NUTRITIONAL AND SOIL FERTILITY BENEFITS: INFLUENCE OF FERTILIZERS ON GROUNDNUTS (*Arachis hypogaea* L.) YIELD AND SOIL NITROGEN CONTRIBUTION FOR SMALLHOLDER FARMERS IN UGANDA

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FOREWORD

This report was written as my final thesis report in fulfilment of the requirements of my Master of Science studies under the Plant production systems group at Wageningen University. The research work was conducted in the Northern region of Uganda from September 2013 to January 2014 under the N2 Africa project running under the theme: "Putting Nitrogen fixation to work for the smallholder farmers in Africa" which focuses on promoting the use of inoculants and inorganic fertilizers for grain legume production. The project was funded by N2 Africa through its funding by the Bill and Melinda Gates Foundation administered by Wageningen University and International Institute of Tropical Agriculture (IITA) and the International Livestock Research Institute (ILRI). The N2 Africa project is being implemented in 13 African countries through different implementing partners. Makerere University and World Vision among others are the implementing partners in Uganda. I have been working with these two partners in Uganda during my field work.

Taruvinga Badza

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In addition, I would like to extend my warmest gratitude to N2 Africa and its implementing partners in Uganda; Makerere University and World Vision Minakulu staff, there are no words good enough to describe how grateful I am. You housed me, you gave me directions in addition to all the necessary administrative services I needed. I highly appreciate your support. Last but not least, the Plant Production Systems Group staff, I say thank you, you are so amazing.

I say, thank you all for cooperatively working together with me for the success of this project and in fostering the battle of bringing out new and improved technologies to our farmers out there. This shall enable them to produce enough in quantity and quality to feed the ever growing world population. God bless you all.

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SUMMARY

Soil fertility depletion is a major problem in the developing world and has remained a cause for concern in most discussions, conferences and meetings. Output per unit area for most agricultural crops is highly affected especially in the smallholder farming sector yet the world population is increasing and needs to be fed. Proper quantity and quality food is required to address issues of food insecurity but the land cannot cope due to the ever declining soil fertility. Researchers and scientists are pondering on daily basis, trying to unlock and offer socially acceptable and economically viable strategies that make the nutrient degraded soils improved in its crop productivity. The use of legumes and micro dosing of inorganic fertiliser among other management options are part of the available strategies to incorporate into the current farming systems to reduce the current problem.

It is in this context that an experimental study was carried out in Atek parish in Minakulu Sub-County of Oyam district in the Northern region of Uganda. The experiment was done in the second season of the year2013. Planting was done on the 27th of September 2013 and harvested on the 9th of January 2014. The study objective was evaluating the need for fertilization with P, K and gypsum to increase groundnut productivity of smallholder farmers Uganda. Specific focus was on the influence of these fertilizers on pod, grain and stover yield, nodulation, pod number per plant, shelling percentage and 100 seed weight. A split-split plot design was used with two gypsum rates of 0 and 150 kg gypsum ha^{-1} as the main treatments, two K rates of 0 and 20 kg K ha^{-1} as sub treatment and four P rates of 0; 10; 20 and 30 kg P ha^{-1} as sub-sub treatments. There were four replicates on two sites; Alati B and Jeriko village. SERENUT 5, a groundnut variety released in 2010 and still new in the study area was used for this experiment. The experiment was under rain fed conditions.

P application showed significant influence (P<0.05) on pod, grain and stover yield, nodule number per plant, 100 seed weight and shelling percentage. Its main influence was more expressed in Alati B especially on pod and stover yields among other parameters than in Jeriko. Application rate of 20 kg P ha^{-1} gave outstanding results over the control, 10 and 30 kg P rates on all measured parameters. The grain yield ranges from 1148 to1548 kg ha^{-1} in Alati B and 608 to 831 kg ha^{-1} in Jeriko village with the control giving the lower yields whilst 20 kg P had the higher yields. Application of P at 10, 20 and 30 kg ha^{-1} did not give significant different pod and grain yield between them but their yields where higher than the control at Alati B. The same P response was observed at Jeriko on grain yield though at this site, the yield at 10, 30 kg P and the control were not different statistically. P effects on pod and stover yields were not significant at Jeriko site. K x P interaction effects were also significant (P = 0.023) on stover yield at Alati B. The stover yield from this interaction was so variable between these fertilizer rates combinations.

Gypsum and K did not show significant effects on pod, grain and stover yields at both sites, however, their interaction significantly (P = 0.013) influenced stover yield at Alati

B and 100 seed weight (*P* = 0.015) at Jeriko. For both stover yield and seed weight, 0 and 20 kg K rates did not give significant different stover yield and or seed weight regardless of applied with or without gypsum. For 100 seed weight, at no K, seed weight was significantly higher on applied gypsum compared to no gypsum plots whilst the seed weight at 20 K did not change. In addition, P influence on 100 seed weight showed that the seed weight on the control, 10 and 30 kg P did not differ significantly whilst 20 kg P's seed weight was not different with 10 kg P rate.

There was no significant influence of fertilizer application on pod number per plant at both sites. At the main interaction, pod per plant ranges from 21.4 to 27 at Alati and from 14.5 to 23.3 pod at Jeriko village.

Nodulation was positively influenced by P application at both sites. Basing on P application, 20kg P had higher (120 nodules per plant) than 100.3 for the control at Alati B and 104.6 for 20 kg P against 88 for the control at Jeriko. There were no significant differences in nodulation between the control, 10 and 30 kg P rates. Gypsum application had a negative influence on nodulation whilst K did not have any significant influence. 150 kg gypsum application reduced nodule number per plant from 118.8 recorded on the control plot to 100 nodules per plant.

Shelling percentage responded positively to the influence of both P and gypsum application at the two sites and to their interaction effect. 20 kg P exhibited the highest shelling percentage, 10 and 30 with the medium whilst the lowest was recorded at the control. 150 kg gypsum showed relatively higher percentage than 0 gypsum whilst, at gypsum x P interaction; 20 kg P with 150 kg gypsum overrides all other combinations of these two fertilizers' shelling percentage.

In view of P influence, average grain yield gains ha^{-1} of 239; 400 and 313 kg over control were recorded at Alati B whereas at Jeriko site only 77; 224 and 120 kg ha^{-1} were realised as grain benefit from P1, P2 and P3 respectively. Converting the grain yield gain less the grain quantity to cover SSP costs in monetary value, a farmer would realise US$180.26; US$267.36 and US$56.19 at Alati B and US$-14.02; US$55.48 and US$-175.40 at Jeriko from P1; P2 and P3 respectively.

On all measured parameters, crop growth, vigour and fertilizer responses, Alati B surpasses Jeriko village. Through P fertilizer application to groundnut, farmers can improve their crop growth and realize increased yields as exhibited by P in this study. Ca and K nutrients are not yet limiting to groundnut growth on the soils of the study area. As a build-up on this research, further studies should be done focusing on measuring nutrient uptake, nutrient use efficiency, and apparent nutrient recovery as well as testing the protein and oil content and quality of this variety under such condition as in this study.

1 INTRODUCTION

Soil fertility depletion is a perpetual major problem in the farming sector in Sub Saharan Africa (SSA) region (Ennin et al., 2004, Dakora and Keya, 1996, Graham and Vance, 2000). The problem has been and is still affecting the output per unit area for most crops especially in the smallholder farming sector, with the resultant effect on exacerbation of food insecurity in developing countries. The world population is increasing (UN, 2004, Population Reference Bureau, 2013, Graham and Vance, 2000) and so as the Ugandan population. Uganda's population has risen from 27.7 million in 2006 to 34 million in 2012 (Zirarema, 2012) and is expected to reach 46.1 million by 2025 (HNP Stats, 2011). This will increase food demand and further puts pressure on food supplies. Most African nations' people are food insecure, both in quantity and quality. Menale et al. (2011) reported that expansion of agricultural land in Uganda is no longer possible anymore. Therefore, to produce enough to feed the population in need, production increase has to be achieved through improved crop management techniques (Menale et al., 2011), so as to increase the output per unit area. This is the target most researchers have to focus on.

In Uganda, as like the whole of SSA region, most smallholder farmers are experiencing soil fertility losses and this is one of the major problems in the agricultural sector. The continuous crop production without adequate supply of fertilizers gave rise to soil nutrient depletion and resulted in declining yields (Bagarama et al., 2012) hence food shortages in parts of the country. Although nutrient losses are high, there is very low use of external fertilizers on most crops (Okello et al., 2010). This was attributed to high fertilizer costs (Angadi et al., 1990) and limited financial resource base of many smallholder farmers in developing countries (Moyo et al., 2007). As a result, fertilizer use is limited to maize. Even though the fertilizers are applied mainly to maize, the application is still very low due to poor financial base of many farmers. Therefore, this negatively contributes to the total food requirement since the total production remains low.

To enhance output per unit area and subsequently boost production of cereal crops, the cropping system should include the use of fertilizers. Since the inorganic fertilizers are mostly out of reach to many small holder farmers in the developing world due to high costs, inclusion of legumes in the system is an alternative as they contribute nitrogen into the soil through atmospheric nitrogen fixation (Okello et al., 2013). In addition, they are environmentally friendly since they diversify the cropping system and regulate pest and disease cycles, and the fertilizer which they add to the soil for the following crop is cheaper (Nkot et al., 2011) than the use of inorganic fertilizers. However, in a way to enhance vigorous growth in early stages of crop development, of the small quantities of inorganic fertilizers the farmers get, a fraction should be allotted to legumes to enhance their early vegetative growth.

If incorporated into the cropping system, legume crops could be another mitigation measure to declining soil fertility (Okello et al., 2013). In Uganda, farmers grow legume crops such as cowpeas, (*Vigna unguiculata* (L). Walp) beans (*Phaseolus vulgaris* L.), groundnuts (*Arachis hypogaea* L.) and soybean (*Glycine max* (L) Merr). Groundnut is the second major legume crop grown after beans (Okello et al., 2010). Its inclusion among other legumes in the cropping system may improve soil fertility level (Okello et al., 2013) especially soil N replenishment. Other essential nutrient elements which might be needed to enhance growth, optimum nodulation, N-fixation and yield of groundnut are P, K and calcium (Ojiem et al., 2007, Meena et al., 2007, Angadi et al., 1990, Graham and Vance, 2000).

With reports pointing out that many soils in SSA are known for their limited inherent supply of the major nutrients, Vlek et al. (1997) indicated loses of 22, 3, and 17 kg of N, P, and K ha^{-1} yr^{-1} respectively in the SSA region. Continuous nutrient mining was noted (Giller and Cadisch, 1995), with P identified as the most limiting element (Graham and Vance, 2000) in SSA soils. Ebanyat et al. (2009) reported that substantial amounts of these major nutrient loses were recorded in Uganda with 20-40, 3.5-6.6 and 17-33 kg of N, P and K being lost ha^{-1} yr^{-1} respectively. In view of these observed loses and the ever reported low levels of major nutrient elements in SSA soils, soil fertility replenishment strategies are necessary to reduce the probable deficiencies of these nutrients. Graham and Vance (2000) cited that, P is required in high concentration for N-fixing plants to provide adequate Adenosine Tri-Phosphate (ATP), for nitrogenase functions (Ribet and Drevon, 1996, Al Niemi et al., 1997), signalling transduction, nodulation and enhancement of N-fixation (Graham and Vance, 2000).

Calcium can be supplied through application of calcitic lime if liming is required for raising the soil pH. However, when liming is not necessary, gypsum can be the best option as Ca source because it is highly mobile and it avails the required nutrients well in time. Calcium is an important and critical nutrient element required especially during pegging (Wright et al., 2009) to avoid the crop resulting in “pops” or empty pods leading to higher shelling percentage in most depleted sandy soils and also for nodulation and maximum root growth (Meena et al., 2007). In addition to N and P, K is another major nutrient element which is required for proper plant growth. It is of importance to plants for photosynthesis, enzymes activities and for plants to be tolerant to biotic and abiotic stresses. In this study, K was not considered as a major nutrient problem; however, its influence to the measured parameters in this experiment was also assessed to see if its application was essential to groundnut in the study area.

If given adequate nutrients, groundnut fixes atmospheric nitrogen into the soil during growth. Its subsequent retained residues after harvesting are of great use for soil fertility replenishment and it reduces low soil nutrition problems to the subsequent crop. It was reported that groundnuts can fix 50 to 150kg N ha^{-1} (Giller, 2001) and other figures as high as 210 kg ha^{-1} were recorded (Bell et al., 1994). The N benefit to the subsequent crop by incorporating groundnut and other legume stover and the fallen leaves is estimated to 20% of the initially applied N (McDonagh et al., 1993).

Most of legume crops are bacterial strain specific for nodulation. However, this is not always the case for groundnut or for cowpea, such crops are considered to be promiscuous (Castro et al., 1999) because they can usually be nodulated by a range of rhizobium bacteria naturally present in the soil. Groundnut crop responses to inoculation are rare and limited to poorly fertile sand soils where the rhizobium population density is too low for optimum nodulation. Ball et al. (1983) stated that growing groundnut on soils which have been previously grown under this same crop could rarely require rhizobia inoculation. This could be also the same if the soils were cropped to other N-fixing legumes before, for the rhizobium bacteria is believed to be in abundance in such soils.

Application of fertilizers could improve groundnut output per unit area up from the current yield of 0.8 ton ha^{-1} (Okello et al., 2010) which is far much below the potential yield level of 3 tons ha^{-1}. The improved yield of groundnuts will therefore, reduces the quantity of current importation of the crop, hence reduction of the low dietary diversity issues which has been recorded (WFP, 2013) in Uganda.

This study aimed at investigating the influence of different combinations of phosphorus, potassium and gypsum fertilizers on nodulation, N_2 fixation, yield and yield components (pod number, shelling percentage and 100 seed weight) of groundnut. With the main objective of evaluating the need for fertilization with P, K and gypsum towards increased groundnut productivity of smallholder farmers in Uganda, the specific focus was; to determine nodulation, yield (pod, grain and stover) and grain yield components responses of SERENUT 5 variety to P, and gypsum fertilizers; and to quantify biological nitrogen fixation of groundnut grown under different rates of P and gypsum fertilizers. Two research questions were formulated. These were to look on; how do different P and gypsum fertiliser application rates affect groundnut nodulation, N_2-fixation, yield and yield components, and on; what quantity of fixed nitrogen amount could be contributed to the soil by groundnut grown with different P and gypsum fertilizer application rates? We hypothesised that; application of P and gypsum fertilizers to a groundnut crop enhances nodulation, N_2-fixation, yield and yield components, and that, if groundnut crop is supplied with P and gypsum fertilizers, it adds more fixed N to the soil than a non-fertilized crop. P influence was expected to be seen on all measured parameters but with a stronger effect on nodulation relative to gypsum. For gypsum, robust contribution was expected on seed weight and subsequently on shelling percentage compared to other parameters. The inclusion of K was to test whether it is also a crop growth limiting nutrient in the study area and its positive contributions to the overall growth and yield was expected. Overall, the study was to give an assessment of the potential benefits of applying P, K and gypsum fertilizers to groundnut in terms of its soil nutrition contribution and yield improvement.

To achieve the intended aim, objectives and to test the hypothesis of this study, a field experiment was conducted. A medium maturing groundnut variety, SERENUT 5, was planted with different rates of P, K and gypsum fertilizers in a split-split plot design in the Northern region of Uganda in Minakulu sub-county of Oyam district in the year 2013 second season.

2 MATERIALS AND METHODS

2.1 Study site

A field experiment was conducted on two different sites; Alati B village 02^o 23' 47.4''N and 032^o 23' 23.8''E (1062 m a.s.l) and Jeriko village 02^o 23' 26.0''N and 032^o 23' 15.6'' E (1057 m a.s.l) which are in Atek parish in Minakulu Sub County of Oyam district (Appendix I) in the Northern region of Uganda. This region has a bimodal rainfall that ranges between 800-1350 mm and an average temperature of 23.5^{0}C per year (Climate-Data.Org, 2013). The longer (main) season comes in March to July whilst the second (shorter) season runs from August to December. The experiment was established in the second season. Planting was done in September 2013 and harvested in early January 2014. The total rainfall received during the experimentation year was 1653.2 mm of which half of it was recorded in the second season and was concentrated in the first 3 $^1/_2$ months with an average temperature of 26.3^{0}C (Fig 2.2). The trials were on-farm trials but mainly managed by the researcher. The sites were selected on farmers' fields based on perceived soil fertility.

2.1.1 Soil

Before planting, soil samples of 0.5 kg were collected per site for laboratory tests. 10 sub samples per site were taken using an auger at a depth of 0.20 m. One composite sample was made from the 10 sub samples collected. The samples were air dried to constant weight and were sent to Makerere University's soil and plant analytical laboratory for processing and analysis. The analysed properties include; soil pH, soil organic carbon, soil texture and available nutrients including N, Olsen P, exchangeable bases, Ca^{2+}, Mg^{2+}, Na^+ and K^+. The tests showed that the soils at both sites were sand clay loam (Table 3.1).

