Antracol) (1997B) at 12,000=/ha and application cost of 15,000=/ha	27,000.00
7. Harvesting 25 people/ha x 1,500=/person	37,500.00
8. Threshing 10 people/ha x 1,500=/person	15,000.00
9. Sorting and bagging at 1,500= per bag of beans	
10. Transport to the market Transport cost at 1,500=/bag for 30 km distance and market tax of 5,000=/bag	

Table A2 The effect of nutrients and weeds on bean yield ha^{-1} (kg) and % yield reductions in the 1996, 1997A and B seasons

Treatment	1996		1997A		1997B	
	Seed yield ($kg\ ha^{-1}$)	Percent[a] yield reduction	Seed yield ($kg\ ha^{-1}$)	Percent[a] yield reduction	Seed yield ($kg\ ha^{-1}$)	Percent[a] yield reduction
NPK, weed-free beans	1,406.05	0.00	249.46	0.00	1,059.25	0.00
NPK, bean-galinsoga	699.84	-50.23	179.06	-28.45	540.75	-48.95
NPK, bean-nightshade or bidens[b]	1,185.77	-15.66	110.66	-55.64	517.61	-51.13
OPK, weed-free beans	1,425.61	0.00	227.51	0.00	914.11	0.00
OPK, bean-galinsoga	1,039.92	-27.05	170.61	-25.01	441.57	-51.69
OPK, bean-nightshade or bidens[b]	1,030.39	-27.72	109.90	-51.69	601.17	-34.23
NOK, weed-free beans	1,706.08	0.00	255.86	0.00	1,342.76	0.00
NOK, bean-galinsoga	1,374.04	-19.46	175.79	-31.29	937.56	-30.18
NOK, bean-nightshade or bidens[b]	1,667.25	-2.28	148.59	-41.93	606.74	-54.81
NPO, weed-free beans	711.21	0.00	239.33	0.00	1,148.15	0.00
NPO, bean-galinsoga	243.78	-65.72	139.96	-41.52	547.02	-52.36
NPO, bean-nightshade or bidens[b]	368.98	-48.12	138.52	-42.12	476.43	-58.50
OOO, weed-free beans	567.54	0.00	262.42	0.00	753.36	0.00
OOO, bean-galinsoga	366.44	-35.43	159.96	-39.04	619.44	-17.78
OOO, bean-nightshade or bidens[b]	323.59	-42.98	120.78	-53.97	568.85	-24.49

[a]Percent yield reductions are calculated for bean yields in comparison to their weed-free beans as the standard base at each nutrient,
[b]In 1996, *S. nigrum* was used and in 1997, *B. pilosa* was used.

APPENDIX B
(ADDITIONAL TABLES AND FIGURES FOR CHAPTER 4)

Table B1 Questionnaire used for the weed species abundance survey in Uganda in 1997

General information:

1. Region.....District.....County.....Village.....
Farmer's Serial #.....Farmer's Name.....

2. Latitude.....Longitude.....Altitude.....

3. Topographic position of the field/plot (slope class) (i) hill top, (ii) upper slope, (iii) mid slope, (iv) lower slope, (v) upper valley, and (vi) valley

Climatic variables:

4. Average climatic data for 1996 and 1997
Rainfall amount, temperature (minimum temperature and maximum temperature) and relative humidity

Soil factors:

5. What is the soil texture? (i) Clayey (ii) sandy (iii) Loam (iv) others

6. Which soil texture is preferred for crop production? Reasons.....

7. Which soil type is best for crop production? (name some of the crops with preferred soil types) (i) Black (ii) Brown (iii) Light (iv) Heavy (iv) Others, specify. Reasons.....

8. Determine the soil depth of the surface plow layer (cm) .....

9. Soil nutrient analysis results for the soil samples from this field
N.....K.....P.....Ca.....Mg.....%C.....soil pH.....

10. What drainage class does the field fall? (i) well-drained (ii) fairly drained (iii) poorly drained.

Table B1 (Continued)

11. Does soil fertility affect the choice of land for crop production as regard weeds? (yes/no)
If yes, which one do you choose for which crop as regards weeds? (i) very fertile (ii) medium fertility (ii) less fertile (iv) others, specify

Crop	Soil type	Weeds most prominent if other soil types

Weeds and their economic importance:

12. Note and count these weeds from each field by using the line method

Broadleaf weeds	No.	Grasses	No.
(a) *Bidens pilosa*		(a) *Cynodon dactylon*	
(b) *Galinsoga parviflora*		(b) *Digitaria* sp.	
(c) *Amaranthus* sp.		(c) *Setaria* sp.	
(d) *Datura stramonium*		(d) *Panicum maximum*	
(e) *Solanum nigrum*		(e) *Eleusine indica*	
(f) *Portulaca oleracea*		(f) *Sorghum halepense*	
(g) *Euphorbia* sp.		(g) *Cyperus* sp.	
(h) *Oxalis latifolia*		(h) *Imperata cylindrica*	
(i) *Commelina* sp.			
(j) *Ageratum conyzoides*			

13. Make observations on other weed species that are common in the region/area

14. Which weeds prevail generally in the area (ask the farmers as to which weeds are more common in order of importance)

15. What factors do you think affect the abundance and distribution of weeds in this area? Check lists below: (a) Soil depth (b) soil pH (c) soil drainage (d) soil fertility (nutrients available) (e) cropping system (f) others, specify.
Explain.....
Probe to get specific information on which weed species are effected more by the mentioned factors.

16. Rate the seriousness of galinsoga, bidens and nightshade in crop production: (a) extremely serious (over 60% yield reduction), (b) very

Table B1 (Continued)

serious (30 – 60% yield reduction), (c) serious (10 – 30% yield reduction), and (d) not serious or no effect (less than 10% yield reduction).
If they are serious weeds, arrange them in order of importance in regard to crop production (name some crops where each weed is important).
Crop Weed

17. What are the economic uses of these weeds if any
(a) Galinsoga (b) Bidens (c) Nightshade

18. Does the use of farmyard manure have any effect on weeds? (yes/no)
Explain with emphasis on specific weeds affected by the use of FYM.

Cropping history of the field and current cropping system:
19. Note the crops grown this season on the plot

20. Crops grown last season on this plot

21. Seasons since land was in fallow

22. Seasons since the land was last used for perennial crops

23. What was the land preparation method on this plot this season
(a) land opening (b) land harrowing

24. The number of weeding this season on this plot?

25. Did you apply herbicides on this plot this season? (yes/no). If yes, which type.....
Last season? (yes/no). If yes, which type.....

Table B2 Additive Main Effect and Multiplicative Interaction (AMMI) model for estimation of weed abundance data

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Multiple regression analysis was carried out in order to derive models to explain the distribution and abundance of weed species in relation to environmental variables. Regression analysis was applied to the original weed species data. In order to increase the accuracy of prediction of the models and reduce 'noise' in the data, regression analysis was also applied to estimated weed species data. Additive Main Effect and Multiplicative interaction (AMMI) model was applied to the original data (Gauch, 1988; Gauch and Furnas, 1991) using the MATMODEL computer program (Gauch, 1990). The AMMI model applies the additive analysis of variance (ANOVA) to the two-way data, and then applies the multiplicative principal components analysis (PCA) model to the residual from the additive model, that is, to the interaction. Using the below model equation, weed species abundance or number at each sampling site was estimated. Regression analysis was then applied to the estimated weed species abundance data. The AMMI model used was:

$$Y_{ge} = \mu + \alpha_g + \beta_e + \Sigma_n \lambda_n \gamma_{gn} \delta_{en} + \varepsilon_{ge}$$

where
Y_{ge} is the number of a weed species g in sample site e;
μ is the ground mean number;
α_g are the weed species mean deviations (the weed species means minus the grand mean);
β_e are the sample site mean deviations (the weed species sample means minus the grand mean);
λ_n is the eigenvalue of principal components analysis (PCA) axis n;
γ_{gn} and δ_{en} are the weed species and sample site PCA scores for PCA axis n;
n is the number of PCA axes retained in the model; and
ε_{ge} is the residual.

Using the estimated weed abundance data, the prediction power of *B. pilosa* and *S. halepense* were improved but not the other weeds. For the other weeds, the models reported were from the original data.

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λ_n is the eigenvalue of principal components analysis (PCA) axis n;
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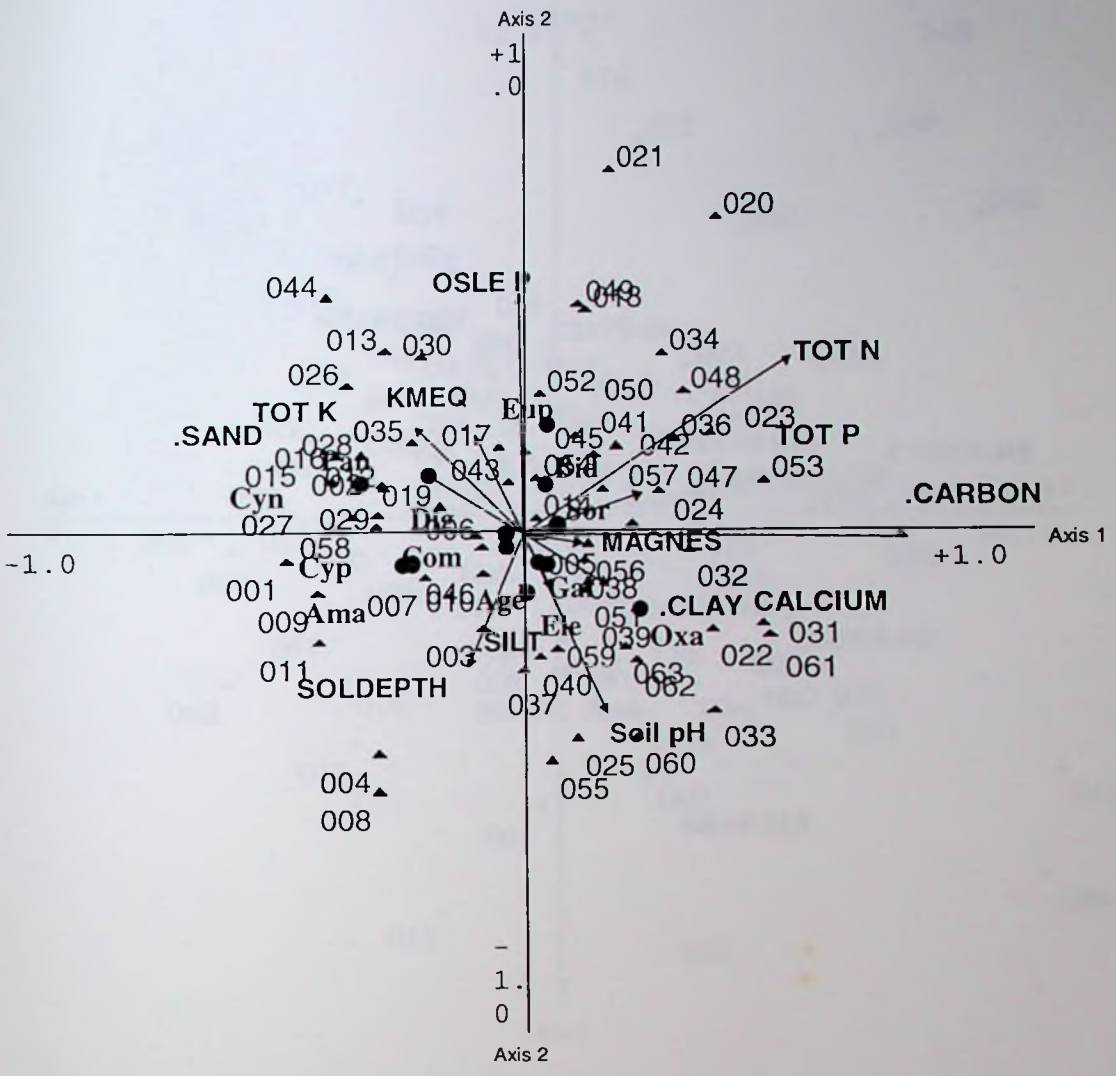

Figure B1 Triplot based on canonical correspondence analysis of weed species abundance with respect to 13 soil variables for 63 sample (field) sites (where 001-018 were sites in Pallisa district, 019-037 were sites in Kamuli district, 038-052 were sites in Iganga district and 053-063 were sites in Mpigi district) in cultivated fields in Uganda. Note: arrows are soil environmental variables, black dots are weed species (●) and solid triangles (▲) are sample sites or fields. The meanings of the abbreviations for weed species and soil environmental variables are as indicated in Figure 4.2