The air-dried soil samples were sieved through a 2 mm sieve and subjected to physical and chemical analysis following standard methods described by (Okalebo et al., 1993). Soil pH was measured in a soil water solution ratio of 1:2.5; Organic matter by potassium dichromate wet acid oxidation method; total N determined by Kjeldhal digestion; extractable P by Bray P1 method; exchangeable bases from an ammonium acetate extract by flame photometry (K^+, Na^+) and atomic absorption spectrophotometry (Ca^{2+}, Mg^{2+}); and particle size distribution (texture) using the Bouyoucos (hydrometer) method.

2.2 Experimental design

The experiment was laid out in a split-split plot design with 2 rates of gypsum as main treatment, 2 rates of potassium as sub treatment and 4 rates of phosphorus as sub-sub treatment, and 1 groundnut variety giving rise to 16 treatments (Appendix III b) at each site. Phosphorus and potassium rates were randomly assigned to each gypsum treatment whilst gypsum treatments were randomly assigned to each main plot within a block. Each treatment was replicated 4 times; therefore, each site had 64 experimental units in total. Each experimental unit was 12m^2 (4m x 3m) in size with 9 rows of 3 m long. The total size of the field was 38 m x 29.5 m giving an area of 1121 m^2 (0.11 ha) (Appendix IV) at each site. Adjacent to each block, there was a fallow strip measuring 0.5 m x block length (18.5 m) long. These strips, received similar fertilizer rates of 15 kg P and 20 kg K ha^{-1}. From the fallow strips, reference crops were collected for assessment of biological nitrogen fixation (BNF).

During the biomass collection, 2 outer rows on either side and 0.5 m on the front and back of each plot were discarded to avoid edge effects. Each net plot was divided into two sections. One section was for nodulation and N fixation assessment and the other one was for final yield assessment (Fig 2.1).

2.3 Crop management

2.3.1 Planting

Before planting, the land was ploughed by an ox-drawn plough to a depth of 0.25 m. SERENUT 5, a bunchy type groundnut variety was used for this experiment. This is a medium duration maturing variety that takes 105 days to mature. Planting was done at a depth of 0.04-0.05 m on the 27th and 28th of September 2013 for Alati B and Jeriko village respectively. The plant spacing was 0.45 m inter-row and 0.15 m in-row giving a plant population of 148 148 plants ha^{-1} and 20 plants per 3 m row. In the season before the experiment, Alati B site was planted to cassava and maize was planted on Jeriko site.

2.3.2 Fertilization

At planting, P and K fertilizers were applied in furrows as basal dressing to the respective plots. P was applied in form of single super phosphate (SSP). It was applied at the rates of; 0, 10, 20 and 30 kg P ha^{-1} which translated to the rates of 0, 0.13, 0.27, and 0.4 kg SSP per each particular sub-sub plot of 4 m x 3 m area. K was applied in form of muriate of potash (MOP) at the rates of 0 and 20 kg K ha^{-1}. This translated to 40 kg MOP ha^{-1} and 0.048 kg MOP per experimental unit (12 m^2). For the fallow strips, 0.16 kg SSP and 0.037 kg MOP was applied per strip (9.25 m^2).

Top dressing with gypsum was done at the rates of 0 and 150 kg ha^{-1}, where 0 was for the plots not receiving gypsum and 0.18 kg gypsum was applied per plot (12 m^2) for the treatments to receive 150 kg ha^{-1} gypsum. This was applied on the 5th of November 2013 at the beginning of pegging when the crop was at 50% flowering stage, that was thirty-eight (38) days after sowing (DAS). The application was done directly on the crop and worked into the soil using hoes.

2.3.3 Weeding

Weed control was done using hoes. Three weeding sessions were conducted to make sure that the crop is kept weed free throughout the whole season. This was done on the 14th, 29th of October and 13th of December 2013 for the 1st, 2nd and 3rd weeding sessions respectively.

The experimental unit schematic diagram

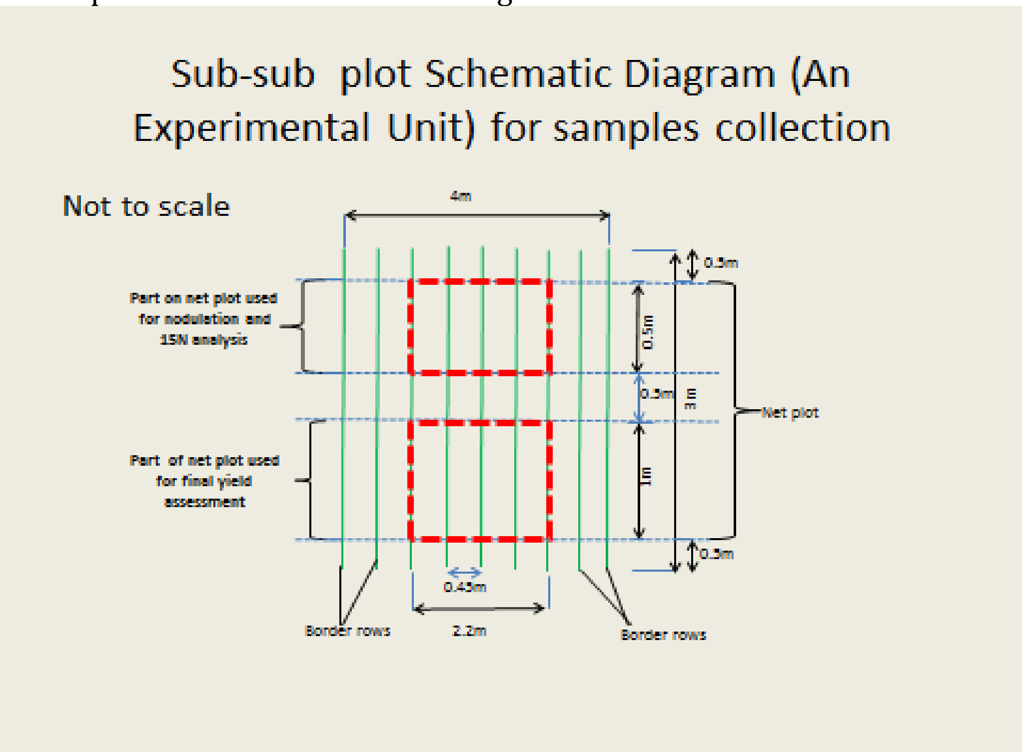


Fig 2.1 Schematic diagram of the subplot showing the net plot which is subdivided to indicate the part of the net plot to be used for nodulation and N-fixation assessment and the part to be used for final yield assessment.

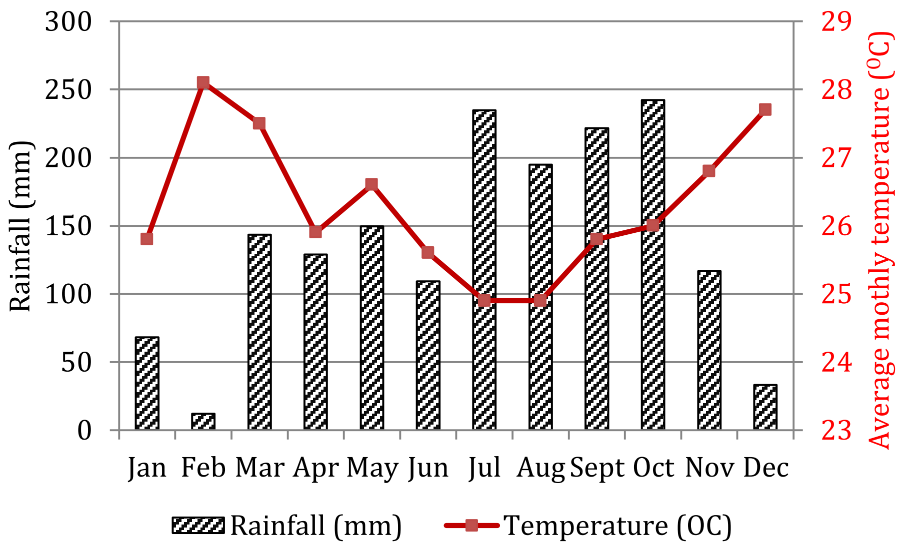


Fig 2.2 Total monthly rainfall (mm) and average monthly temperature (^0C) for the study area during the experimentation year 2013.

2.4 Sample collection, measurements, calculations and laboratory tests

Plant and soil samples were collected for laboratory tests for this experiment. The aspects below were looked into and where necessary, some measurements, tests and calculations were done in order to give substantial information of the experiment.

2.4.1 Emergence and plant population

Emergence was assessed to find out the emergence percentage per each experimental unit. The plant population was determined at 14 DAS through physical counting of the standing live plants.

2.4.1.1 Emergence percentage

Two weeks after planting, crop establishment assessment was conducted. Per each experimental unit, physical plant count was done. Five rows were randomly selected per each experimental unit; plants were counted and recorded against the expected 100 plants for the five rows. The total emerged plants recorded per each experimental unit were used to calculate the emergence percentage for that specific sub plot.

2.5 Nodulation assessment and Pod count

When maximum biomass was expected to have been achieved, at mid-podding stage, i.e. 83 days after sowing, nodulation was assessed. This was the time when maximum crop growth and N accumulation was expected. All plants per net experimental plot were uprooted after digging around each plant. This was done on an area of 0.5 m x 2.2 m (1.1 m^2) of the net experimental unit (Fig 2.1). From the total plants uprooted per plot, 10 plants were selected for nodule and pod count. Number of nodules (nodule scoring) and pods per plant were noted as well as the number of effective nodules. The counted nodules and effective nodules from the 10 plants were summed up and the average nodule and pod number per plant was calculated by dividing the total number by 10 for each sub experimental unit.

2.6 Groundnut biomass sampling for biological N-fixation estimates

From the same area and plants used for nodulation assessment (Fig 2.1), biomass for BNF assessment was collected. The total number of plants on the sample area was determined by physical count of the plants. Above ground parts of all the plants uprooted from the net plot were cut at ground level. All of the harvested biomass was weighed and above ground fresh weight of each experimental plot was determined and recorded. A 200 g weight sub samples were taken from the total above ground fresh biomass, labelled, air dried to remove excess moisture for 24 hours, and then oven dried at 65^{0}C for 72 hours until a constant weight was achieved. From the oven, the sub-samples were re-weighed and grounded to pass a 0.5 mm sieve and taken for laboratory tests for δ ^{15}N analysis through the use of δ^{15}N natural abundance technique.

2.7 Biomass for reference crop

From the corresponding fallow strips per block on each site, 2 - 3 non-legume broadleaf weeds and one grass species were collected. These were used as reference crops for N_2 fixation assessment. The broad leaf weeds; *Amaranthus hybridus* and *Bidens pilosa* were collected on Alati B site whilst *Bidens pilosa, Acathospermum hispdum* and *Cochorus trilochlorus* were collected on Jeriko site together with *Sorghum halapense* grass which was collected at both sites.

These weeds were each collected separately at the same time the crop biomass for BNF was collected. Only above ground biomass of the selected weeds was harvested. For each weed species, a sub sample of 200 g fresh weight was collected with a relative proportion of all above ground plant parts in the sub sample to be representative of the whole plant. The samples were labelled, air dried and then oven at $65^{0}C$ for 72 hours until a constant weight was achieved. The samples were grounded to pass a 0.5 mm sieve and then taken to the laboratory together with processed groundnut biomass for $\delta^{15}N$ analysis. N_2 fixed was to be calculated as described by Peoples et al. (1989) for $\delta^{15}N$ natural abundance technique.

2.8 Harvesting and Final Yield Assessment

Harvesting was carried out when the crop was physiologically mature at 105 days after sowing on 9th January 2014. Yield was measured based on; weight of pods, shelling percentage, grain yield and stover dry matter weight. Number of plants was first determined per area of 2.2 m^2 of the net experimental plot (Fig 2.1) (undisturbed area during nodulation assessment). All the plants were uprooted and assessed for grain yield, above ground fresh and dry matter weight as described below.

2.8.1 Pod weight and shelling percentage

During harvesting, all mature pods from the plants uprooted from a 2.2 m^2 area were removed from the haulms, weighed and recorded. This was total pod fresh weight. A sub-sample of 200 g weight was taken from the total quantity of the pods and weighed (sub-sample pod fresh weight) then oven dried for 72 hours and was used to calculate the pod and grain yield.

Pod yield was calculated as:

$$\text{Pod Yield (kg ha}^{-1}\text{)} = \frac{\text{Total Pod FW (g)} * \text{Sub}-\text{sample Pod DW (g)} * 10}{\text{Sub}-\text{sample Pod FW (g)} * \text{Net Area Harvested (m2)}}$$

Shelling percentage as a yield component was calculated per experimental unit. The oven dried pod sub samples taken from the entire harvest of each experimental unit were weighed (pod dry weight) and then shelled. The shelled grain and the husks were weighed separately and the shelling percentage was calculated as per formula below:

$$\text{Shelling percentage (\%)} = \frac{\text{weight of shelled peanuts}}{\text{weight of unshelled peanuts}} * 100$$

Husk Yield (kg ha^{-1}) was calculated as;

Husk Yield = (1- (Shelling percentage/100)) * Pod Yield

From the obtained shelling percentage, the final grain yield was calculated basing on this formula:

Grain Yield = Shelling percentage/100 * Pod Yield

2.8.2 Stover yield

At harvesting stage, the above ground plant biomass was measured from the 2.2 m^2 area of the experimental unit which have been reserved for yield assessment. All of the above ground parts of the harvested plants and the fallen leaves were collected and weighed. This was the total fresh weight of above ground biomass. A 200 g weight sub-sample was taken, weighed and oven dried at 65^{O}C for 72 hours until constant weight was achieved. The sub-samples were re-weighed to determine the dry weight. From the sub-sample values of fresh weight (FW) and dry weight (DW) obtained above, the stover yield was calculated using the formula below:

$$\text{Haulm Yield (kg ha}^{-1}\text{)} = \frac{Total\ Haulm\ FW\ (g) * Sub-sample\ haulm\ DW\ (g) * 10}{Sub-sample\ haulm\ FW\ (g) * Net\ Area\ harvested\ (m2)}$$

The husk and haulm yield were then used to calculate the Stover yield as below:

Stover Yield (kg ha^{-1}) = Haulm Yield + Husk Yield

2.9 Cost benefit analysis

To assess how beneficial fertilizer application was, a simple cost benefit analysis was computed soon after harvesting. P fertilizer cost was considered as the variable cost to evaluate if it warrants investing on fertilizer use at small scale farming level focusing on the returns obtained on different application rates used in this study. Average grain yield obtained under the influence of each P application rate less the grain yield from the control (P0) were used to obtain the average grain yield gain. This yield gain less the yield required to cover P cost was then converted into monetary value and regarded as the net SSP use benefit (Table 3.4) gained by the farmer per hectare after paying for their fertilizer cost under a particular P application rate. Fertilizer cost used to calculate variable costs was the purchase price on which SSP was bought at. The price was obtained as an average of the observed SSP cost prices from a number of retailers selling fertilizers in Kampala (Uganda capital). Farm gate price obtained from farmer groups in consultation with the local extension officer of the study area was taken as the groundnut market price to compute income in the experimentation year.

2.10 Statistical Analysis

GenStat 15th Edition statistical package was used for data analysis. The data was subjected to Analysis of Variance (ANOVA) for determining the effects using a Split-split plot design. To test for significance and interactions, a threshold P value of 0.05 was used. When the interactions and main effects were significantly different the least significant difference (LSD) test (α = 0.05) was used to separate the means. The ANOVA outputs are presented in Appendix V-XI.

3 RESULTS

3.1 Soil characteristics of the experimental sites

Texturally, the soils at both sites were sand clay loam with moderately acidic pH (Table 3.1). Since the pH level was within the acceptable range for crop growth no correction measures for pH were taken. The extractable P on the sites was classified under the low category after soil analysis using the Bray P1 method. According to London (1991), if available P is < 5 mg kg^{-1} it's regarded as low, 5- 15 mg kg^{-1} as medium and > 15 mg kg^{-1} as high. The exchangeable bases on the sites were on the acceptable levels except for Ca which was low at Alati B (1.5 $cmol_c$ kg^{-1}), N was low whilst organic carbon was on the higher category London (1984). Generally, the soils at both sites were considerably of low fertility level when taking into account the major nutrients like N and P which are also nutrients of high influence to the overall crop yield.

3.2 General crop growth

Emergence assessment was started 7 days after planting. Very few plants could be visibly seen coming out but mostly only cracks could be observed on planting stations, an indication that plants were emerging, therefore, no plant count was done within that period. On the 16^{th} day after planting, thorough emergence assessment was carried out for most of the plants have already emerged. Alati B site had better emergence percentage with an average of 83.3%. Jeriko site's emergence percentage was moderate; however, some plots had emergence percentage as low as 30% (Appendix XII). On average, Jeriko site had 69.8% with a range between 30 and 91% whilst a range of 70 - 100% was observed at Alati B. Replanting was done on the 18^{th} day after the first planting in order to have uniform plant population. Observations were that most of the first planted seeds were still emerging which shows that some seeds have been covered by soil aggregates whilst some could not have been placed on enough moisture during the first planting. It was also later observed that soils at Jeriko site were shallow and could easily lose moisture in a very short space of time. This was not noticed during site selection since the site had been ploughed few days before its selection. Generally, crop growth was good at Alati B but at Jeriko, some plants showed stunted growth and the replanted plants did not properly catch up with the first planted plants in both growth and reproduction vigour.