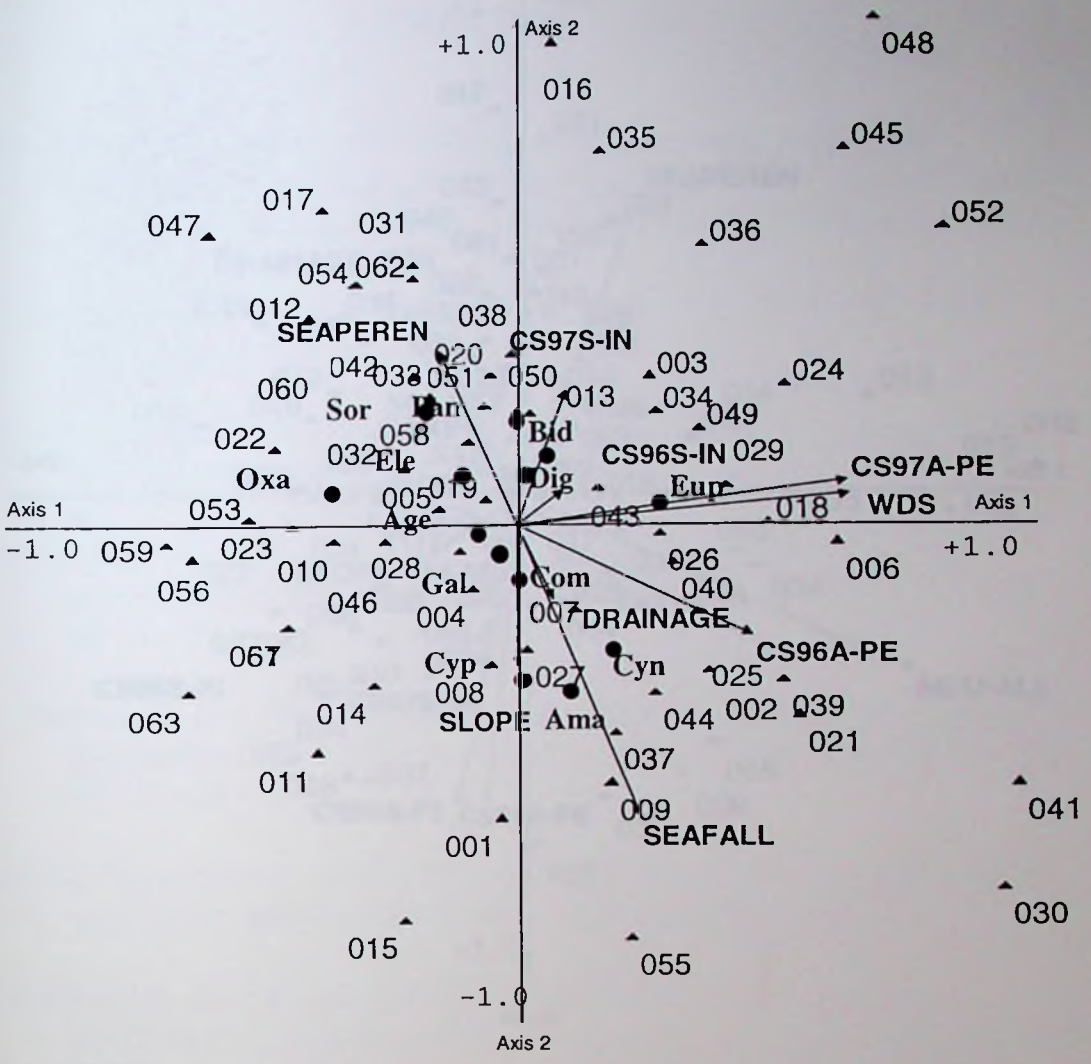

Figure B2 Triplot based on canonical correspondence analysis of weed species abundance with respect to 9 cropping system environmental variables for 63 sample (field) sites (where 001-018 were sites in Pallisa district, 019-037 were sites in Kamuli district, 038-052 were sites in Iganga district and 053-063 were sites in Mpigi district) in cultivated fields in Uganda. Note: arrows are cropping system environmental variables, black dots are weed species (●) and solid triangles (▲) are sample sites or fields. The meanings of the abbreviations for weed species and soil environmental variables are as indicated in Figures 4.2 and 4.3, respectively

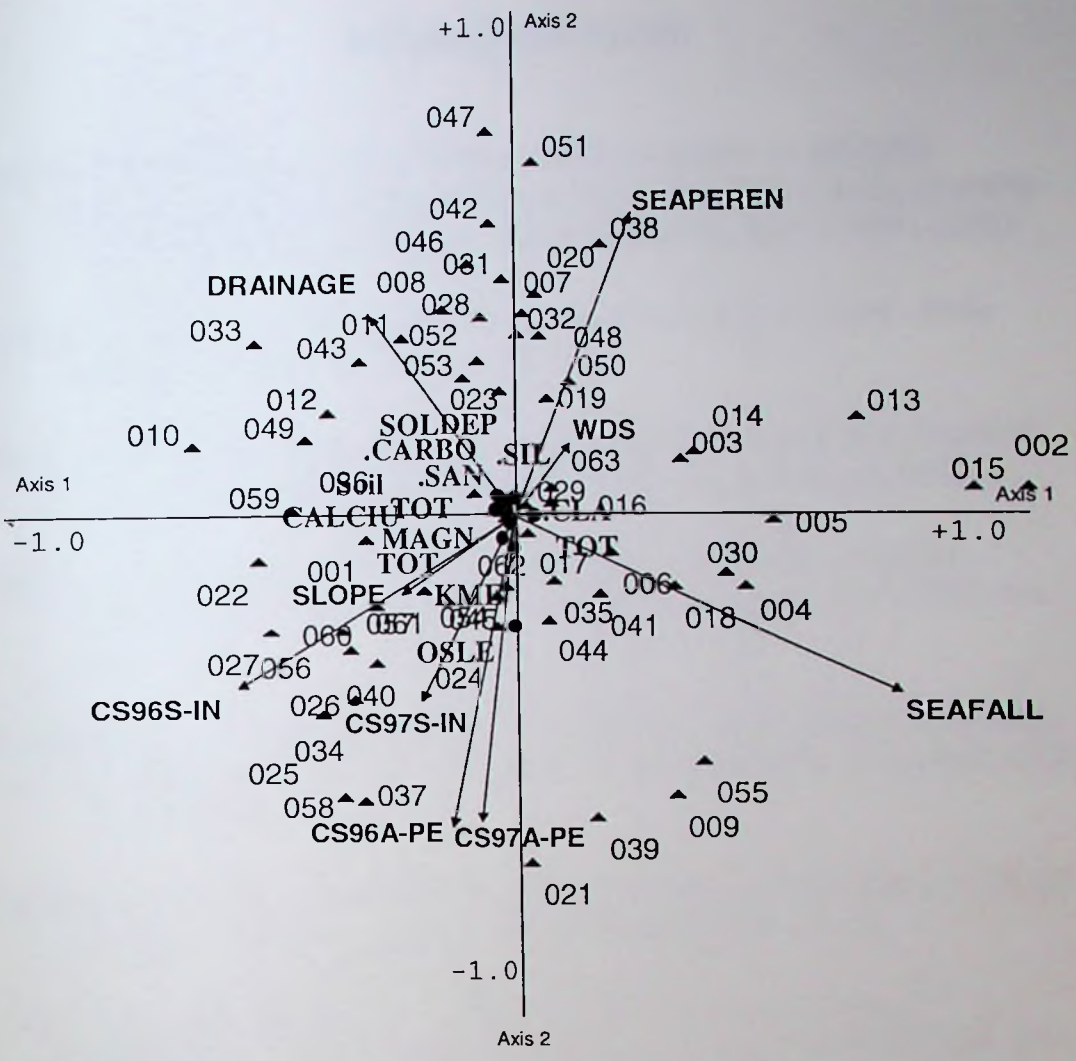

Figure B3 Triplot based on canonical correspondence analysis of 13 soil environmental variables with respect to 9 cropping system environmental variables for 63 sample (field) sites (where 001-018 were sites in Pallisa district, 019-037 were sites in Kamuli district, 038-052 were sites in Iganga district and 053-063 were sites in Mpigi district) in cultivated fields in Uganda. Note: arrows are cropping system environmental variables, black dots are soil environmental variables (●) and solid triangles (▲) are sample sites or fields. The meanings of the abbreviations for soil and cropping system environmental variables are as indicated in Figures 4.2 and 4.3, respectively

LITERATURE CITED

Abd-Alla M. A., and A. M. A. Wahab. 1995. Response of nitrogen fixation, nodule activities and growth to potassium supply in water-stressed broad bean. Journal of Plant Nutrition, **18**(7): 1391-1402.