3.3 Fertilizer effect on pod, grain and stover yield performance

P application had a significant influence on yield with strong effect ($P < 0.001$) on grain and pod ($P = 0.025$) yield in Alati B village (Appendix V & VI) whereas in Jeriko village, its significant ($P = 0.048$) effects were observed on grain yield (Appendix VI) whilst on pod and stover yields it was not significant ($P > 0.05$) (Appendix V & VII).

P application gave grain yield ranging from 1148 to 1548 kg ha^{-1} at Alati B and 608 to 831 kg ha^{-1} at Jeriko village. Control treatment had the lowest grain yield at both sites whilst 20 kg P ha^{-1} gave the highest yield, however, although P application influenced grain yield, this was more pronounced at Alati B where 10, 20 and 30 kg P ha^{-1} rates resulted in yields which were not significantly different between the three rates but significantly higher than the control (Fig 3.1). The same order of P effect could be observed also on pod yield at Alati B. At Jeriko, control grain yield was not statistically different to that of 10 and 30 kg P application rates which in turn their yields were also not significantly different from 20 kg P ha^{-1} yield (Fig 3.2). No significant effect of the applied fertilisers could be seen on pod and stover yields at Jeriko site (Appendix V & VII).

The effects of gypsum and K were not significant (P > 0.05). The interactions gypsum x K (P =0.013) showed significant effect on stover yield in Alati B, however, the stover yield was not significantly different at 0 and 20 kg K ha^{-1} even when applied with or without gypsum. Though stover yield was not statistically different between the two K rates at 150 kg gypsum, numerically, application of gypsum resulted in lower stover yield at 20 kg K than at no gypsum application (Fig 3.3). In addition, K x P interaction effect was significant on stover yield at Alati B. Although this interaction showed an influence on stover yield, the yield was highly variable on different combinations of the two fertilizers. Without K application, 20 kg P yield was not significantly different from 10 and 30 kg P which their yields were not significantly different from the control. The yields did not change much on the control, 10 and 30 kg P when K was applied except at 20 kg P where the yield was significantly reduced from 2963 kg ha^{-1} at 0 K to 2563 kg at 20 kg K (Fig 3.4).

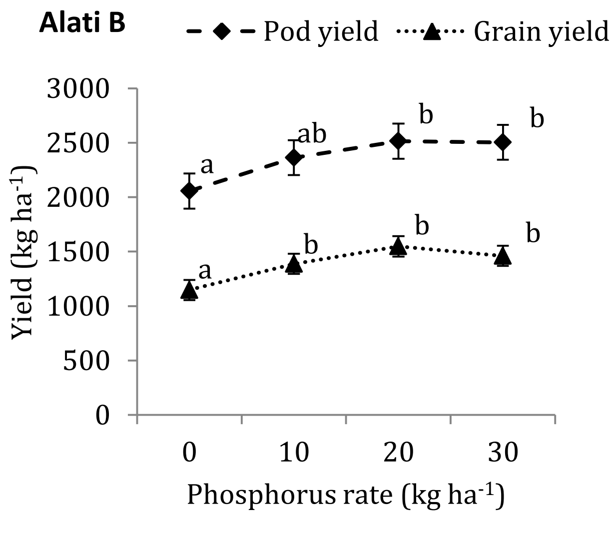


Fig 3.1 Pod and grain yields (kg ha-1) for Alati B as influenced by P application rate. LSD = 327 and 188 for pod and grain yield respectively. Different letters per variate indicate means which differ significantly (P=0.05). Bars indicate standard errors of differences of means (SED).

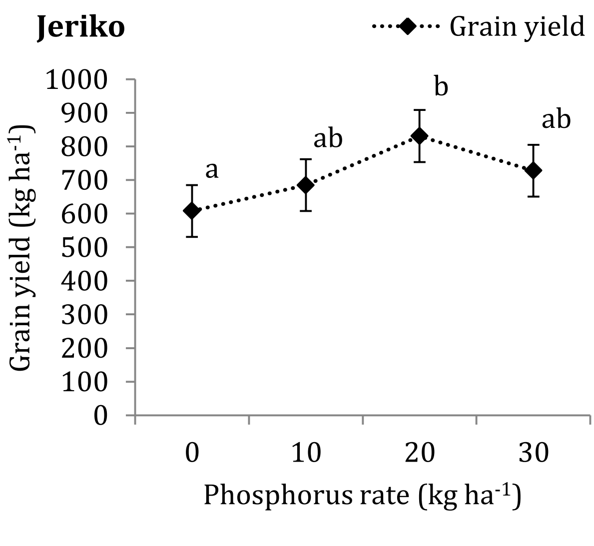
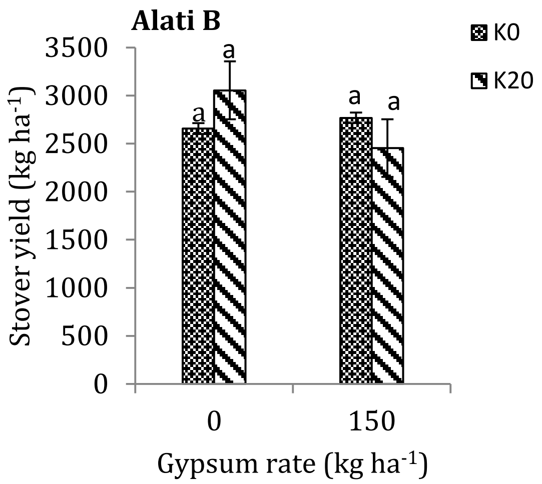


Fig 3.2 Grain yields (kg ha^{-1}) for Jeriko as influenced by P application rate. LSDs = 157.2. Different letters indicate the means which are significantly different (P=0.05). Bars indicate standard errors of differences of means.



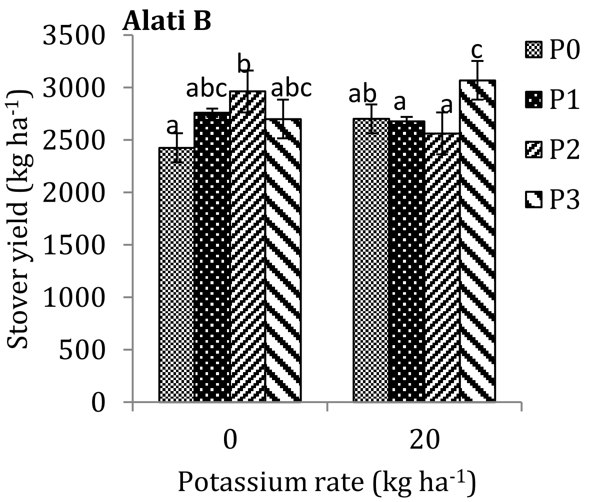


Fig 3.3 Stover yield (kg ha^{-1}) as influenced by the interaction of gypsum and K application rates. LSD = 1083.8. The similar letters indicate that the means are not significantly different (*P*=0.05).

Fig 3.4 Stover yield (kg ha^{-1}) as influenced by the interaction of K and P application rates. LSD = 387.3. Different letters indicate that the means are significantly different (*P*=0.05)

The main interaction effects of P, K and gypsum on grain yield were not significant ($P >$ 0.05) at both villages (Appendix VI). Grain yields were ranging from 919 to 1564 kg ha^{-1} at Alati B site and from 506 to 979 kg ha^{-1} at Jeriko village. The lowest grain yield values were recorded on the control plots whilst the highest were observed from the G1 x K0 x P2 treatment (Table 3.2). Statistically, these fertilizer rates did not give a significant influence to the grain yield, however, in agronomic terms, application of P at 20 kg and 150 kg gypsum ha^{-1} showed a greater improvement on yields than any other treatment.

3.4 Pod Number per plant in response to fertilizer application

At both villages, fertilizer application showed no significant (P >0.05) effect on pod number per plant (Appendix VIII). Pod number per plant was between the range of 21.4 to 27.78 (Alati B) and 14.5 to 20.72 (Jeriko). The lowest pod number per plant was observed on the control at Alati B and on the G1 x K1 x P0 interaction on Jeriko village whilst the highest was recorded at G0 x K0 x P3 and G1 x K0 x P3 interaction for Alati B and Jeriko villages respectively (Table 3.3).

Table 3.1 Physical and chemical properties of soils on Alati B and Jeriko villages, the experimental sites in season 2013B in the Northern region of Uganda.

					Exchangeable bases				Particle size			Soil type
Site	pH	P (ppm)	N	Organic C	Na	K	Mg	Ca	Sand	Clay	Silt	
			(%)		(cmolc kg^{-1})				(%)			
Alati B	6.38	3.73	0.19	2.15	0.08	0.32	0.98	1.5	64	28	8	Sand clay loam
Jeriko	6.49	0.76	0.23	2.31	0.05	0.56	1.02	2.2	64	26	10	Sand clay loam
Critical values[1]	-	15	0.5-1	2	-	0.2-1.5	< 3	> 2	-	-	-	-

[1] London (1991) and 1984. Booker tropical soil manual: A handbook for soil survey and agricultural land evaluation in the tropics and subtropics.

Table 3.2 Grain yield (kg ha^{-1}) for the two villages as influenced by different application rates of gypsum, K and P fertilizers.

Alati B

		Phosphorus rate (kg ha^{-1})			
Gypsum (kg ha^{-1})	Potassium (kg ha^{-1})	**0**	**10**	**20**	**30**
0	0	919	1325	1368	1434
	20	1345	1438	1503	1432
150	0	1190	1442	1972	1414
	20	1138	1342	1349	1564

P = 0.106; $LSD_{0.05}$ = 702.3; SED[1] = 301.6;

Jeriko

Gypsum (kg ha^{-1})	Potassium (kg ha^{-1})				
0	0	506	656	819	712
	20	576	709	754	768
150	0	791	727	979	789
	20	558	646	774	643

P = 0.944; $LSD_{0.05}$ = 385.0; SED = 185.8

[1] SED = Standard error of difference of means

Table 3.3 Pod number per plant (average pod number per plant) for the two villages as influenced by different application rates of gypsum, K and P fertilizers.

Alati B

		Phosphorus rate (kg ha^{-1})			
Gypsum (kg ha^{-1})	Potassium (kg ha^{-1})	**0**	**10**	**20**	**30**
0	0	23.7	25.83	26	27.78
	20	23.78	23.25	24.85	24.93
150	0	22.78	22.3	25.6	23.4
	20	21.4	27.33	25.03	24.15

P = 0.232; $LSD_{0.05}$ = 4.456; SED[1] = 2.212

Jeriko

Gypsum (kg ha^{-1})	Potassium (kg ha^{-1})				
0	0	14.5	20	20.12	20.72
	20	21.23	20.25	19.65	16.3
150	0	19.95	19.3	19.77	22.32
	20	16.7	21.33	20.02	19.57

P = 0.053; $LSD_{0.05}$ = 4.707; SED = 2.335

[1]SED = Standard error of difference of means

Table 3.4 Cost benefit analysis of groundnut with respect to P application for Alati B and Jeriko villages in the second season of 2013.

	Unit	Alati B				Jeriko			
		P0[1]	**P1**	**P2**	**P3**	**P0**	**P1**	**P2**	**P3**
Area (ha)		1	1	1	1	1	1	1	1
Average yield	kg ha^{-1}	1147.80	1386.82	1548.20	1461.03	607.66	684.78	831.49	727.89
Average yield gain ha^{-1}	kg	0.00	239.02	400.40	313.23	0.00	77.12	223.83	120.23
Market price[2]	US$ kg^{-1}	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20
Gross income	US$	1377.36	1664.18	1857.84	1753.23	729.19	821.73	997.79	873.47
SSP required[3]	kg ha^{-1}	0	111	222	333	0	111	222	333
SSP cost[4]	US$ $(50\ kg)^{-1}$	0.00	48.00	48.00	48.00	0.00	48.00	48.00	48.00
Total SSP cost	US$	0.00	106.56	213.12	319.68	0.00	106.56	213.12	319.68
Net Income	US$	1377.36	1557.62	1644.72	1433.55	729.19	715.17	784.67	553.79
SSP use benefit	US$[5]	0.00	180.26	267.36	56.19	0.00	-14.02	55.48	-175.40

[1] P treatments based on P application rates used for this experiment.
[2] Price based on the observed farm gate price in the study area.
[3] Single super phosphate with 9% phosphorus applied to meet P requirements in this experiment.
[4] Retail cost price charged for SSP in 2013.
[5] currency conversion was based on the banking exchange rate of US$1: 2500 Ugandan Shillings.

3.5 Nodule count in response to gypsum and phosphorus application

The effect of P application on nodulation was significant (P = 0.016) on Alati B and (P = 0.034) on Jeriko (Appendix IX). Also, gypsum had a significant effect (P = 0.019) (Alati B), whereas K effects were insignificant (P =0.05) at both sites. Number of nodules per plant was not significantly different between control, 10 and 30 kg P on both sites whereas at 20 kg P, the nodule number was significantly higher (120.8) than the control (100.3) at Alati B and 88 for the control against 104.6 at 20 kg P at Jeriko site (Fig 3.5). Although 20 kg P had higher nodule number per plant than the control, its nodulation was not significantly different with 10 and 30 kg P at Jeriko whilst at Alati B, 30 kg P had weaker nodulation than 20 kg P which in turn did not differ significantly with that of 10 kg P rate.

Nodule number per plant was also significantly (P = 0.019) influenced by gypsum application at Alati B. Higher nodule per plant (118.8) was observed at 0 gypsum application against 100 nodules per plant at 150 kg gypsum (Fig 3.6). There was no significant effect of K on nodulation at both sites (Appendix IX)

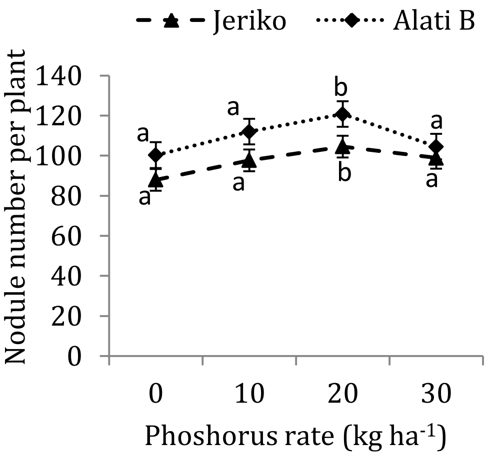


Fig 3.5 Nodule count (nodule number per plant) as influenced by P application rate (kg ha^{-1}). LSD = 13.01 and 10.99 for Alati B and Jeriko respectively. Different letters per village indicate the means which differ significantly (P =0.05). Bars indicate standard errors of differences of means.

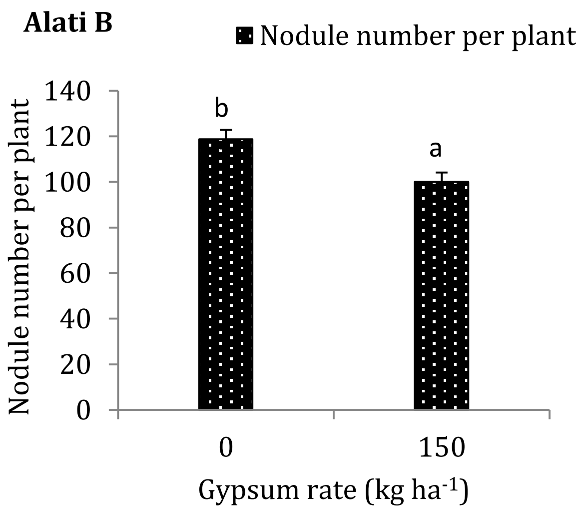


Fig 3.6 Nodule count (nodule number per plant) as influenced by gypsum application rate (kg ha^{-1}). LSD = 12.95. Different letters indicate the means which differ significantly (P =0.05). Bars indicate standard errors of differences of means.

3.6 100 seed weight (g) as influenced by fertilizers

P application rate had a significant effect on 100 seed weight (P = 0.023) for Alati B (Appendix X) but not at Jeriko. At 0, 10 and 30 kg P ha^{-1} application rates, 100 seed weight was not significantly different. The 20 kg P rate had seed weight that was not statistically different from the seed weight at 10 kg P; whereas relative to control and 30 kg P, its seed weight was significantly higher than the seed weight of the two rates (Fig 3.7).

Gypsum and K individual effects were not significant (P >0.05) at both sites, but their interaction effect was significant (P = 0.015) at Jeriko (Appendix X). 100 seed weight did not differ significantly at 0 and 20 kg K ha^{-1} regardless of grown with or without gypsum. However, when applied with 150 kg gypsum ha^{-1}, the 100 seed weight was significantly higher at 0 K (36.14 g) than at the same K rate (31.86 g) without gypsum (Fig 3.8).