Agamalian H. S. 1983. Competition of annual weeds in broccoli. Proc. West. Soc. Weed Sci. (Abst.) **36**: 192.

Aldrich R. J. 1984. Weed-crop ecology: Principles in weed management. Breton Publishers, Wadsworth Inc., Belmont, California 94002.

Andersson T. N., and P. Milberg. 1998. Weed flora and the relative importance of site, crop, crop rotation and nitrogen. Weed Science, **46**: 30-38.

Andreasen C., J. C. Streibig, and H. Haas. 1991. Soil properties affecting the distribution of 37 weed species in Danish fields. Weed Research, **31**: 181-187.

Bhaskar A., and K. G. Vyas. 1988. Studies on competition between wheat and *Chenopidium album* L. Weed Research, **28**: 53-58.

Blackshaw R. E. 1991. Hairy nightshade (*Solanum sarrachoides*) interference in dry beans (*Phaseolus vulgaris*). Weed Science, **39**: 48-53.

Brandao M. G. L, A. U. Krettli, L. S. R. Soares, C. G. C. Nery, and H. C. Marinuzzi. 1997. Antimalarial activity of extracts and fractions from *Bidens pilosa* and other *Bidens* species (Asteraceae) correlated with the presence of acetylene and flavonoids compounds. Journal of Ethnopharmacology, **57**(2): 131-138.

Brouwer R. 1962a. Distribution of dry matter in the plant. Netherlands Journal of Agricultural Science, **10**(5): 361-376.

Brouwer R. 1962b. Nutritive influences on the distribution of dry matter in the plant. Netherlands Journal of Agricultural Science, **10**(5): 399-408.

Burnside O. C., M. J. Wiens, B. J. Holder, S. Weisberg, E. A. Ristau, M. M. Johnson, and J. H. Cameron. 1998. Critical periods for weed control in dry beans (*Phaseolus vulgaris*). Weed Science, **46**: 301-306.

Buttery B. R., S. J. Park, and W. I. Findlay. 1987. Growth and yield of white bean (*Phaseolus vulgaris* L.) in response to nitrogen, phosphorus and potassium fertilizer and to inoculation with *Rhizobium*. Canadian Journal of Plant Science, **67**: 425-432.

Callaway M. B. 1992. A compendium of crop varietal tolerance to weeds. American Journal of Alternative Agriculture, **7**(4): 169-180.

Cakmak I., C. Hengeler, and H. Marschner. 1994. Partitioning of shoot and root dry matter and carbohydrates in bean plants suffering from phosphorus, potassium and magnesium deficiency. Journal of Experimental Botany, **45**(278): 1245-1250.

Carvalho D. A. de. 1980. Study on specific competition of weeds on bean crop. I. Competitive effects of marmalade grass (*Brachiaria plantaginea* (Link) Hitch.) and black spanish needle (*Bidens pilosa* L.) at different densities on growth and mineral nutrition of common bean (*Phaseolus vulgaris* L.). Ciencia e Pratica, **4**(2): 171-179.

Carvalho D. A. de. 1981. Study on specific competition of weeds in beans. II. Competitive effects of different densities of marmalade grass (*Brachiaria plantaginea* (Link) Hitch.) and black spanish needle (*Bidens pilosa* L.) on final stand, grain yield and primary components of beans (*Phaseolus vulgaris* L.). Ciencia e Pratica, **5**(2): 138-143.

Ceha L. J, C. Presperin, E. Young, M. Allswede, and T. Erickson. 1997. Anticholinergic toxicity from nightshade berry poisoning responsive to physostigmine. Journal of Emergency Medicine, **15**(1): 65-69.

Cerna L., and V. Valdez. 1987. Influence of *Sorghum halepense* and *Bidens pilosa* populations on the yield of beans Pirata 2. Turrialba, **37**(4): 303-309.

Chancellor R. J. 1985. Changes in the weed flora of an arable field cultivated for 20 years. Journal of Applied Ecology, **22**(2): 491-501.

Chapin F. S., III R. H. Groves, and L. T. Evans. 1989. Physiological determinants of growth rate in response to phosphorus supply in wild and cultivated *Hordeum* species. Oecologia, **79**: 96-105.

Chikoye D., S. F. Weise, and C. J. Swanton. 1995. Influence of common ragweed (*Ambrosia artemisiifolia*) time of emergence and density on white bean (*Phaseolus vulgaris*). Weed Science, **43**(3): 375-380.

Chivinge O. A. and M. A. Schweppenhauser. 1995. Competition of soybean with blackjack (*Bidens pilosa* L.) and pigweed (*Amaranthus hybridus* L.). African Crop Science Journal, **3**(1): 73-82.

Chivinge O. A. 1996. Studies on the germination and seedling emergence of *Bidens pilosa* and its response to fertilizer application. Transactions of the Zimbabwe Scientific Association, **70**: 1-5.

Christensen L. P., J. Lam, and T. Thomasen. 1990. A chalcone and other constituents of *Bidens tripartitus*. Phytochemistry, **29**(10): 3155-3156.

CIAT (Centro Internacional de Agricultura Tropical). 1987. Standard system for the evaluation of bean germplasm. van Schoonhoven A., and Pastor-Corrales M. A. (compilers), Cali, Colombia. 54 pp.

Conard S. G., and S. R. Radosevich. 1979. Ecological fitness of *Senecio vulgaris* and *Amaranthus retroflexus* biotypes susceptible and resistant to atrazine. Journal of Applied Ecology, **16**: 171-177.

Creelman R. A., H. S. Manson, R. J. Bensen, J. S. Boyer, and J. E. Mullet. 1989. Water deficit and abscisic acid cause differential inhibition of

shoot versus root growth in soybean seedlings. Plant Physiology, **92** (1): 205-214.

Croster M. P., and J. B. Masiunas. 1998. The effect of weed-free period and nitrogen on eastern black nightshade competition with english pea. Hortscience, **33**(1): 88-91.

Dale M. R. T., A. G. Thomas, and E. A. John. 1992. Environmental factors including management practices as correlates of weed community composition in spring seeded crops. Canadian Journal of Botany, **70**: 1931-1939.

Derksen D. A., A. G. Thomas, G. P. Lafond, H. A. Loeppky, and C. J. Swanton. 1994. Impact of agronomic practices on weed communities: Fallow within tillage systems. Weed Science, **42**: 184-194.

Di Tomaso J. M. 1995. Approaches for improving crop competitiveness through the manipulation of fertilization strategies. Weed Science, **43**: 491-497.

Donald C. M. 1963. Competition among crop and pasture plants. Advances in Agronomy, **15**: 1-118.

Edje O. T., L. K. Mughogho, and U. W. U. Ayonoadu. 1975. Responses of dry beans to varying nitrogen levels. Agronomy Journal, **67**(2): 251-255.

El-Ghandour I. A., M. A. O. Sharawy and E. M. Abdel-Moniem. 1996. Impact of vesicular arbuscular mycorrhizal fungi and rhizobium on the growth and P, N and Fe uptake by faba-bean. Fertilizer Research, **43**(1-3): 43-48.

Elmore C. D., J. D. Hesketh, J. E. Ephrath, and D. M. Alm. 1994. Physiological, morphological, and phenological aspects of crop-weed competitive strategies. Review of Weed Science, **6**: 51-76.

Ervio R. , S. Hyvarinen, L. R. Ervio, and J. Salonen. 1994. Soil properties affecting weed distribution in spring cereal and vegetable fields. Agricultural Science in Finland, **3**(5): 497-504.

Ervio R. L., and J. Salonen. 1987. Changes in the weed population of spring cereals in Finland. Annales Agriculturae Fenniiae, **26**(3): 201-226.

Evanylo G. K., and G. W. Zehnder. 1989. Common ragweed interference in snap beans at various soil potassium levels. Applied Agricultural Research, **4**(2): 101-105.

Everaarts A. P. 1992. Response of weeds to application of nitrogen, phosphorus and potassiun on low-fertility acid soils in Suriname. Weed Research, **32**: 385-390.

Fageria N. K. 1989. Effects of phosphorus on growth, yield and nutrient accumulation in the common bean. Tropical Agriculture (Trinidad), **66**(3): 249-255.

Fageria N. K., and A. M. de Carvalho. 1996. Response of common bean to phosphorus on acid soils. Communications in Soil Science and Plant Analysis, **28**(5-8): 1447-1458.

Fageria N. K., F. J. P. Zimmermann, and V. C. Baligar. 1995. Lime and phosphorus interactions on growth and nutrient uptake by upland rice, wheat, common bean, and corn in oxisol. Journal of Plant Nutrition, **18**(11): 2519-2532.

FAO. 1993. World soil resources. An explanatory note on the FAO World Soil Resources Map at 1:25 000 000 scale. World Soil Resources Report, 66 Rev. 1. 66 pp.

FAO. 1998. FAO Quarterly Bulletin of Statistics, **11**(1/2): 49

Fawole I., W. H. Gabelman, and G. C. Gerloff. 1982. Genetic control of root development in beans (*Phaseolus vulgaris* L.) grown under phosphorus stress. J. Amer. Soc. Hort. Sci., **107**(1): 98-100.

Felippe G. M., and J. E. Dale. 1990. The effects of phosphate supply on growth of plants from the Brasilian Cerrado: Experiments with seedlings of the annual weed, *Bidens gardneri* Baker (Compositeae) and the tree *Qualea grandiflora* (Mart.) (Vochysiaceae). Oecologia, **82**(1): 81-86.

Fennimore S. A., L. W. Mitich, and S. R. Radosevich. 1984. Interference among bean (*Phaseolus vulgaris*), barnyard grass (*Echinochloa crus-galli*), and black nightshade (*Solanum nigrum*). Weed Science, **32**: 336-342.

Firbank L. G., and A. R. Watkinson. 1985. On the analysis of competition within two-species mixtures of plants. Journal of Applied Ecology, **22**: 503-517.

Fischer R. A., and R. E. Miles. 1973. The role of spatial pattern in the competition between crop plants and weeds. A theoretical analysis. Math. Biosci., **18**: 335-350.

Flor C. A., and M. T. Thung. 1989. Nutritional disorders. In: Schwartz H. F. and M. A. Pastor-Corrales (eds.) Bean production problems in the tropics. CIAT, Cali, Colombia, 726 pp.

Foster H. L. 1971. Rapid routine soil analysis and plant analysis without automatic equipment. I. Routine soil analysis. East African Agriculture and Forestry Journal, **37**(2): 160-170.

Frick B., and A. G. Thomas. 1992. Weed surveys in different tillage systems in southwestern Ontario field crops. Canadian Journal of Plant Science, **72**(4): 1337-1347.

Gauch H. G. 1982. Multivariate analysis in community ecology. Cambridge University Press, Cambridge. 298 pp.

Gauch H. G. 1988. Model selection and validation for yield trials with interaction. Biometrics, **44**: 705-715.

Gauch H. G. 1990. MATMODEL version 2.0: AMMI and related analysis for two-way data matrices. Microcomputer Power, Ithaca, NY.

Gauch H. G., and R. E. Furnas. 1991. Statistical analysis of yield trials with MATMODEL. Agronomy Journal, **83**(5): 916-920.

Gee G. W., and J. W. Bauder. 1986. Particle-size analysis. Pages 383-411 *in* Methods of soil analysis. Part 1. Physical and mineralogical methods.

Gerdemann J. W. 1968. Vesicular-Arbuscular mycorrhiza and plant growth. Phytopathology, **6**: 397-418.

Gerloff G. C. 1963. Comparative mineral nutrition of plants. Ann. Rev. Plant Physiol. **14**: 107-124.

Goldberg D. E. 1987. Neighborhood competition in old-field plant community. Ecology, **68**: 1211-1223.

Greenwood D. J. 1983. Quantitative theory and the control of soil fertility. New Phytologist, **94**: 1-18.

Greenwood D. J., A. Gerwitz, D. A. Stones, and A. Barnes. 1982. Root development of vegetable crops. Plant Soil, **68**: 75-96.

Gregory P. J. 1988. Growth and functioning of plant roots. In: Russell's soil conditions and plant growth (Alan Wild, ed.). Longman Scientific & Technical, Longman Group UK Ltd, Longman House, Burnt Mill, Harlow, Essex CM20 2JE.

Grime J. P., and R. Hunt. 1975. Relative growth rate: Its range and adaptive significance in a local flora. Journal of Ecology, **63**: 393-422.

Hakansson S. 1986. Competition between crops and weeds - influencing factors, experimental methods and research needs. Proc. EWRS Symposium 1986, Economic Weed Control, 49-60 pp.

Harper J. L. 1977. Population biology of plants. Academic Press, New York.

Harrop J. F. 1970. Soils. Pages 43 – 71 *in* J. D. Jameson (ed.) Agriculture in Uganda. Oxford University Press, London.