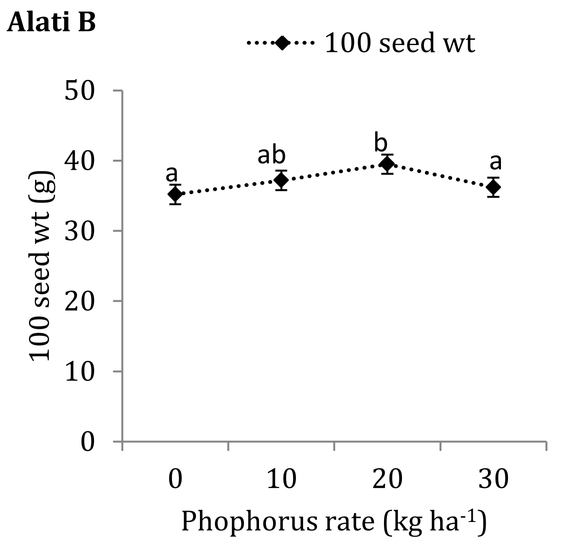


Fig 3.7 100 seed weight (g) for Alati B village as influenced by P application rate (kg ha^{-1}). LSD =2.786. Different letters show the means which are significantly different (P=0.05). Bars indicate standard errors of differences of means.

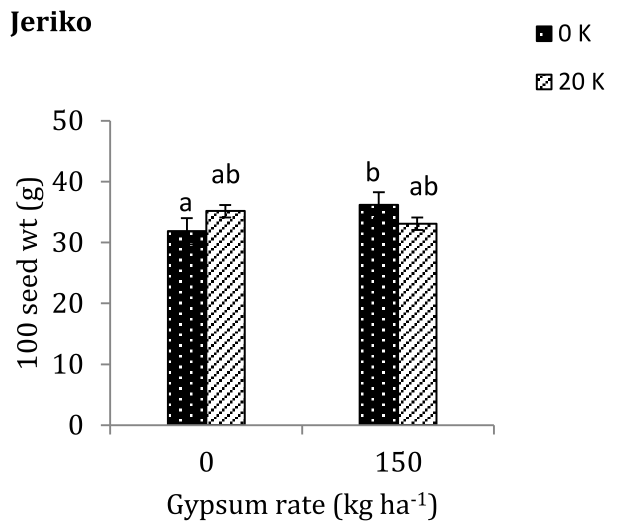


Fig 3.8 100 seed weight (g) for Jeriko village as influenced by application rate (kg ha^{-1}) of gypsum and K interaction. LSD =3.877. Different letters show the means which are significantly different (P=0.05). Bars indicate standard errors of differences of means.

3.7 Shelling percentage (%)

For shelling percentage, P application had strong significant effect (P <.001) at the two villages. K effect was not significant (P =0.05). On Fig 3.9, P application had highest significant effect on shelling percentage on both sites at 20 kg P rate, medium at 10 and 30 kg P rate and the lowest percentage at the control. At Alati B, 20 kg P had 61.6 %, 58.6 and 58.3 % for 10 and 30 kg P respectively and 55.8 % at the control, whilst at Jeriko, 59.9 % was observed at 20 kg P, 56.2 and 55.6 % for 10 and 30 kg P respectively and 54.1% for the control. At Jeriko site, the shelling percentage at 30 kg P was not significantly different from the control.

In addition, gypsum had a minor effect (P=0.007) at Alati B and (P = 0.014) at Jeriko on shelling percentage. At both sites, significantly higher shelling percentage was observed when gypsum was applied than on non-gypsum applied crop. 150 kg gypsum had 59.5 % at Alati B and 56.7 % at Jeriko whilst with no gypsum; Alati B had 57.6 % and 56.2 % been recorded at Jeriko (Fig 3.10).

Gypsum x P interaction also had a significant (P = 0.05) effect on shelling percentage at Jeriko (Appendix XI). With or without gypsum applied, shelling percentage did not differ significantly between 0, 10 and 30 kg P. At no gypsum conditions, 20 kg P had a shelling percentage which was not statistically different from that of 10 and 30 P rate but when gypsum was applied, shelling percentage was significantly higher than the control, 10 and 30 P (Fig 3.11). A significant difference in shelling percentage between applied and non-applied gypsum treatments was recorded at 20 kg P where gypsum applied resulted in 61.8 % against 58.1 % under no gypsum conditions than at any other P rates.

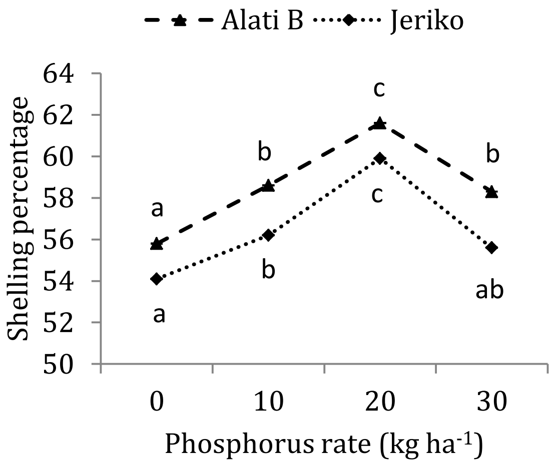


Fig 3.9 Shelling percentage for the two villages as influenced by P application rates. LSD = 1.203 and 1.827 for Alati B and Jeriko respectively. The percentages and LSDs were multiplied by 100. Different letters per village indicate the means which differ significantly (P=0.05). Bars indicate standard errors of differences of means.

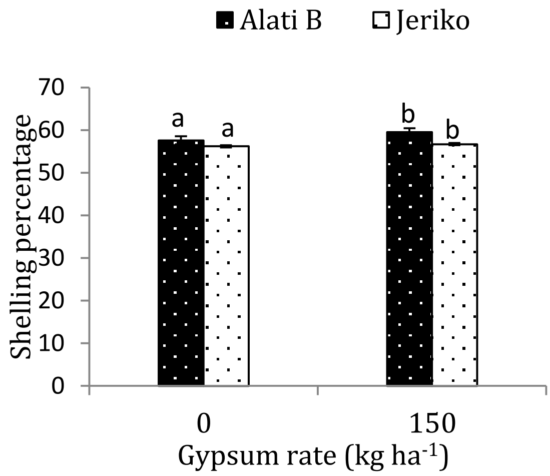


Fig 3.10 Shelling percentage for the two villages as influenced by gypsum application rates. LSD = 0.883 (Alati B) and 0.275 (Jeriko). The percentages and LSDs were multiplied by 100. Different letters per village indicate the means which differ significantly (P=0.05). Bars indicate standard errors of differences of means.

3.8 Additional grain yield benefit in response to fertilizer application.

With the control treatment giving an average grain yield of 919 and 506 kg ha^{-1} for Alati B and Jeriko respectively (Table 3.2), there was an outright grain yield benefit as a result of fertiliser application (Fig 3.12). Phosphorus application had an outstanding influence to the yield increase. Treatments with phosphorus had grain increase ranging from 44–100% (Alati B) and 27- 93% (Jeriko) whilst treatments without P contributed 24–46% and 10- 56% yield increase for Alati B and Jeriko respectively (Fig 3.12). On average, in relation to P application, the percentage yield increase in response to fertilizer application followed the order 20 kg P > 30 kg P > 10 kg P > 0 kg P for both experimental sites.

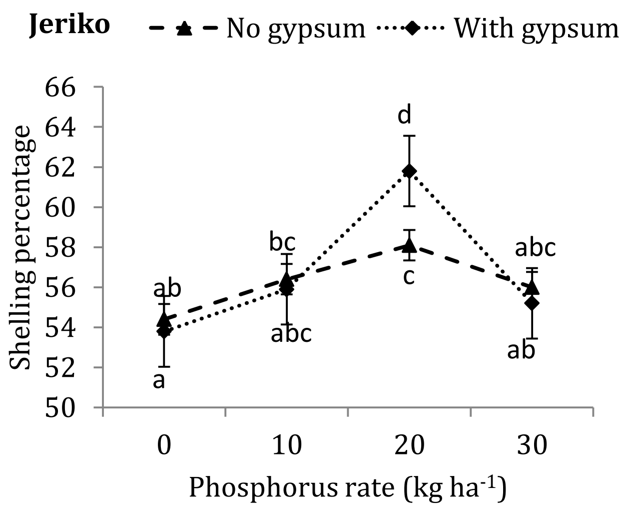


Fig 3.11 Shelling percentage for the Jeriko village as influenced by the interaction of gypsum and P application rates. LSD = 2.243. The percentages and LSD were multiplied by 100. Different letters indicate the means which differ significantly (*P*=0.05). Bars indicate standard errors of differences of means.

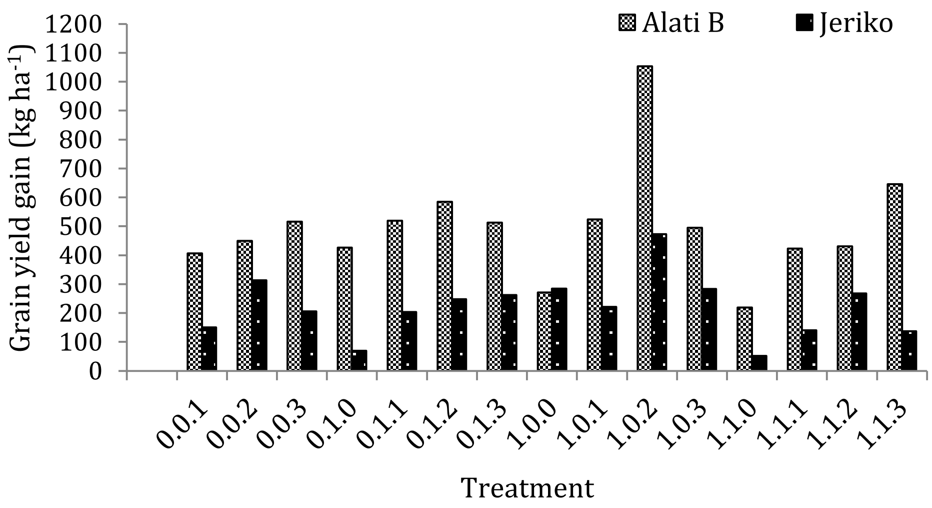


Fig 3.12 Average grain yield benefit (kg ha^{-1}) in response to fertilizer application for Alati B and Jeriko experimental sites. The order of treatment code follows G.K.P where G= gypsum with (0=0 kg, 1= 150 kg gypsum ha^{-1}), K= Potassium (0= 0 kg, 1= 20 kg K ha^{-1}) and P= Phosphorus (0, 1, 2, and 3 representing 0, 10, 20, and 30 kg P ha^{-1} respectively).

3.9 Cost-benefit analysis

Higher returns were realised at 20 kg P ha^{-1} than any other P rates. The SSP use benefits over the control were obtained by subtracting returns at the control from returns of each fertilizer treatment and these are the actual returns after paying the costs for SSP. Losses were observed at Jeriko on P1 and P3 mainly due to the low yields obtained at this site hence the grain yield gains were not higher enough to cover the fertilizer costs. In view of P influence, average grain yield gains ha^{-1} of 239; 400 and 313 kg over control were recorded at Alati B whereas at Jeriko site only 77; 224 and 120 kg ha^{-1} were realised as grain benefit from P1, P2 and P3 respectively (Table 3.4). Converting the grain yield gain less the grain quantity to cover SSP costs in monetary value, a farmer would realise US$180.26; US$267.36 and US$56.19 at Alati B and US$-14.02; US$55.48 and US$-175.40 at Jeriko from P1; P2 and P3 respectively (Table 3.4).

4 DISCUSSION

The aim of this study was to evaluate groundnut nodulation, N_2 fixation, yield and yield components responses to inorganic fertilizer application in Uganda. A field experiment was conducted in the second growing season of the year 2013.

4.1 Soil characteristics

Generally, the soils at both sites had very low P content. K and Ca were not deficient except at Alati B where Ca was below adequate (Table 3.1). With these observations, strong responses were expected on P because this was the most deficient nutrient, medium response on Ca at Alati B and very low response on K application. At Jeriko site, it was later observed that the soil was shallow and could quickly loss moisture, this had a strong bearing on the overall crop growth and performance and resulted in relatively lower yields than Alati B.

4.2 Fertilizers' influence on yield, yield components and nodulation

The results obtained showed that phosphorus was the main limiting and deficient nutrient for groundnut performance during the experimental season. Phosphorus application influenced pod, grain, and stover yields, 100 seed weight, nodulation and shelling percentage of groundnut. The results agreed with other studies carried out in Africa and elsewhere around the world where significance influence of P was observed on yields and other parameters of different grain and non-grain legumes as well as other non-legume crops like maize (Naab et al., 2009, Kamara et al., 2011, Shiyam, 2010, Veeramani and Subrahmaniyan, 2011, Mupangwa and Tagwira, 2005, Tran Thi Thu Ha, 2011, Kabir et al., 2013).

An increase of pod and grain yield (Fig 3.1 & Fig 3.2), nodule number per plant (Fig 3.5), 100 seed weight (Fig 3.7) and shelling percentage (Fig 3.9) was observed with the increase in P up to 20 kg P ha^{-1}. At 30 kg P ha^{-1}, these parameters could either remain unchanged as on 20 P or could show a negative respond to P. The decline or unchanged values of pod and grain yield, nodule number per plant, 100 seed weight and shelling percentage when P rate was increased from 20 to 30 kg P ha^{-1} contradicts with other researches on which an increase of the above measured parameters was observed at and above 30 kg P ha^{-1} application rate (Singh and Chaudhari, 1996, Singh and Ahuja, 1985). This decline shows a variability that exists in P requirements for crops depending on different conditions and initial available P. Also, a range between 10 to 65 kg P ha^{-1} was reportedly gave positive significance results in legumes yield and yield attributes (Kumar and Sreekumaran, 1992, Rath et al., 2000) but this was not the case in this study at above 20 kg P rate. This could be due to limited absorption of micronutrients. Micronutrients such as zinc (Zn), iron (Fe) and copper (Cu) play important roles in plant physiology and metabolic processes. However, if P concentration is high in the soil, it is known to "lock" and reduce the absorption and utilization of these micronutrients especially Zn (Mousavi, 2011) and Fe (Murphy et al., 1981) through P to micronutrients interactions. This interaction results in P-induced micronutrients deficiency (Murphy et al., 1981) hence reduces enzymatic activities on physiological and metabolic processes which in turn negatively affect dry matter accumulation and leads to low yields. This could be one of the reasons of negative effect of higher P rate above 20 kg.

The positive results observed here strengthen the idea that P is important on the activation of metabolic processes necessary for vegetative growth resulting in high dry matter accumulation (Hemalatha et al., 2013, Gobarah et al., 2006) among other roles like building up of phospholipids and nucleic acids (Kabir et al., 2013) giving rise to better grain yield and seed weight. This concurs with the reports that P is one of the most limiting, deficient and declining nutrients in most soils in SSA (Wang et al., 2014, Graham and Vance, 2000) as its influence after application was more prominent. Pod and seed grain as the sink of the metabolic processes in groundnut benefit much on dry matter assimilates from the above ground parts during growth phase hence increase in yields and 100 seed weight.

Fig 3.5 shows nodulation's positive response to P application. This indicates that P is one of the important nutrients required for nodulating legumes as a precursor for energy transfer in form of ATP during nitrogen fixation (Hossain et al., 2007, Graham and Vance, 2000) and crop growth. The results agree with previous researches like Bhuiyan et al. (2008) who cited a rise in nodulation after P application on mung bean (*Vigna radiata* L.). Pramanik et al. (2009) observed an increase in nodule number per plant on seven green manure legume species in Bangladesh as P level was increased to 36 kg P ha^{-1} and recorded the lowest at 18 kg P ha^{-1}. Similarly, Tairo and Ndakidemi (2013) reported a significant rise in nodule number per plant in Tanzania in both glass house and field experiment on soybean (*Glycine max* (L). Merr) in response to P application.

Application of gypsum resulted in a reduction of nodule number per plant compared to plots without gypsum (Fig 3.6). This result contradicted with studies of Meena et al. (2007) who reported a positive influence of gypsum as Ca source on nodulation. The observed result on Ca effects in this current study could be attributed to the fraction of Ca from SSP which contains 21% Ca. This means that for the plots that received P fertilizer, there was an additional 23; 47 and 72 kg Ca ha^{-1} from 10; 20 and 30 kg P ha^{-1} rates respectively added at planting to the already available inherent soil Ca. With that amount of Ca from P, any additional Ca from gypsum could not bore a positive contribution. Gypsum contains 22% Ca, implying that experimental units applied with gypsum were receiving 33 kg Ca ha^{-1} at 50% flowering. Blamey and Chapman (1982) indicated that there is a tendency of high gypsum application to reduce nodulation by possibly increasing the activity of Al- ions and this could be possibly another reason for the reduced nodulation in this study. In addition, it might be in combination with reduced molybdenum (Mo) availability due to SO_4^{2-} antagonism as observed by Reisenauer (1963). Similarly, Shamsuddin et al. (1992) observed a greater reduction in nodule number per plant for groundnut at the same level of Al- ions concentration with increasing Ca concentration in a solution. Furthermore, studies by Lynd and Ansman

(1989a) and Purcino and Lynd (1986) showed no significant increase in nodulation after addition of Ca on soils of pH >6.1 on several legume species. However, at this moment, the result of this current study could not be conclusive to confirm that gypsum addition has no positive effect on groundnut nodulation in Northern Uganda.

Hosseinzadeh et al. (2012) and Hassan and Mahmoud (2014) observed a strong positive influence of gypsum over control on pod, grain, and stover yield of groundnut, whilst in this study, main effects of gypsum did not show positive significant influences on these parameters and so as K. This could be attributed to some soil factors or soil chemical reactions leading to reduced absorption of micronutrients. Also, it could be because of the initial availability of Ca together with Ca from P and also might be K of the soils of the two villages as explained above. The sites exhibited adequacy in these nutrients (Table 3.1) though at Alati B, Ca was fairly below average. Therefore, any additional application of such nutrients could not make any positive contribution to the parameters measured in the study.

Gypsum's main effects were observed on shelling percentage. The response was relatively stronger on Alati B (P = 0.007) than Jeriko (P = 0.014) village. Higher shelling percentage was recorded with application of gypsum where Alati B had 59.5% on gypsum applied plots against 57.6 % on the control. The similar response was also observed at Jeriko village where gypsum application resulted in 56.7 % whilst the control had 56.2 % (Fig 3.10). This result agrees with the expectation that fertilizer response could be robust when applied to low than high fertile soil and Alati B had lower inherent Ca content than Jeriko site (Table 3.1). In addition, gypsum's interaction with P was positive, especially at 20 kg P ha^{-1} where 61.8 % was recorded on applied gypsum against 58.1% on no gypsum (Fig 3.11). This is an indication of the positive contribution of Ca on pod filling and reduction of 'pops' or empty pods (Kabir et al., 2013). Similar results were reported by Kamara et al. (2011) on positive effects of gypsum application on shelling percentage.

However, although gypsum had a positive influence on shelling percentage, the influence was not so strong and could not show a significant influence towards pod and grain yield improvement. This could be attributed to the fact that gypsum did not have a significant influence on other yield components like pod number and 100 seed weight. As it has been observed that gypsum contributed to pod filling by positive shelling percentage in this study, the resultant seed remained small and lighter in weight as exhibited on the recorded low seed weight. This is an indication of minimal biomass channelled towards the seed. Another probable factor to this could be moisture stress during the last one and half month of the season. This was a late planted crop and the rains in the experimentation season were concentrated between August and mid-November (Appendix II) and there was no other effective rainfall from that time up to harvesting time. This means the crop had moisture stress during pod filling resulting in smaller and lighter seeds which could not have strong contribution towards grain yield.

K application did not show significant effects on the measured parameters in this study. Some antagonistic interaction effects were observed between K and gypsum as observed on stover yield (Fig 3.3) and 100 seed weight (Fig 3.8). Numerically, stover yields and seed weight were higher at 20 kg K without gypsum but all declined on the application of 150 kg gypsum. Similarly, there was no significant difference in these parameters between 0 and 20 kg K ha^{-1} regardless of being applied with or without gypsum. This may have been associated with excessive cations in the soil thereby creating competition and imbalances between K and other nutrients especially Mg and Ca since these are strong competitors of K (Lin, 2010). It has been reported that when there is high Ca in the soil there is a tendency of reduced K uptake (Overstreet et al., 1951) and this could be another reason for the observed results in this study. Looking closely to K and gypsum individual influences when the other element of the two was at 0, it shows that there are imbalances of soil cations if these elements are not optimally applied which in turn exacerbate the reduction in performance of the other.

In this study, it has been observed that the measured parameters' responses to gypsum and K application effects were close to none. This was highlighted above as could have been due to antagonism between the two fertilizers which saw their magnitude of grain yield gain over control being 80 and 6 kg ha^{-1} for gypsum and K application respectively whilst P had 400 kg ha^{-1} at its high yielding rate of 20 kg P ha^{-1}. Another possible factor could be the design used; the split-split plot design. This might have caused the low statistical *power* of gypsum and K treatments on expressing their influence since gypsum was used as the main treatment, K as a sub treatment whilst P was the sub-sub treatment and subsequently gypsum and K had relatively low degrees of freedom than P. The choice of this design was based on the management aspect of gypsum application. This fertilizer was applied mid-season when the crop was at 50 % flowering and farmers were involved in the application. Therefore, to avoid a mix up of plots for applied or not applied gypsum which could be seen in designs like randomized complete block design (RCBD), a split-split plot design was seen as a better option on which a stand-alone whole plot for applied or not applied gypsum could be clear. Basing on such presumed low statistical *power* as a limitation of split-split plot design, a design such as RCBD is recommended for future researches to limit such experimental errors.

Statistically, there was no significant influence of gypsum, P and K or interactive effects of these fertilizers on pod number per plant in this study. However, although pod number per plant was so variable, agronomically, P remained highly influential especially under no gypsum and no K and at application of 150 kg gypsum and 20 kg K conditions (Table 3.3). This implies that there were some interactive effects of these fertilisers to positively influence pod formation and growth.

Measuring nitrogen fixation was one of the objectives in this study. Nitrogen fixation is important in the farming systems as it contributes to soil fertility with relatively limited costs than purchasing of inorganic fertilizers. In this study, the idea was to quantify the nitrogen that would be fixed by groundnut and be in a position to fully advise farmers on soil fertility benefits they could get by including fertilizer use as a management option for this crop in their farming systems. However, this objective was not achieved due to immigration restrictions on the transfer of plant samples from Uganda to Wageningen University at which they were supposed to be tested for nitrogen fixation. The samples were received at the Netherlands immigration but were sent back to Uganda citing some documentation irregularities.

4.3 Cost-benefit analysis

Grain yield responded positively to P influence than gypsum and K fertilizer application. Therefore, P was observed to be the most contributing nutrient element to the increased grain yield over control hence the cost benefit analysis was conducted focusing on the extra benefit derived from P than other fertilizers. Basing on the SSP cost price and the total SSP applied to cater from the required P rates in the experiment, 89; 178 and 266 kg of grain ha^{-1} were required as extra grain yield to cover the costs of SSP for P1, P2 and P3 respectively (Table 3.4).

Although the grain yield and yield gain followed the order of P2 > P3 >P1, SSP cost at P3 was higher than at P1 and P2 rates (Table 3.4). This had resulted in monetary value of the net yield gain being more favourable at P1 and P2 with the later giving the highest value than the former (Table 3.4). This was observed at both sites. P application showed that it is beneficial but the benefits were much higher at Alati B than at Jeriko. Jeriko had relatively lower grain yields than Alati B hence its yield gain at P1 and P3 could not cover the SSP cost resulting in P use losses at that site. This could be associated with the poor crop performance at Jeriko as affected by soil depth. The soils at Jeriko site were shallow that they could quickly lose soil moisture resulting in very minimal utilisation of soil nutrients, and poor crop growth hence poor yields. Above 20 kg P application had little benefit to the farmers, therefore a range between 10 to 20 kg P ha^{-1} could be observed as the most suitable.

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

This study showed that P application is highly influential to the overall growth, nodulation, seed weight, shelling percentage and yield of groundnut. The positive response of groundnut to P application is an indication that P is a highly deficient and limiting nutrient element for groundnut production in the study area. Improved yields were recorded after P application. However, above 20 kg P rate the yield benefit was not much lucrative, therefore, it can be concluded that with the observed overall significant influence on pod, grain and stover yields, pod and nodule number per plant, seed weight and shelling percentage of groundnut at 20 kg P ha^{-1}, this is the optimum rate for improved groundnut production in Northern Uganda.

Application of Ca and K did not show much individual influence to the crop except through their interactive effects. Gypsum application resulted in an enhanced shelling percentage, but the effects were not much stronger whilst K effects could not be established in this study. This indicates that these nutrients were not limiting to the crop performance and were adequate as the soil analysis results indicate. However, Ca and K are equally important nutrients for groundnut but their application should be highly based on soil analysis results for the probable application rates. If applied above their optimum rates, the two fertilizers may results in an antagonistic behaviour and affect crop performance as shown in this experiment.

Overall, with the grain yield benefits and the additional returns realised over non fertilised crop, we can conclusively say, inorganic fertiliser use is necessary in the smallholder farming system in Uganda and warrants investment as it improves groundnut productivity.

5.2 Recommendations for further research

This study did not unravel all of the interesting areas in groundnut or legumes under the environmental conditions and factors explained here. Aspects such as nutrient uptake rates, nutrient use efficiencies (NUE) like physiological and agronomic nutrient efficiency and the average nutrient recovery (ARN) need to be determined. These are important aspects for they can show how much yield benefits can be derived per unit of nutrient applied and the nutrient conversion efficiency of groundnuts under the growing conditions as in this study. In addition, further research need to be done on testing and ascertaining protein and oil content for assurance on the grain quality of the studied variety under the studied factors and conditions.

Furthermore, there is high variability which can exist on soils of different regions and different seasons; as a result crop performance could not be the same under such conditions. Therefore, I recommend that this study be also carried out in the longer season of March to July, as well as in other groundnut growing regions of Uganda for the benefit of all smallholder farmers in the country so as to see how the performance will be during that season and in other regions. This will enable researchers to give a detailed advisory service to the farmers towards improved groundnut productivity.

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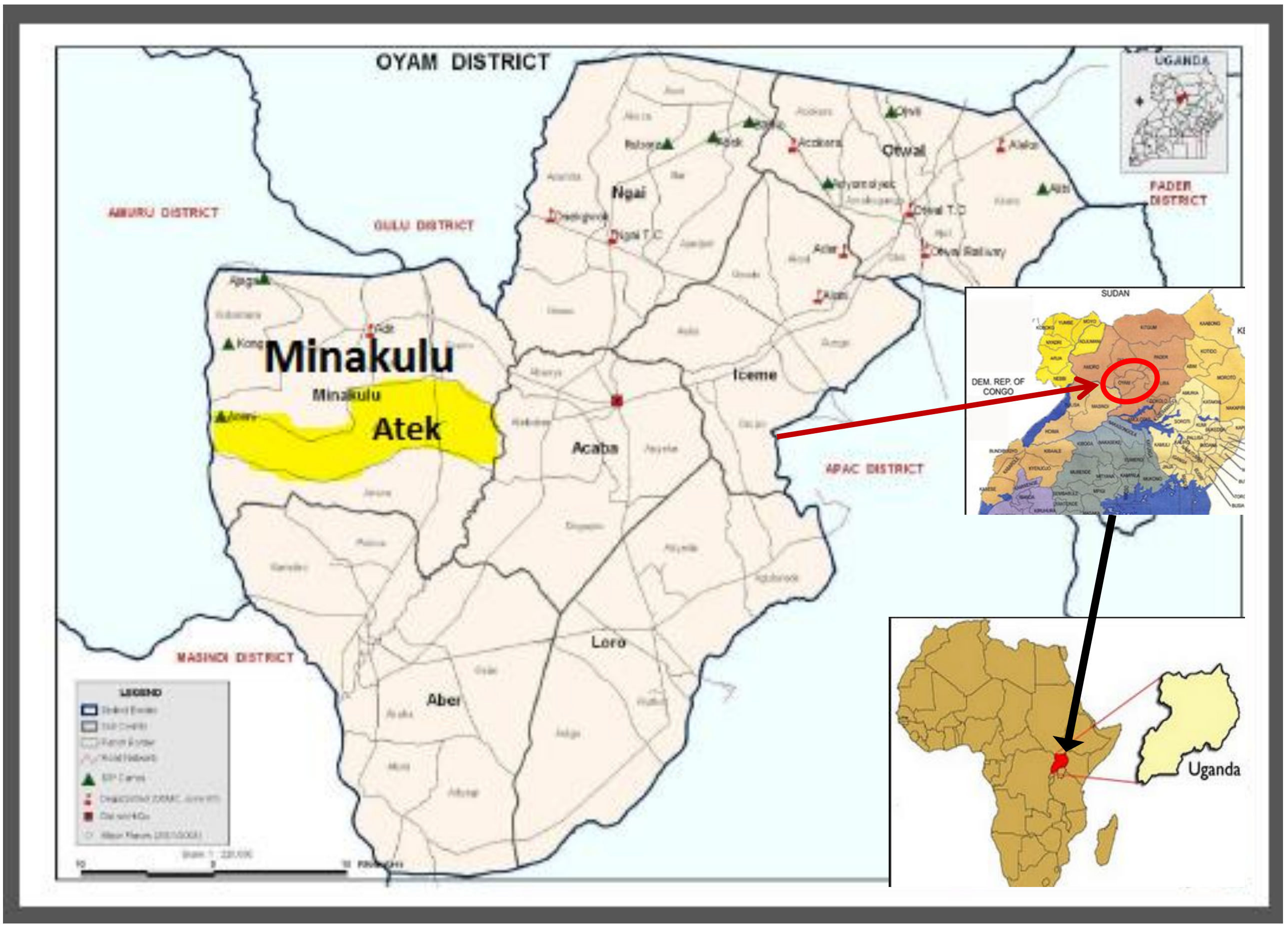
APPENDICES

Appendix I - Study site map



Study area

Appendix II - Rainfall (mm) data for the year 2013

Date/ Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
1	0.2	TR[1]	-	-	1.8	-	-	TR	2.7	0.7	-	-
2	-	-	-	-	18.6	-	TR	79.6	8.4	2.5	2.6	-
3	-	-	-	2.1	-	5.9	13.3	TR	-	20.8	-	-
4	-	-	-	TR	9.5	9.6	31.4	12.0	TR	0.5	3.5	-
5	0.2	-	0.7	2.7	7.8	34.3	-	10.4	0.3	0.4	1.5	2.1
6	-	0.2	0.4	6.6	31.4	-	-	2.0	-	1.5	TR	0.8
7	15.7	-	0.2	0.2	TR	-	6.0	-	4.5	3.9	2.2	-
8	-	-	3.0	5.5	-	-	-	2.1	11.2	0.1	2.3	-
9	2.7	-	1.8	4.8	17.5	-	-	TR	30.2	76.5	5.2	-
10	0.6	-	-	6.3	4.5	-	-	-	-	0.1	3.6	7.7
11	-	-	-	15.1	-	0.5	-	3.0	-	-	-	6.7
12	-	-	3.4	0.6	12.9	0.1	-	2.0	-	18.8	42.8	13.5
13	-	-	16.9	1.8	TR	-	20.3	-	8.1	-	-	1.5
14	-	0.1	-	2.0	2.7	-	TR	-	-	-	11.8	-
15	-	-	-	-	-	1.4	-	4.4	-	0.6	30.0	-
16	-	-	-	TR	-	35.7	-	-	0.5	1.8	11.0	-
17	-	-	0.6	-	-	-	-	12.3	3.0	14.2	-	-
18	-	-	0.8	3.1	-	-	12.4	10.5	8.5	6.2	-	-
19	-	-	2.2	-	6.8	0.5	-	0.2	4.1	-	-	-
20	-	6.0	1.2	-	7.1	0.2	18.8	1.6	21.0	-	-	-
21	-	5.7	16.5	12.7	-	0.9	1.6	34.0	-	12.2	-	-
22	-	-	6.0	0.2	-	2.3	-	0.8	15.3	1.5	-	-
23	-	-	TR	-	-	1.2	-	0.6	1.5	-	TR	-
24	-	-	TR	4.5	-	TR	47.3	1.6	50.7	22.1	TR	-
25	-	-	27.0	3.6	14.2	-	6.4	TR	-	1.6	-	-
26	-	-	-	TR	-	0.6	0.3	6.9	-	9.4	-	-
27	-	-	9.0	13.1	-	-	27.9	-	-	TR	-	-
28	-	-	TR	13.6	6.6	-	2.2	-	44.5	11.9	-	-
29	46.5	-	24.1	29.3	-	14.4	20.7	10.7	7.0	13.2	-	TR
30	TR	-	29.6	1.1	TR	1.5	25.3	-	-	-	-	-
31	2.2	-	-	-	-	-	-	TR	-	-	-	0.7
Total	**68.1**	**12.0**	**143.3**	**128.8**	**149.4**	**109.1**	**234.6**	**194.7**	**221.5**	**242.2**	**116.5**	**33.0**

[1]TR =Trace rainfall < 0.05 mm

APPENDIX III

Appendix III a. - EXPERIMENTAL LAYOUT – 2013- 2014

Field Experiment - PPS – 80436 – MSc Thesis

Design:

Split-split plot design

Factors and levels

Gypsum (G):	G0 = 0 kg ha^{-1} or no gypsum
	G1 = 150 kg gypsum ha^{-1}
Potassium (K):	K0 = 0 kg K ha^{-1} or no K
	K1 = 20 kg K ha^{-1}
Phosphorus (P):	P0 = 0 kg P ha^{-1} or no P
	P1 = 10 kg P ha^{-1}
	P2 = 20 kg P ha^{-1}
	P3 = 30 kg P ha^{-1}
Variety:	SERENUT 5
Blocks:	4 per site
Sites:	2 (1 per village)

Further specifications

Location:	Alati B village (02^{o} 23’ 47.4’’N & 032^{o} 23’ 23.8’’E) and Jeriko village (02^{o} 23’ 29.0’’N & 032^{o} 23’ 15.6’’E) - Minakulu Sub-County, Oyam district-Uganda
Altitude:	1062 m a.s.l (Alati B) and 1057 m a.s.l (Jeriko)
Sowing date:	September 27, 2013 (Alati B) and September 28, 2013 (Jeriko)
Harvesting date:	January 09, 2014 (Alati B) and January 10, 2014 (Jeriko)
Field dimensions:	38 m x 29.5 m
Fallow strip dimensions:	0.5 m x 18.5 m
Experimental unit:	4 m x 3 m.
Plant spacing:	0.45 m inter-row x 0.15 m in-row
Sowing density:	+/-180 plants per experimental unit
Sowing depth:	4 - 5 cm
Disease and weed control:	No disease control; and manual weeding using hoes
Fertilization:	According to treatment (see Factors and levels above)
Received rainfall:	807.9 mm (2nd season)

Appendix III b. - Treatment structure

Treatment number, type and code used on the phosphorus x potassium x gypsum rates (kg ha^{-1}) on groundnut experiment in season 2013B in Northern region of Uganda.