Hegde D. M., and K. Srinivas. 1991. Growth, yield, nutrient uptake and water use of banana crops under drip and basin irrigation with N and K fertilization. Tropical Agriculture (Trinidad), **68**(4): 331-334.

Hoogenboom G., K. J. Boote, and J. W. Jones. 1988. Root distribution of dry bean under drought stress. Annual Report of the Bean Improvement Cooperative, **41**:16

Hoveland C. S., G. A. Buchanam, and M. C. Harris. 1975. Response of weeds to soil phosphorus and potassium. Weed Science, **24**(2): 194-201.

Hume L. 1982. The long-term effects of fertilizer application and three rotation on weed communities in wheat (after 21-22 years at Indian Head, Saskatchewan). Canadian Journal of Plant Science, **62**: 741-750.

Hume L., S. Tessier, and F. B. Dyck. 1991. Tillage and rotation influences on weed community composition in wheat (*Triticum aestivum* L.) in southwestern Saskatchewan. Canadian Journal of Plant Science, **71**: 783-789.

Ivany J. A. 1971. *Galinsoga ciliata* (Raf.) Blake and *G. parviflora* Cav.: Germination, growth, development and control. Ph.D. Thesis, Cornell University, Ithaca, NY. 164 pp.

Ivany J. A., and R. D. Sweet. 1973. Germination, growth and control of Galinsoga. Weed Science, **21**(1): 41-45.

Ivens G. W. 1971. East Africa Weeds and their Control. Oxford University Press, Nairobi, 250 pp.

Jager A. K., A. Hutchings, and J. van Staden. 1996. Screening of Zulu medicine plants for prostaglandin-synthesis inhibitors. Journal of Ethnopharmacology, **52**(2): 95-100.

Jjemba P. K., and B. S. Male-Kayiwa. 1993. N fixation by local bean cultivars under Uganda soil conditions. Annual Report of the Bean Improvement Cooperative, **36**: 109-110.

Jolliffe P. A., A. N. Nimjas, and V. C. Runeckles. 1984. A reinterpretation of yield relationships in replacement series experiments. Journal of Applied Ecology, **21**: 227-243.

Khan M. M. A., S. H. A. Samiullah, and R. M. Afridi. 1995. Response of black nightshade (*Solanum nigrum* L.) to nitrogen application. Journal of Agronomy and Crop Science, **174**(2): 91-98.

Kisakye J., M. Nabasirye, W. Tushemereirwe, C. Bakamwangiraki, and J. B. Kavuma. 1987. A diagnostic survey of Kabale District, Uganda. In: R. A. Kirkby (ed.) Proc. Workshop Bean Res. in Eastern Africa, 22 - 25th June, 1987. CIAT African Workshop Series, No. 2. CIAT, Cali, Colombia.

Koske R. E., and J. N. Gemma. 1989. A modified procedure for staining roots to detect VA mycorrhizas. Mycological Research, **92**(4): 486-488.

Langdale-Brown I. 1970. Vegetation. Pages 90 – 97 *in* Agriculture in Uganda (J. D. Jameson, ed.). Oxford University Press, London.

Lynch J., A. Lauchli, and E. Epstein. 1991. Vegetative growth of the common bean in response to phosphorus nutrition. Crop Science, **31**(2): 380-387.

Lynch J., and J. J. van Beem. 1993. Growth and architecture of seedling roots of common bean genotypes. Crop Science, **33**: 1253 - 1257.

Lynch J. P., and J. W. White. 1992. Shoot nitrogen dynamics in tropical common beans. Crop Science, **32**: 392-397.

Machado J. dos S., A. J. Netto, G. A. de A. Guedos, and P. M. de Rezende. 1979. Effects of phosphorus and molybdenum on the common bean (*Phaseolus vulgaris* L.) cultivated on oxisol soils. Ciencia e Pratica, **3**(2): 101-106.

Maillet J., and H. Abdel-Fatah. 1983. Preliminary studies on competition between *Solanum nigrum* spp. *nigrum* L. (black nightshade) and transplanted *Lycopersicon esculentum* Mill. (tomato). Weed Research, **23**: 217-219.

Majek B. A., and S. A. Johnston. 1986. Diethatyl for hairy galinsoga (*Galinsoga ciliata*) control in pepper (*Capsicum annuum*) integrated with cultural practices for phytophthora blight control. Weed Science, **34**: 569-571.

Malik V. S., C. J. Swanton, and T. E. Michaels. 1993. Interaction of white bean (*Phaseolus vulgaris* L.) cultivars, row spacing and seedling density with annual weeds. Weed Science, **41**(1): 62-68.

Marschner H. 1986. Mineral nutrition of higher plants. Institute of plant nutrition, University of Hohenheim, Federal Republic of Germany. Academic Press Inc. (London) Ltd. 674pp.

Maynard E. T. 1992. Demography and competitiveness of velvetleaf (*Abutilon theophrasti* Medik.) in dry beans (*Phaseolus vulgaris*). Ph.D. Thesis, Cornell University. Ithaca, NY. 238 pp.

McIntyre S., C. M. Finlayson, P. Y. Ladiges, and D. S. Mitchell. 1991. Weed community composition and rice husbandry practices in New South Wales, Australia. Agriculture, Ecosystems and Environment, **35**: 27-45.

McLaughlin M. F. 1978. Crop growth and weed competition. Ph.D. Thesis, Cornell University, Ithaca, NY, 187 pp.

McWhorter C. G., and E. E. Hartwig. 1972. Competition of johnson grass and cocklebur with 6 soybean varieties. Weed Science, **20**: 56-59.

Miller T. E., and P. A. Werner. 1987. Competitive effects and responses between plant species in a first-year old field community. Ecology, **68**: 1201-1210.

Minchin P. E. H., M. R. Thorpe, and J. F. Farrar. 1994. Short-term control of root:shoot partitioning. Journal of Experimental Botany, **45**(274): 615-622.

Mohler C. L. 1996. Ecological bases for cultural control of annual weeds. Journal of Production Agriculture, **9**: 468-474.

Mukula J., M. Raatikainen, R. Lallukka, and T. Raatikainen. 1969. Composition of weed flora in spring cereals in Finland. Annales Agriculturae Fenniae, **8**(2): 59-110.

Murphy L. S. 1983. Potassium interactions with other elements. In: Potassium for agriculture. Potash and phosphate Institute, Atlanta. 183-203 pp.

Newman E. I. 1966. A method of estimating the total length of root in a sample. Journal of Applied Ecology, **3**: 139-145.

Nieto J., and D. W. Staniforth. 1961. Corn-foxtail competition under various production conditions. Agronomy Journal, **53**: 1-5.

Ogg A. G., and B. S. Rogers. 1989. Taxonomy, distribution, biology, and control of black nightshade (*Solanum nigrum*) and related species in the United States and Canada. Review of Weed Science, **4**: 25-58.