Treatment number	Treatment type	Treatment code
1	0 Gypsum*0 Potassium*0 Phosphorus	G0 K0 P0
2	0 Gypsum*0 Potassium*10Phosphorus	G0 K0 P1
3	0 Gypsum*0 Potassium*20Phosphorus	G0 K0 P2
4	0 Gypsum*0 Potassium*30 Phosphorus	G0 K0 P3
5	0 Gypsum*20 Potassium*0 Phosphorus	G0 K1 P0
6	0 Gypsum*20 Potassium*10 Phosphorus	G0 K1 P1
7	0 Gypsum*20 Potassium*20 Phosphorus	G0 K1 P2
8	0 Gypsum*20 Potassium*30 Phosphorus	G0 K1 P3
9	150 Gypsum*0 Potassium*0 Phosphorus	G1 K0 P0
10	150 Gypsum*0 Potassium*10 Phosphorus	G1 K0 P1
11	150 Gypsum*0 Potassium*20 Phosphorus	G1 K0 P2
12	150 Gypsum*0 Potassium*30 Phosphorus	G1 K0 P3
13	150 Gypsum*20 Potassium*0 Phosphorus	G1 K1 P0
14	150 Gypsum*20 Potassium*10 Phosphorus	G1 K1 P1
15	150 Gypsum*20 Potassium*20 Phosphorus	G1 K1 P2
16	150 Gypsum*20 Potassium*30 Phosphorus	G1 K1 P3

Appendix III c. - Treatment layout

Alati B site

Levels: Gypsum - G0 =0 kg ha^{-1}; G1 = 150 kg gypsum ha^{-1}
Potassium - K0 = 0 kg ha^{-1}; K1 = 20 kg K ha^{-1}
Phosphorus - P0 = 0; P1=10; P2 = 20; P3 = 30 kg P ha^{-1}

Block 3							Block 4					
G1 K1 P3	G1 K1 P2	G1 K1 P1	G1 K1 P0	Path	Fallow Strip	Path	G1 K1 P2	G1 K1 P0	G1 K1 P3	G1 K1 P1	Path	Fallow Strip
G1 K0 P0	G1 K0 P3	G1 K0 P2	G1 K0 P1				G1 K0 P0	G1 K0 P1	G1 K0 P2	G1 K0 P3		
G0 K0 P2	G0 K0 P1	G0 K0 P0	G0 K0 P3				G0 K1 P1	G0 K1 P3	G0 K1 P0	G0 K1 P2		
G0 K1 P1	G0 K1 P0	G0 K1 P3	G0 K1 P2				G0 K0 P3	G0 K0 P2	G0 K0 P1	G0 K0 P0		

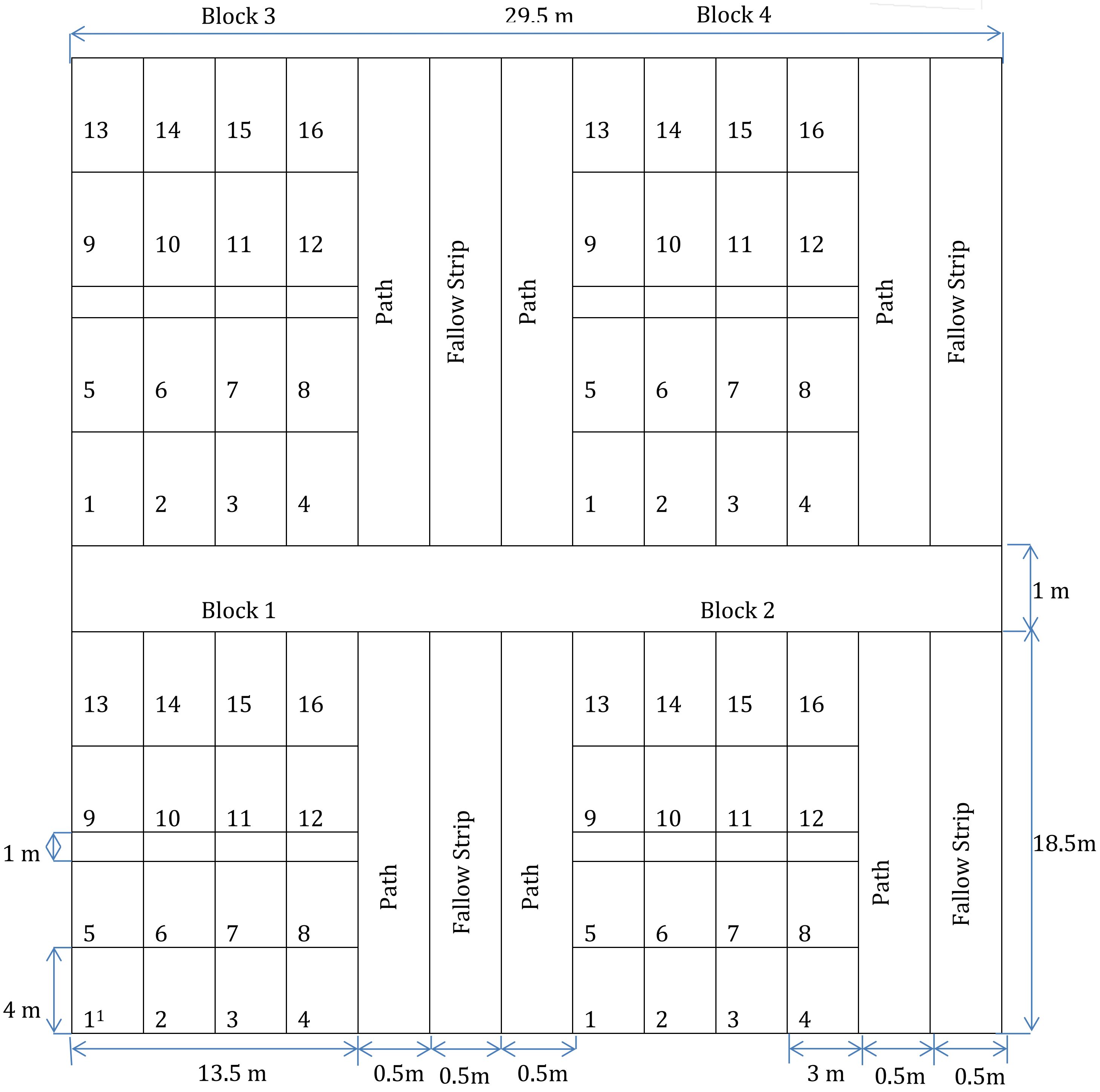
Block 1							Block 2					
G0 K0 P2	G0 K0 P1	G0 K0 P3	G0 K0 P0	Path	Fallow Strip	Path	G1 K1 P1	G1 K1 P0	G1 K1 P2	G1 K1 P3	Path	Fallow Strip
G0 K1 P0	G0 K1 P3	G0 K1 P1	G0 K1 P2				G1 K0 P3	G1 K0 P2	G1 K0 P0	G1 K0 P1		
G1 K0 P1	G1 K0 P2	G1 K0 P0	G1 K0 P3				G0 K1 P2	G0 K1 P1	G0 K1 P3	G0 K1 P0		
G1 K1 P3	G1 K1 P0	G1 K1 P2	G1 K1 P1				G0 K0 P0	G0 K0 P3	G0 K0 P1	G0 K0 P2		

Jeriko site

Block 3							Block 4					
G0 K1 P2	G0 K1 P1	G0 K1 P3	G0 K1 P0	Path	Fallow Strip	Path	G1 K0 P0	G1 K0 P2	G1 K0 P1	G1 K0 P3	Path	Fallow Strip
G0 K0 P0	G0 K0 P2	G0 K0 P1	G0 K0 P3				G1 K1 P3	G1 K1 P1	G1 K1 P2	G1 K1 P0		
G1 K1 P3	G1 K1 P0	G1 K1 P2	G1 K1 P1				G0 K1 P1	G0 K1 P3	G0 K1 P0	G0 K1 P2		
G1 K0 P1	G1 K0 P3	G1 K0 P0	G1 K0 P2				G0 K0 P2	G0 K0 P0	G0 K0 P3	G0 K0 P1		
Block 1							**Block 2**					
G1 K1 P1	G1 K1 P0	G1 K1 P3	G1 K1 P2	Path	Fallow Strip	Path	G0 K0 P3	G0 K0 P2	G0 K0 P1	G0 K0 P0	Path	Fallow Strip
G1 K0 P3	G1 K0 P2	G1 K0 P1	G1 K0 P0				G0 K1 P2	G0 K1 P1	G0 K1 P0	G0 K1 P3		
G0 K1 P0	G0 K1 P1	G0 K1 P2	G0 K1 P3				G1 K0 P0	G1 K0 P3	G1 K0 P2	G1 K0 P1		
G0 K0 P2	G0 K0 P3	G0 K0 P0	G0 K0 P1				G1 K1 P1	G1 K1 P0	G1 K1 P3	G1 K1 P2		

Appendix IV-The field layout

Not to scale



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[1] A digit in each plot represents plot number.

Appendix V-Analysis of variance for pod yield

Analysis of variance – Alati B

Variate: Pod yield (kg ha^{-1})

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
B stratum	3	3312276.	1104092.	0.44	
B.Gypsum stratum					
Gypsum	1	47299.	47299.	0.02	0.900
Residual	3	7539280.	2513093.	7.07	
B.Gypsum.K stratum					
K	1	305.	305.	0.00	0.978
Gypsum.K	1	1305228.	1305228.	3.67	0.104
Residual	6	2133651.	355608.	1.71	
B.Gypsum.K.P stratum					
P	3	2187334.	729111.	3.51	0.025
Gypsum.P	3	231869.	77290.	0.37	0.774
K.P	3	1130571.	376857.	1.81	0.162
Gypsum.K.P	3	1043512.	347837.	1.67	0.190
Residual	36	7487856.	207996.		
Total	63	26419181.			

Analysis of variance- Jeriko

Variate: Pod yield (kg ha^{-1})

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
B stratum	3	5902386.	1967462.	3.63	
B.Gypsum stratum					
Gypsum	1	103728.	103728.	0.19	0.691
Residual	3	1625607.	541869.	2.00	
B.Gypsum.K stratum					
K	1	277519.	277519.	1.03	0.350
Gypsum.K	1	470143.	470143.	1.74	0.236
Residual	6	1623247.	270541.	1.92	
B.Gypsum.K.P stratum					
P	3	612106.	204035.	1.45	0.246
Gypsum.P	3	186387.	62129.	0.44	0.726
K.P	3	65730.	21910.	0.16	0.926
Gypsum.K.P	3	89162.	29721.	0.21	0.888
Residual	36	5079747.	141104.		
Total	63	16035763.			

Tables of means

Variate: Pod yield

Grand mean 2360.

Gypsum	0 kg/ha	150 kg/ha
	2332.	2387.

K	0 kg/ha	20 kg/ha
	2357.	2362.

P	0 kg/ha	10 kg/ha	20 kg/ha	30 kg/ha
	2057.	2363.	2515.	2504.

Gypsum	K	0 kg/ha	20 kg/ha
0 kg/ha		2187.	2477.
150 kg/ha		2527.	2246.

Gypsum	P	0 kg/ha	10 kg/ha	20 kg/ha	30 kg/ha
0 kg/ha		2080.	2384.	2389.	2477.
150 kg/ha		2034.	2342.	2640.	2531.

K	P	0 kg/ha	10 kg/ha	20 kg/ha	30 kg/ha
0 kg/ha		1889.	2354.	2718.	2469.
20 kg/ha		2225.	2371.	2312.	2539.

Gypsum	K	P	0 kg/ha	10 kg/ha	20 kg/ha	30 kg/ha
0 kg/ha	0 kg/ha		1694.	2256.	2306.	2495.
	20 kg/ha		2466.	2512.	2473.	2459.
150 kg/ha	0 kg/ha		2084.	2453.	3130.	2443.
	20 kg/ha		1983.	2231.	2151.	2619.

Tables of means

Variate: Pod yield (kg ha^{-1})

Grand mean 1257.

Gypsum	0 kg/ha	150 kg/ha
	1217.	1297.

K	0 kg/ha	20 kg/ha
	1323.	1191.

P	0 kg/ha	10 kg/ha	20 kg/ha	30 kg/ha
	1121.	1217.	1382.	1309.

Gypsum	K	0 kg/ha	20 kg/ha
0 kg/ha		1197.	1237.
150 kg/ha		1449.	1146.

Gypsum	P	0 kg/ha	10 kg/ha	20 kg/ha	30 kg/ha
0 kg/ha		992.	1206.	1347.	1322.
150 kg/ha		1250.	1228.	1416.	1295.

K	P	0 kg/ha	10 kg/ha	20 kg/ha	30 kg/ha
0 kg/ha		1210.	1245.	1487.	1350.
20 kg/ha		1032.	1188.	1276.	1268.

Gypsum	K	P	0 kg/ha	10 kg/ha	20 kg/ha	30 kg/ha
0 kg/ha	0 kg/ha		936.	1187.	1389.	1275.
	20 kg/ha		1048.	1224.	1305.	1369.
150 kg/ha	0 kg/ha		1484.	1303.	1584.	1424.
	20 kg/ha		1016.	1153.	1248.	1166

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Standard errors of differences of means

Table	Gypsum	K	P	Gypsum K
rep.	32	32	16	16
d.f.	3	6	36	3.87
s.e.d.	396.3	149.1	161.2	423.4
Except when comparing means with the same level(s) of				
Gypsum				210.8

Table	Gypsum P	K P	Gypsum K P
rep.	8	8	4
s.e.d.	442.8	247.4	507.2
d.f.	4.65	30.09	7.81
Except when comparing means with the same level(s) of			
Gypsum	228.0		349.9
d.f.	36		30.09
K		228.0	
d.f.		36	
Gypsum.K			322.5
d.f.			36
Gypsum.P			349.9
d.f.			30.09

Standard errors of differences of means

Table	Gypsum	K	P	Gypsum K
rep.	32	32	16	16
d.f.	3	6	36	6.00
s.e.d.	184.0	130.0	132.8	225.3
Except when comparing means with the same level(s) of				
Gypsum				183.9

Table	Gypsum P	K P	Gypsum K P
rep.	8	8	4
s.e.d.	245.6	208.2	322.0
d.f.	9.06	28.03	21.18
Except when comparing means with the same level(s) of			
Gypsum	187.8		294.5
d.f.	36		28.03
K		187.8	
d.f.		36	
Gypsum.K			265.6
d.f.			36
Gypsum.P			294.5
d.f.			28.03

Least significant differences of means (5% level)

Table	Gypsum	K	P	Gypsum K
rep.	32	32	16	16
d.f.	3	6	36	3.87
l.s.d.	1261.3	364.8	327.0	1191.3
Except when comparing means with the same level(s) of				
Gypsum				515.9

Table	Gypsum P	K P	Gypsum K P
rep.	8	8	4
l.s.d.	1164.4	505.3	1174.6
d.f.	4.65	30.09	7.81
Except when comparing means with the same level(s) of			
Gypsum	462.5		714.6
d.f.	36		30.09
K		462.5	
d.f.		36	
Gypsum.K			654.0
d.f.			36
Gypsum.P			714.6
d.f.			30.09

Duncan's multiple range test

P

	Mean	
0 kg/ha	2057	a
10 kg/ha	2363	ab
30 kg/ha	2504	b
20 kg/ha	2515	b

Least significant differences of means (5% level)

Table	Gypsum	K	P	Gypsum K
rep.	32	32	16	16
d.f.	3	6	36	6.00
l.s.d.	585.7	318.2	269.3	551.5
Except when comparing means with the same level(s) of				
Gypsum				450.0

Table	Gypsum P	K P	Gypsum K P
rep.	8	8	4
l.s.d.	555.1	426.6	669.3
d.f.	9.06	28.03	21.18
Except when comparing means with the same level(s) of			
Gypsum	380.9		603.2
d.f.	36		28.03
K		380.9	
d.f.		36	
Gypsum.K			538.7
d.f.			36
Gypsum.P			603.2
d.f.			28.03

Duncan's multiple range test

P

	Mean	
0 kg/ha	1121	a
10 kg/ha	1217	a
30 kg/ha	1309	a
20 kg/ha	1382	a

Appendix VI-Analysis of variance for grain yield

Analysis of variance- Alati B

Variate: Grain_yield (kg ha^{-1})

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
B stratum	3	1373964.	457988.	0.51	
B.Gypsum stratum					
Gypsum	1	104697.	104697.	0.12	0.756
Residual	3	2708553.	902851.	6.47	
B.Gypsum.K stratum					
K	1	516.	516.	0.00	0.953
Gypsum.K	1	421650.	421650.	3.02	0.133
Residual	6	837566.	139594.	2.03	
B.Gypsum.K.P stratum					
P	3	1418872.	472957.	6.88	<.001
Gypsum.P	3	115128.	38376.	0.56	0.646
K.P	3	398470.	132823.	1.93	0.142
Gypsum.K.P	3	451441.	150480.	2.19	0.106
Residual	36	2475562.	68766.		
Total	63	10306419.			