Okalebo J. R., K. W. Gathua, and P. L. Woomer. 1993. Soil pH and Electroconductivity. In: Laboratory methods of soil and plant analysis: A Working Manual. 88 pp.

Otabbong E., M. M. L. Izquierdo, S. F. T. Talavera, U. H. Geber and L. J. R. Ohlander. 1991. Response to P fertilizer of *Phaseolus vulgaris* L. growing with or without weeds in a highly P-fixing mollic Andosol. Tropical Agriculture (Trinidad), **8**(4): 339-343.

Pachico D. 1989. Trends in world common bean production. In: Schwartz H. F. and M. A. Pastor- Corrales (eds.) Bean production in the Tropics. CIAT, Cali, Colombia. 726 pp.

Pandey R. P., and P. J. Parmar. 1994. The exotic flora of Rajasthan. Journal of Economic and Taxonomic Botany, **18**(1): 105-136.

Patterson D. T. 1995. Effects of environmental stress on weed/crop interactions. Weed Science, **43**: 483-490.

Peterson D. E., and J. D. Nalewaja. 1992. Environment influences on green foxtail (*Setaria viridis*) competition with wheat (*Triticum aestivum*). Weed Technology, **6**: 607-610.

Ponce R. G., C. Zancada, M. Verdugo, and L. Salas. 1996. Plant height as a factor in competition between black nightshade and two horticultural crops (tomato and pepper). Journal of Horticultural Science, **71**(3): 453-460.

Pysek P., and J. Leps. 1991. Response of a weed community to nitrogen fertilization: a multivariate analysis. Journal of Vegetation Science, **2**: 237-244.

Qasem J. R. 1992. Nutrient accumulation by weeds and their associated vegetable crops. Journal of Horticultural Science, **67**(2): 189-195.

Rabe T., and J. van Staden. 1997. Antibacterial activity of South African plants used for medicinal purposes. Journal of Ethnopharmacology, **56**(1): 81-87.

Radford P. J. 1967. Growth analysis formulae - Their use and abuse. Crop Science, **7**(3): 171-175.

Radosevich S. R. 1987. Methods to study interactions among crops and weeds. Weed Technology, **1**: 190-198.

Rai J. P. N., and R. S. Tripathi. 1983. Population regulation of *Galinsoga ciliata* and *G. parviflora*. Effect of sowing pattern, population density and soil moisture and texture. Weed Research, **23**: 151-163.

Rai J. P. N., and R. S. Tripathi. 1984. Population dynamics of different seedlings cohorts of two co-existing annual weeds, *Galinsoga ciliata* and*G. paviflora*, on two contrasting sites. Acta Ecologia, **5**(19): 357-368.

Rai J. P. N., and R. S. Tripathi. 1986. Effects of density and soil nitrogen levels on growth of *Galinsoga quadriradiata* and *G. paviflora* in pure and mixed stands. Canada Journal of Botany, **64**: 2708-2715.

Rai J. P. N., and R. S. Tripathi. 1987. Germination and plant survival and growth of *Galinsoga perviflora* Cav. as related to food and energy content of its ray-achenes and disc-achines. Acta Oecologica Oecologia Plantarum, **8**(2): 155-166.

Rasmussen P. E. 1995. Effects of fertilizer and stubble burning on downy brome competition in winter wheat. Communications in Soil Science and Plant Analysis, **26**(7/8): 951-960.

Reddy K. N., and M. Singh. 1992. Germination and emergence of hairy beggarticks *Bidens pilosa*. Weed Science, **40**(2): 195-199.

Rejmanek M., G. R. Robinson, and E. Rejmankova. 1989. Weed-crop competition: Experimental designs and models for data analysis. Weed Science, **37**: 276-284.

Richmond G. S. 1993. A review of the use of Eremophila (Myoporaceae) by Australian aborigines. Journal of the Adelaide Botanic Gardens, **15**(2): 101-107.

Robert H. A., and P. A. Dawkins. 1967. Effect of cultivation on the numbers of viable weed seeds in soil. Weed Research, **7**: 290-301.

Rwiza, H. T. 1991. Jimson weed food poisoning an epidemic at Usangi Tanzania rural government hospital. Tropical and Geographical Medicine, **43**(1/2): 85-90.

Saavedra M., L. Garcia-Torres, E. Hernandez-Bermejo, and B. Hidalgo. 1990. Influences of environmental factors on weed flora in crops in the Guadalquivir valley. Weed Research, **30**: 363-374.

Salonen J. 1993. Weed infestation and factors affecting weed incidence in spring cereals in Finland - a multivariate approach. Agricultural Science in Finland, **2**: 525-536.

Sangakkara R., U. A. Hartwig, and J. Nosberger. 1996. Growth and symbiotic nitrogen fixation of *Vicia faba* and *Phaseolus vulgaris* as affected by fertilizer potassium and temperature. Journal of the Science of Food and Agriculture, **70**(3): 315-320.

Scheldeman X., B. Meylemans, and P. Van- Damme. 1995. Weed distribution in relation to pH and soil texture in dry and intermediate lowland zones of Sri Lanka. Mededelingen Faculteit Landbouwkundige en Toegepaste Biologische Westenschappen Universiteit Gent, **60**(2A): 235-242.

Seibert A. C., and R. B. Pearce. 1993. Growth analysis of weed and crop species with reference to seed weight. Weed Science, **41**: 52-56.

Shea P. F., W. H. Gabelman, and G. C. Gerloff. 1968. Genetic control of potassium nutrition in snap beans, *Phaseolus vulgaris* L. Annual Report of the Bean Improvement Cooperative, **11**: 43.

Shontz N. N., and J. P. Shontz. 1972. Competition for nutrients between ecotypes of *Galinsoga ciliata*. Journal of Ecology, **60**: 89-92.

Sibuga K. P., and J. D. Bandeen. 1980. Effects of various densities of green foxtail (*Setaria viridis* (L.) Beauv.) and lambsquarters (*Chenopodium album* L.) on nitrogen uptake and yield of corn. East Africa Agricultural and Forestry Journal, **45**: 214-221.

Silvertown J. W., and J. L. Doust. 1993. Introduction to Plant Population Biology. Blackwell Scientific Publications, Oxford, London.

Sindel B. M., and P. W. Michael. 1992. Growth and competitiveness of *Senecio madagascariensis* Poiv. (fireweed) in relation to fertilizer use and increases in soil fertility. Weed Research, **32**: 399-406.

Singh S. P., C. A. Urrea, J. A. Gutierrez, and J. Garcia. 1989. Selection for yield at two fertilizer levels in small-seeded common bean. Canadian Journal of Plant Science, **69**: 1011-1017.

Smilauer P. 1992. CanoDraw User's Guide v.3.0. Microcomputer Power, Ithaca, NY, USA. 118 pp.

Snaydon R. W., and C. D. Howe. 1986. Root and shoot competition between established ryegrass and invading grass seedlings. Journal of Applied Ecology, **23**: 667-674.