Analysis of variance- Jeriko

Variate: Grain yield (kg ha^{-1})

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
B stratum	3	1927880.	642627.	3.72	
B.Gypsum stratum					
Gypsum	1	41402.	41402.	0.24	0.658
Residual	3	517629.	172543.	1.88	
B.Gypsum.K stratum					
K	1	75735.	75735.	0.83	0.398
Gypsum.K	1	151785.	151785.	1.66	0.245
Residual	6	549310.	91552.	1.90	
B.Gypsum.K.P stratum					
P	3	418494.	139498.	2.90	0.048
Gypsum.P	3	64833.	21611.	0.45	0.719
K.P	3	32487.	10829.	0.23	0.878
Gypsum.K.P	3	18305.	6102.	0.13	0.944
Residual	36	1730314.	48064.		
Total	63	5528174.			

Tables of means

Variate: Grain_yield

Grand mean 1386.

Gypsum	0 kg/ha	150 kg/ha
	1346.	1426.

K	0 kg/ha	20 kg/ha
	1383.	1389.

P	0 kg/ha	10 kg/ha	20 kg/ha	30 kg/ha
	1148.	1387.	1548.	1461.

Gypsum	K	0 kg/ha	20 kg/ha
0 kg/ha		1262.	1430.
150 kg/ha		1505.	1348.

Gypsum	P	0 kg/ha	10 kg/ha	20 kg/ha	30 kg/ha
0 kg/ha		1132.	1382.	1436.	1433.
150 kg/ha		1164.	1392.	1661.	1489.

K	P	0 kg/ha	10 kg/ha	20 kg/ha	30 kg/ha
0 kg/ha		1054.	1384.	1670.	1424.
20 kg/ha		1241.	1390.	1426.	1498.

Gypsum	K	P	0 kg/ha	10 kg/ha	20 kg/ha	30 kg/ha
0 kg/ha	0 kg/ha		919.	1325.	1368.	1434.
	20 kg/ha		1345.	1438.	1503.	1432.
150 kg/ha	0 kg/ha		1190.	1442.	1972.	1414.
	20 kg/ha		1138.	1342.	1349.	1564.

Tables of means

Variate: Grain_yield (kg/ha)

Grand mean 713.

Gypsum	0 kg/ha	150 kg/ha
	688.	738.

K	0 kg/ha	20 kg/ha
	747.	679.

P	0 kg/ha	10 kg/ha	20 kg/ha	30 kg/ha
	608.	685.	831.	728.

Gypsum	K	0 kg/ha	20 kg/ha
0 kg/ha		673.	702.
150 kg/ha		821.	655.

Gypsum	P	0 kg/ha	10 kg/ha	20 kg/ha	30 kg/ha
0 kg/ha		541.	683.	786.	740.
150 kg/ha		674.	687.	877.	716.

K	P	0 kg/ha	10 kg/ha	20 kg/ha	30 kg/ha
0 kg/ha		648.	692.	899.	750.
20 kg/ha		567.	678.	764.	706.

Gypsum	K	P	0 kg/ha	10 kg/ha	20 kg/ha	30 kg/ha
0 kg/ha	0 kg/ha		506.	656.	819.	712.
	20 kg/ha		576.	709.	754.	768.
150 kg/ha	0 kg/ha		791.	727.	979.	789.
	20 kg/ha		558.	646.	774.	643.

Standard errors of differences of means

Table	Gypsum	K	P	Gypsum K
rep.	32	32	16	16
d.f.	3	6	36	3.95
s.e.d.	237.5	93.4	92.7	255.3
Except when comparing means with the same level(s) of				
Gypsum				132.1

Table	Gypsum P	K P	Gypsum K P
rep.	8	8	4
s.e.d.	263.3	147.0	301.6
d.f.	4.51	27.01	7.57
Except when comparing means with the same level(s) of			
Gypsum	131.1		207.9
d.f.	36		27.01
K		131.1	
d.f.		36	
Gypsum.K			185.4
d.f.			36
Gypsum.P			207.9
d.f.			27.01

Least significant differences of means (5% level)

Table	Gypsum	K	P	Gypsum K
rep.	32	32	16	16
d.f.	3	6	36	3.95
l.s.d.	756.0	228.6	188.0	712.1

Standard errors of differences of means

Table	Gypsum	K	P	Gypsum K
rep.	32	32	16	16
d.f.	3	6	36	6.16
s.e.d.	103.8	75.6	77.5	128.5
Except when comparing means with the same level(s) of				
Gypsum				107.0

Table	Gypsum P	K P	Gypsum K P
rep.	8	8	4
s.e.d.	140.7	121.4	185.8
d.f.	9.55	28.15	22.39
Except when comparing means with the same level(s) of			
Gypsum	109.6		171.7
d.f.	36		28.15
K		109.6	
d.f.		36	
Gypsum.K			155.0
d.f.			36
Gypsum.P			171.7
d.f.			28.15

Least significant differences of means (5% level)

Table	Gypsum	K	P	Gypsum K
rep.	32	32	16	16
d.f.	3	6	36	6.16
l.s.d.	330.5	185.1	157.2	312.4

Except when comparing means with the same level(s) of
Gypsum 323.2

Table	Gypsum P	K P	Gypsum K P
rep.	8	8	4
l.s.d.	699.6	301.7	702.3
d.f.	4.51	27.01	7.57
Except when comparing means with the same level(s) of			
Gypsum	265.9		426.6
d.f.	36		27.01
K		265.9	
d.f.		36	
Gypsum.K			376.1
d.f.			36
Gypsum.P			426.6
d.f.			27.01

Duncan's multiple range test

P

	Mean	
0 kg/ha	1148	a
10 kg/ha	1387	b
30 kg/ha	1461	b
20 kg/ha	1548	b

Except when comparing means with the same level(s) of
Gypsum 261.8

Table	Gypsum P	K P	Gypsum K P
rep.	8	8	4
l.s.d.	315.5	248.6	385.0
d.f.	9.55	28.15	22.39
Except when comparing means with the same level(s) of			
Gypsum	222.3		351.6
d.f.	36		28.15
K		222.3	
d.f.		36	
Gypsum.K			314.4
d.f.			36
Gypsum.P			351.6
d.f.			28.15

Duncan's multiple range test

P

	Mean	
0 kg/ha	607.7	a
10 kg/ha	684.8	ab
30 kg/ha	727.9	ab
20 kg/ha	831.5	b

Appendix VII-Analysis of variance for stover yield

Analysis of variance- Alati B

Variate: Stover_yield (kg ha^{-1})

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
B stratum	3	1635755.	545252.	0.27	
B.Gypsum stratum					
Gypsum	1	959200.	959200.	0.48	0.539
Residual	3	6031416.	2010472.	12.10	
B.Gypsum.K stratum					
K	1	26996.	26996.	0.16	0.701
Gypsum.K	1	2025545.	2025545.	12.19	0.013
Residual	6	997172.	166195.	1.19	
B.Gypsum.K.P stratum					
P	3	842839.	280946.	2.02	0.128
Gypsum.P	3	46146.	15382.	0.11	0.953
K.P	3	1492018.	497339.	3.58	0.023
Gypsum.K.P	3	560203.	186734.	1.34	0.276
Residual	36	5007136.	139087.		
Total	63	19624426.			

Analysis of variance- Jeriko

Variate: Stover_yield (kg ha^{-1})

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
B stratum	3	2730490.	910163.	2.49	
B.Gypsum stratum					
Gypsum	1	693.	693.	0.00	0.968
Residual	3	1095556.	365185.	1.60	
B.Gypsum.K stratum					
K	1	56872.	56872.	0.25	0.636
Gypsum.K	1	494438.	494438.	2.16	0.192
Residual	6	1370598.	228433.	1.39	
B.Gypsum.K.P stratum					
P	3	690474.	230158.	1.40	0.258
Gypsum.P	3	463759.	154586.	0.94	0.430
K.P	3	20592.	6864.	0.04	0.988
Gypsum.K.P	3	19135.	6378.	0.04	0.990
Residual	36	5905638.	164046.		
Total	63	12848245.			

Tables of means

Variate: Stover_yield (kg ha^{-1})

Grand mean 2733.

Gypsum	0 kg/ha	150 kg/ha
	2855.	2610.

K	0 kg/ha	20 kg/ha
	2712.	2753.

P	0 kg/ha	10 kg/ha	20 kg/ha	30 kg/ha
	2564.	2719.	2763.	2885.

Gypsum	K	0 kg/ha	20 kg/ha
0 kg/ha		2657.	3054.
150 kg/ha		2768.	2453.

Gypsum	P	0 kg/ha	10 kg/ha	20 kg/ha	30 kg/ha
0 kg/ha		2687.	2851.	2843.	3039.
150 kg/ha		2441.	2587.	2683.	2730.

K	P	0 kg/ha	10 kg/ha	20 kg/ha	30 kg/ha
0 kg/ha		2426.	2760.	2963.	2700.
20 kg/ha		2702.	2678.	2563.	3069.

Gypsum	K	P	0 kg/ha	10 kg/ha	20 kg/ha	30 kg/ha
0 kg/ha	0 kg/ha		2383.	2645.	2775.	2824.
	20 kg/ha		2991.	3057.	2912.	3254.
150 kg/ha	0 kg/ha		2469.	2875.	3152.	2575.
	20 kg/ha		2413.	2300.	2214.	2885

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Tables of means

Variate: Stover_yield (kg ha^{-1})

Grand mean 2223.

Gypsum	0 kg/ha	150 kg/ha
	2220.	2226.

K	0 kg/ha	20 kg/ha
	2253.	2193.

P	0 kg/ha	10 kg/ha	20 kg/ha	30 kg/ha
	2057.	2221.	2280.	2334.

Gypsum	K	0 kg/ha	20 kg/ha
0 kg/ha		2162.	2278.
150 kg/ha		2344.	2109.

Gypsum	P	0 kg/ha	10 kg/ha	20 kg/ha	30 kg/ha
0 kg/ha		1908.	2279.	2300.	2392.
150 kg/ha		2205.	2164.	2260.	2276.

K	P	0 kg/ha	10 kg/ha	20 kg/ha	30 kg/ha
0 kg/ha		2078.	2271.	2285.	2378.
20 kg/ha		2036.	2172.	2275.	2290.

Gypsum	K	P	0 kg/ha	10 kg/ha	20 kg/ha	30 kg/ha
0 kg/ha	0 kg/ha		1857.	2249.	2222.	2319.
	20 kg/ha		1960.	2308.	2378.	2465.
150 kg/ha	0 kg/ha		2299.	2292.	2347.	2438.
	20 kg/ha		2111.	2036.	2172.	2115

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Standard errors of differences of means

Table	Gypsum	K	P	Gypsum K
rep.	32	32	16	16
d.f.	3	6	36	3.50
s.e.d.	354.5	101.9	131.9	368.8
Except when comparing means with the same level(s) of				
Gypsum				144.1

Table	Gypsum P	K P	Gypsum K P
rep.	8	8	4
s.e.d.	389.5	191.0	433.8
d.f.	4.36	36.06	6.61
Except when comparing means with the same level(s) of			
Gypsum	186.5		270.1
d.f.	36		36.06
K		186.5	
d.f.		36	
Gypsum.K			263.7
d.f.			36
Gypsum.P			270.1
d.f.			36.06

Least significant differences of means (5% level)

Table	Gypsum	K	P	Gypsum K
rep.	32	32	16	16
d.f.	3	6	36	3.50
l.s.d.	1128.1	249.4	267.4	1083.8

Standard errors of differences of means

Table	Gypsum	K	P	Gypsum K
rep.	32	32	16	16
d.f.	3	6	36	6.63
s.e.d.	151.1	119.5	143.2	192.6
Except when comparing means with the same level(s) of				
Gypsum				169.0

Table	Gypsum P	K P	Gypsum K P
rep.	8	8	4
s.e.d.	231.5	212.2	314.0
d.f.	14.36	33.66	31.10
Except when comparing means with the same level(s) of			
Gypsum	202.5		300.1
d.f.	36		33.66
K		202.5	
d.f.		36	
Gypsum.K			286.4
d.f.			36
Gypsum.P			300.1
d.f.			33.66

Least significant differences of means (5% level)

Table	Gypsum	K	P	Gypsum K
rep.	32	32	16	16
d.f.	3	6	36	6.63
l.s.d.	480.8	292.4	290.4	460.7

Except when comparing means with the same level(s) of				
Gypsum				352.7
Table	Gypsum P	K P	Gypsum K P	
rep.	8	8	4	
l.s.d.	1047.3	387.3	1038.1	
d.f.	4.36	36.06	6.61	
Except when comparing means with the same level(s) of				
Gypsum	378.2		547.7	
d.f.	36		36.06	
K		378.2		
d.f.		36		
Gypsum.K			534.8	
d.f.			36	
Gypsum.P			547.7	
d.f.			36.06	

Duncan's multiple range test

P

	Mean	
0 kg/ha	2564	a
10 kg/ha	2719	ab
20 kg/ha	2763	ab
30 kg/ha	2885	b

Except when comparing means with the same level(s) of				
Gypsum				413.5
Table	Gypsum P	K P	Gypsum K P	
rep.	8	8	4	
l.s.d.	495.3	431.4	640.4	
d.f.	14.36	33.66	31.10	
Except when comparing means with the same level(s) of				
Gypsum	410.7		610.1	
d.f.	36		33.66	
K		410.7		
d.f.		36		
Gypsum.K			580.8	
d.f.			36	
Gypsum.P			610.1	
d.f.			33.66	

Duncan's multiple range test

P

	Mean	
0 kg/ha	2057	a
10 kg/ha	2221	a
20 kg/ha	2280	a
30 kg/ha	2334	a

Appendix VIII-Analysis of variance for pod number per plant

Analysis of variance- Alati B

Variate: Pod_number per plant

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
B stratum	3	188.75	62.92	10.16	
B.Gypsum stratum					
Gypsum	1	16.50	16.50	2.66	0.201
Residual	3	18.58	6.19	0.62	
B.Gypsum.K stratum					
K	1	1.79	1.79	0.18	0.687
Gypsum.K	1	26.65	26.65	2.66	0.154
Residual	6	60.06	10.01	0.97	
B.Gypsum.K.P stratum					
P	3	57.95	19.32	1.87	0.153
Gypsum.P	3	21.26	7.09	0.68	0.567
K.P	3	13.29	4.43	0.43	0.734
Gypsum.K.P	3	46.50	15.50	1.50	0.232
Residual	36	372.58	10.35		
Total	63	823.91			

Analysis of variance- Jeriko

Variate: Pod number per plant

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
B stratum	3	48.35	16.12	1.83	
B.Gypsum stratum					
Gypsum	1	9.61	9.61	1.09	0.373
Residual	3	26.43	8.81	0.99	
B.Gypsum.K stratum					
K	1	0.68	0.68	0.08	0.792
Gypsum.K	1	8.41	8.41	0.94	0.369
Residual	6	53.60	8.93	0.77	
B.Gypsum.K.P stratum					
P	3	43.23	14.41	1.24	0.308
Gypsum.P	3	15.15	5.05	0.44	0.729
K.P	3	68.10	22.70	1.96	0.138
Gypsum.K.P	3	97.57	32.52	2.81	0.053
Residual	36	417.08	11.59		
Total	63	788.20			

Tables of means

Variate: Pod_number per plant

Grand mean 24.50

Gypsum	0 kg/ha	150 kg/ha
	25.01	24.00

K	0 kg/ha	20 kg/ha
	24.67	24.34

P	0 kg/ha	10 kg/ha	20 kg/ha	30 kg/ha
	22.91	24.68	25.37	25.06

Gypsum	K	0 kg/ha	20 kg/ha
0 kg/ha		25.83	24.20
150 kg/ha		23.52	24.48

Gypsum	P	0 kg/ha	10 kg/ha	20 kg/ha	30 kg/ha
0 kg/ha		23.74	24.54	25.43	26.35
150 kg/ha		22.09	24.81	25.31	23.