Srinivas K., and J. V. Rao. 1984. Response of french bean to nitrogen and phosphorus. Indian Journal of Agronomy, **29**(2): 146-149.

Ssali H., and S. O. Keya. 1986. The effects of phosphorus and nitrogen fertilizer level on nodulation, growth and dinitrogen fixation of three bean cultivars. Tropical Agriculture (Trinidad), **63**(2): 105-109.

Staniforth D. W. 1961. Responses of corn hybrids to yellow foxtail competition. Weed Science, **9**: 132-136.

Stejskalova H. 1990. The role of mycorrhizal infection in weed-crop interactions. Agriculture, Ecosystems and Environment, **29**(1-4): 415-419.

Stoller E. W., and R. A. Myers. 1989. Response of soybeans (*Glycine max*) and four broadleaf weeds to reduced irradiance. Weed Science, **37**(4): 570-574.

Stoller E. W., S. K. Harrison, L. M. Wax, E. E. Regnier, and E. D. Nafziger. 1987. Weed interference in soybeans (*Glycine max*). Review of Weed Science, **3**: 155-181.

Tennant D. 1975. A test of a modified line intersect method of estimating root length. Journal of Ecology, **63**: 995-1001.

ter Braak C. J. F. 1986. Canonical correspondence analysis: A new eigenvector technique for multivariate direct gradient analysis. Ecology, **67**(5): 1167-1179.

ter Braak C. J. F. 1987. The analysis of vegetation-environment relationships by canonical correspondence analysis. Vegetatio, **69**: 69-77.

ter Braak C. J. F. 1995. Ordination. In: Data analysis in community and landscape ecology (R. H. G. Jongman, C. J. F. ter Braak and O. F. R. van Tongeren, eds.). 91-173 pp.

ter Braak C. J. F. 1996. Unimodal models to relate species to environment. DLO-Agricultural Mathematics Group, Wageningen.

ter Braak C. J. F., and I. C. Prentice. 1988. A theory of gradient analysis. Advances in Ecological Research, **18**: 271-317.

ter Braak C. J. F., and P. Smilauer. 1998. CANOCO Reference Manual and User's Guide to CANOCO for Windows: Software for Canonical Community Ordination (version 4). Microcomputer Power, Ithaca, NY, USA. 352 pp.

Terry P. J., and R. W. Michieka. 1987. Common weeds of East Africa. Food and Agriculture Organization of the United Nations, Rome; FAO Code 14. 184 pp.

Thomas A. G., D. J. Doohan, and McCully. 1994. Weed survey of spring cereals in New Brunswick. Phytoprotection, **75**(3): 113-124.

Thomas A. G., and J. A. Ivany. 1990. The weed flora of Prince Edward Island cereal fields. Weed Science, **38**: 119-124.

Thomas R. J., and M. Hungria. 1988. Effect of potassium on nitrogen fixation, nitrogen transport, and nitrogen harvest index of bean. Journal of Plant Nutrition, **11**(2): 175-188.

Tiley G. E. D. 1970. Weeds. Pages 297 – 317 *in* Agriculture in Uganda (J. D. Jameson, ed.). Oxford University Press, London.

Tisdale S. L., W. L. Nelson, J. D. Beaton, and J. L. Havlin. 1993. Soil fertility and fertilizer. Macmillan Publishing Company, NY. 634 pp.

Tropical Soil Biology and Fertility: A Handbook of Methods. 1993. (J. M. Anderson and J. S. I. Ingram, eds.). CAB International. Wallingford, Oxon OX10 8DE, UK. 171 pp.

Vanegas C. J. A. 1986. Plant density, row spacing and fertilizer effects in weeded and unweeded stands of common beans *Phaseolus vulgaris*. Swedish University of Agricultural Sciences Department of Plant Husbandry Report, **0**(160): 3-43.

Van-Male P., V. Van-Damme, X. Scheldeman, B. Meylemans, and P. Van-Damme. 1996. Effect of management practices on the occurrence of *Echinochloa* sp. in dry and intermediate zone rice fields of Sri Lanka. Mededelingen Faculteit Landbouwkundige en Toegepaste Biologische Westenschappen Universiteit Gent, **61**(3B): 1115-1121.

Vejsadova H., H. Hrselova, Z. Prikryl, and V. Vancuva. 1990. Effect of different phosphorus and nitrogen levels on development of VA mycorrhiza, rhizobial activity and soybean growth. Agriculture, Ecosystems and Environment, **29**: 429-434.

Vengris J., M. Drake, W. G. Colby, and J. Bart. 1953. Chemical composition of weeds and accompanying crop plants. Agronomy Journal, **45**: 213-218.

Walkey A., and I. A. Black. 1934. An examination of the method for determining soil organic matter and a proposed chromic acid titration method. Soil Science, **37**: 29-38.

Wang, J., H. Yang, Z. W. Lin, and H. D. Sun. 1997. Flavonoids from *Bidens pilosa* var. *radiata*. Phytochemistry, **46**(7): 1275-1278.

Whiteaker G., G. C. Gerloff, W. H. Gabelman, and D. Lindgren. 1976. Intraspecific differences in growth of beans at stress levels of phosphorus. Journal of American Society of Horticultural Science, **101**: 474-475.

Wiese A. F., and C. W. Vandiver. 1970. Soil moisture effects on competitive ability of weeds. Weed Science, **18**: 518-519.

Wilson B. J. 1978. The long-term decline of a population of *Avena fatua* L. with different cultivars associated with spring barley cropping. Weed Research, **18**: 25-31.

Wilson J. B. 1988. Shoot competition and root competition. Journal of Applied Ecology, **25**: 279-296.

Wilson R. G. 1993. Wild proso millet (Panicum miliaceum) interference in dry beans (*Phaseolus vulgaris*). Weed Science, **41**(4): 607-610.

Wortmann C. S. 1993. Contribution of bean morphological characteristics to weed suppression. Agronomy Journal, **85**: 840-843.

Wortmann C. S., and D. J. Allen. 1994. African bean production environments: their definition, characteristics and constraints. Network on Bean Research in Africa. Occasional Paper Series 11, Dar es Salaam, Tanzania.

Wortmann C. S., L. Lunze, V. A. Ochwoh, and J. P. Lynch. 1995. Bean improvement for low fertility soils in Africa. African Crop Science Journal, **3**(4): 469-477.

Zimdahl R. L. 1980. Weed - crop competition A Review. International Plant Protection Center, Oregon State University, Corvallis, Oregon. 196 pp.

Zimdahl R. L. 1993. Fundamentals of weed science. Academic Press Inc. 450 pp.

Zollinger R. K., and J. J. Kells. 1992. Perennial sowthistle (*Sonchus arvensis*) interference in soybean (*Glycine max*) and dry edible bean (*Phaseolus vulgaris*). Weed Technology, 7(1): 52-57.