K	P	0 kg/ha	10 kg/ha	20 kg/ha	30 kg/ha
0 kg/ha		23.24	24.06	25.80	25.59
20 kg/ha		22.59	25.29	24.94	24.54

Gypsum	K	P	0 kg/ha	10 kg/ha	20 kg/ha	30 kg/ha
0 kg/ha	0 kg/ha		23.70	25.83	26.00	27.78
	20 kg/ha		23.78	23.25	24.85	24.93
150 kg/ha	0 kg/ha		22.78	22.30	25.60	23.40
	20 kg/ha		21.40	27.33	25.03	24.15

Tables of means

Variate: Pod number per plant

Grand mean 19.48

Gypsum	0 kg/ha	150 kg/ha
	19.10	19.87

K	0 kg/ha	20 kg/ha
	19.59	19.38

P	0 kg/ha	10 kg/ha	20 kg/ha	30 kg/ha
	18.09	20.22	19.89	19.73

Gypsum	K	0 kg/ha	20 kg/ha
0 kg/ha		18.84	19.36
150 kg/ha		20.34	19.41

Gypsum	P	0 kg/ha	10 kg/ha	20 kg/ha	30 kg/ha
0 kg/ha		17.86	20.12	19.89	18.51
150 kg/ha		18.32	20.31	19.90	20.95

K	P	0 kg/ha	10 kg/ha	20 kg/ha	30 kg/ha
0 kg/ha		17.22	19.65	19.95	21.52
20 kg/ha		18.96	20.79	19.84	17.94

Gypsum	K	P	0 kg/ha	10 kg/ha	20 kg/ha	30 kg/ha
0 kg/ha	0 kg/ha		14.50	20.00	20.12	20.72
	20 kg/ha		21.23	20.25	19.65	16.30
150 kg/ha	0 kg/ha		19.95	19.30	19.77	22.32
	20 kg/ha		16.70	21.33	20.02	19.57

Standard errors of differences of means

Table	Gypsum	K	P	Gypsum K
rep.	32	32	16	16
d.f.	3	6	36	8.90
s.e.d.	0.622	0.791	1.137	1.006
Except when comparing means with the same level(s) of				
Gypsum				1.119

Table	Gypsum P	K P	Gypsum K P
rep.	8	8	4
s.e.d.	1.526	1.602	2.212
d.f.	35.06	38.77	44.88
Except when comparing means with the same level(s) of			
Gypsum	1.609		2.265
d.f.	36		38.77
K		1.609	
d.f.		36	
Gypsum.K			2.275
d.f.			36
Gypsum.P			2.265
d.f.			38.77

Least significant differences of means (5% level)

Table	Gypsum	K	P	Gypsum K
rep.	32	32	16	16
d.f.	3	6	36	8.90
l.s.d.	1.980	1.935	2.307	2.280

Standard errors of differences of means

Table	Gypsum	K	P	Gypsum K
rep.	32	32	16	16
d.f.	3	6	36	8.04
s.e.d.	0.742	0.747	1.203	1.053
Except when comparing means with the same level(s) of				
Gypsum				1.057

Table	Gypsum P	K P	Gypsum K P
rep.	8	8	4
s.e.d.	1.650	1.652	2.335
d.f.	31.94	40.74	43.91
Except when comparing means with the same level(s) of			
Gypsum	1.702		2.337
d.f.	36		40.74
K		1.702	
d.f.		36	
Gypsum.K			2.407
d.f.			36
Gypsum.P			2.337
d.f.			40.74

Least significant differences of means (5% level)

Table	Gypsum	K	P	Gypsum K
rep.	32	32	16	16
d.f.	3	6	36	8.04
l.s.d.	2.361	1.828	2.441	2.426

Except when comparing means with the same level(s) of				
Gypsum				2.737
Table	Gypsum	K	Gypsum	
	P	P	K	
			P	
rep.	8	8	4	
l.s.d.	3.097	3.241	4.456	
d.f.	35.06	38.77	44.88	
Except when comparing means with the same level(s) of				
Gypsum	3.262		4.583	
d.f.	36		38.77	
K		3.262		
d.f.		36		
Gypsum.K			4.614	
d.f.			36	
Gypsum.P			4.583	
d.f.			38.77	

Duncan's multiple range test

P

	Mean	
0 kg/ha	22.91	a
10 kg/ha	24.68	a
30 kg/ha	25.06	a
20 kg/ha	25.37	a

Except when comparing means with the same level(s) of				
Gypsum				2.586
Table	Gypsum	K	Gypsum	
	P	P	K	
			P	
rep.	8	8	4	
l.s.d.	3.361	3.338	4.707	
d.f.	31.94	40.74	43.91	
Except when comparing means with the same level(s) of				
Gypsum	3.452		4.720	
d.f.	36		40.74	
K		3.452		
d.f.		36		
Gypsum.K			4.881	
d.f.			36	
Gypsum.P			4.720	
d.f.			40.74	

Duncan's multiple range test

P

	Mean	
0 kg/ha	18.09	a
30 kg/ha	19.73	a
20 kg/ha	19.89	a
10 kg/ha	20.22	a

Appendix IX-Analysis of variance for nodule count

Analysis of variance- Alati B

Variate: Nodule number per plant

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
B stratum	3	3713.4	1237.8	4.67	
B.Gypsum stratum					
Gypsum	1	5655.0	5655.0	21.35	0.019
Residual	3	794.7	264.9	0.71	
B.Gypsum.K stratum					
K	1	100.5	100.5	0.27	0.622
Gypsum.K	1	203.8	203.8	0.55	0.487
Residual	6	2228.4	371.4	1.13	
B.Gypsum.K.P stratum					
P	3	3888.8	1296.3	3.94	0.016
Gypsum.P	3	764.8	254.9	0.77	0.516
K.P	3	576.7	192.2	0.58	0.630
Gypsum.K.P	3	957.4	319.1	0.97	0.418
Residual	36	11857.4	329.4		
Total	63	30741.0			

Analysis of variance- Jeriko

Variate: Nodule number per plant

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
B stratum	3	15508.1	5169.4	9.57	
B.Gypsum stratum					
Gypsum	1	590.5	590.5	1.09	0.373
Residual	3	1620.0	540.0	0.53	
B.Gypsum.K stratum					
K	1	1685.1	1685.1	1.64	0.247
Gypsum.K	1	1115.6	1115.6	1.09	0.337
Residual	6	6160.3	1026.7	4.37	
B.Gypsum.K.P stratum					
P	3	2262.6	754.2	3.21	0.034
Gypsum.P	3	925.4	308.5	1.31	0.285
K.P	3	822.5	274.2	1.17	0.335
Gypsum.K.P	3	230.9	77.0	0.33	0.805
Residual	36	8449.7	234.7		
Total	63	39370.6			

Tables of means

Variate: Nodule_number per plant

Grand mean 109.4

Gypsum	0 kg/ha	150 kg/ha
	118.8	100.0

K	0 kg/ha	20 kg/ha
	110.6	108.1

P	0 kg/ha	10 kg/ha	20 kg/ha	30 kg/ha
	100.3	112.0	120.8	104.5

Gypsum	K	0 kg/ha	20 kg/ha
0 kg/ha		121.8	115.7
150 kg/ha		99.4	100.5

Gypsum	P	0 kg/ha	10 kg/ha	20 kg/ha	30 kg/ha
0 kg/ha		112.3	115.8	130.1	117.0
150 kg/ha		88.3	108.2	111.5	92.0

K	P	0 kg/ha	10 kg/ha	20 kg/ha	30 kg/ha
0 kg/ha		103.1	108.6	121.6	109.2
20 kg/ha		97.4	115.3	119.9	99.8

Gypsum	K	P	0 kg/ha	10 kg/ha	20 kg/ha	30 kg/ha
0 kg/ha	0 kg/ha		116.0	120.5	128.6	122.1
	20 kg/ha		108.5	111.0	131.6	111.9
150 kg/ha	0 kg/ha		90.2	96.7	114.6	96.3
	20 kg/ha		86.3	119.7	108.3	87.7

Tables of means

Variate: Nodule number per plant

Grand mean 97.3

Gypsum	0 kg/ha	150 kg/ha
	100.3	94.3

K	0 kg/ha	20 kg/ha
	102.4	92.2

P	0 kg/ha	10 kg/ha	20 kg/ha	30 kg/ha
	88.0	97.7	104.6	98.9

Gypsum	K	0 kg/ha	20 kg/ha
0 kg/ha		101.3	99.4
150 kg/ha		103.6	85.0

Gypsum	P	0 kg/ha	10 kg/ha	20 kg/ha	30 kg/ha
0 kg/ha		90.0	101.5	113.1	96.8
150 kg/ha		86.1	93.9	96.1	101.0

K	P	0 kg/ha	10 kg/ha	20 kg/ha	30 kg/ha
0 kg/ha		91.9	108.7	105.8	103.4
20 kg/ha		84.2	86.8	103.3	94.4

Gypsum	K	P	0 kg/ha	10 kg/ha	20 kg/ha	30 kg/ha
0 kg/ha	0 kg/ha		88.7	106.7	113.4	96.4
	20 kg/ha		91.2	96.4	112.7	97.2
150 kg/ha	0 kg/ha		95.0	110.7	98.3	110.3
	20 kg/ha		77.2	77.1	93.9	91.7

Standard errors of differences of means

Table	Gypsum	K	P	Gypsum K
rep.	32	32	16	16
d.f.	3	6	36	8.73
s.e.d.	4.07	4.82	6.42	6.31
Except when comparing means with the same level(s) of				
Gypsum				6.81

Table	Gypsum P	K P	Gypsum K P
rep.	8	8	4
s.e.d.	8.85	9.22	12.78
d.f.	31.08	36.88	44.07
Except when comparing means with the same level(s) of			
Gypsum	9.07		13.04
d.f.	36		36.88
K		9.07	
d.f.		36	
Gypsum.K			12.83
d.f.			36
Gypsum.P			13.04
d.f.			36.88

Least significant differences of means (5% level)

Table	Gypsum	K	P	Gypsum K
rep.	32	32	16	16
d.f.	3	6	36	8.73
l.s.d.	12.95	11.79	13.01	14.33

Standard errors of differences of means

Table	Gypsum	K	P	Gypsum K
rep.	32	32	16	16
d.f.	3	6	36	8.99
s.e.d.	5.81	8.01	5.42	9.90
Except when comparing means with the same level(s) of				
Gypsum				11.33

Table	Gypsum P	K P	Gypsum K P
rep.	8	8	4
s.e.d.	8.82	10.40	13.64
d.f.	13.95	15.81	26.99
Except when comparing means with the same level(s) of			
Gypsum	7.66		14.71
d.f.	36		15.81
K		7.66	
d.f.		36	
Gypsum.K			10.83
d.f.			36
Gypsum.P			14.71
d.f.			15.81

Least significant differences of means (5% level)

Table	Gypsum	K	P	Gypsum K
rep.	32	32	16	16
d.f.	3	6	36	8.99
l.s.d.	18.49	19.60	10.99	22.39

Except when comparing means with the same level(s) of				
Gypsum				16.67
Table	Gypsum P	K P	Gypsum K P	
rep.	8	8	4	
l.s.d.	18.05	18.68	25.75	
d.f.	31.08	36.88	44.07	
Except when comparing means with the same level(s) of				
Gypsum	18.40		26.42	
d.f.	36		36.88	
K		18.40		
d.f.		36		
Gypsum.K			26.03	
d.f.			36	
Gypsum.P			26.42	
d.f.			36.88	

Duncan's multiple range test

P

	Mean	
0 kg/ha	100.3	a
30 kg/ha	104.5	a
10 kg/ha	112.0	ab
20 kg/ha	120.8	b

Except when comparing means with the same level(s) of				
Gypsum				27.72
Table	Gypsum P	K P	Gypsum K P	
rep.	8	8	4	
l.s.d.	18.92	22.07	27.98	
d.f.	13.95	15.81	26.99	
Except when comparing means with the same level(s) of				
Gypsum	15.54		31.21	
d.f.	36		15.81	
K		15.54		
d.f.		36		
Gypsum.K			21.97	
d.f.			36	
Gypsum.P			31.21	
d.f.			15.81	

Duncan's multiple range test

P

	Mean	
0 kg/ha	88.04	a
10 kg/ha	97.73	ab
30 kg/ha	98.91	ab
20 kg/ha	104.57	b

Appendix X-Analysis of variance for 100 seed weight

Analysis of variance- Alati B

Variate: 100_seed_weight (g)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
B stratum	3	252.91	84.30	6.03	
B.Gypsum stratum					
Gypsum	1	50.06	50.06	3.58	0.155
Residual	3	41.94	13.98	0.42	
B.Gypsum.K stratum					
K	1	42.94	42.94	1.28	0.301
Gypsum.K	1	64.32	64.32	1.92	0.215
Residual	6	200.97	33.49	2.22	
B.Gypsum.K.P stratum					
P	3	163.07	54.36	3.60	0.023
Gypsum.P	3	68.18	22.73	1.51	0.230
K.P	3	25.63	8.54	0.57	0.641
Gypsum.K.P	3	33.48	11.16	0.74	0.536
Residual	36	543.62	15.10		
Total	63	1487.10			

Analysis of variance- Jeriko

Variate: 100_seed_weight (g)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
B stratum	3	359.13	119.71	4.50	
B.Gypsum stratum					
Gypsum	1	19.59	19.59	0.74	0.454
Residual	3	79.82	26.61	1.90	
B.Gypsum.K stratum					
K	1	0.18	0.18	0.01	0.912
Gypsum.K	1	160.50	160.50	11.48	0.015
Residual	6	83.88	13.98	1.11	
B.Gypsum.K.P stratum					
P	3	76.67	25.56	2.02	0.128
Gypsum.P	3	62.30	20.77	1.64	0.197
K.P	3	6.55	2.18	0.17	0.914
Gypsum.K.P	3	24.65	8.22	0.65	0.588
Residual	36	455.26	12.65		
Total	63	1328.54			

Tables of means

Variate: 100_seed_weight (g)

Grand mean 37.02

Gypsum	0 kg/ha	150 kg/ha
	36.13	37.90

K	0 kg/ha	20 kg/ha
	37.84	36.20

P	0 kg/ha	10 kg/ha	20 kg/ha	30 kg/ha
	35.19	37.19	39.50	36.20

Gypsum	K	0 kg/ha	20 kg/ha
0 kg/ha		35.95	36.32
150 kg/ha		39.72	36.08

Gypsum	P	0 kg/ha	10 kg/ha	20 kg/ha	30 kg/ha
0 kg/ha		33.93	35.55	40.38	34.67
150 kg/ha		36.44	38.83	38.61	37.73

K	P	0 kg/ha	10 kg/ha	20 kg/ha	30 kg/ha
0 kg/ha		35.16	38.39	41.11	36.69
20 kg/ha		35.21	35.99	37.88	35.71

Gypsum	K	P	0 kg/ha	10 kg/ha	20 kg/ha	30 kg/ha
0 kg/ha	0 kg/ha		31.99	35.50	42.09	34.22
	20 kg/ha		35.87	35.59	38.68	35.13
150 kg/ha	0 kg/ha		38.33	41.28	40.13	39.16
	20 kg/ha		34.56	36.38	37.09	36.30

Tables of means

Variate: 100_seed_weight (g)

Grand mean 34.05

Gypsum	0 kg/ha	150 kg/ha
	33.50	34.61

K	0 kg/ha	20 kg/ha
	34.00	34.11

P	0 kg/ha	10 kg/ha	20 kg/ha	30 kg/ha
	32.90	33.63	35.85	33.83

Gypsum	K	0 kg/ha	20 kg/ha
0 kg/ha		31.86	35.14
150 kg/ha		36.14	33.08

Gypsum	P	0 kg/ha	10 kg/ha	20 kg/ha	30 kg/ha
0 kg/ha		31.24	33.29	34.68	34.78
150 kg/ha		34.55	33.97	37.01	32.88

K	P	0 kg/ha	10 kg/ha	20 kg/ha	30 kg/ha
0 kg/ha		32.53	33.49	35.66	34.31
20 kg/ha		33.27	33.77	36.04	33.35

Gypsum	K	P	0 kg/ha	10 kg/ha	20 kg/ha	30 kg/ha
0 kg/ha	0 kg/ha		28.65	31.04	33.20	34.56
	20 kg/ha		33.83	35.54	36.17	35.00
150 kg/ha	0 kg/ha		36.40	35.95	38.13	34.07
	20 kg/ha		32.70	31.99	35.90	31.70

Standard errors of differences of means

Table	Gypsum	K	P	Gypsum K
rep.	32	32	16	16
d.f.	3	6	36	8.94
s.e.d.	0.935	1.447	1.374	1.723
Except when comparing means with the same level(s) of				
Gypsum				2.046

Table	Gypsum P	K P	Gypsum K P
rep.	8	8	4
s.e.d.	1.925	2.219	2.938
d.f.	28.77	25.45	39.71
Except when comparing means with the same level(s) of			
Gypsum	1.943		3.138
d.f.	36		25.45
K		1.943	
d.f.		36	
Gypsum.K			2.748
d.f.			36
Gypsum.P			3.138
d.f.			25.45

Least significant differences of means (5% level)

Table	Gypsum	K	P	Gypsum K
rep.	32	32	16	16
d.f.	3	6	36	8.94
l.s.d.	2.975	3.540	2.786	3.901

Standard errors of differences of means

Table	Gypsum	K	P	Gypsum K
rep.	32	32	16	16
d.f.	3	6	36	6.13
s.e.d.	1.290	0.935	1.257	1.593
Except when comparing means with the same level(s) of				
Gypsum				1.322

Table	Gypsum P	K P	Gypsum K P
rep.	8	8	4
s.e.d.	2.009	1.801	2.698
d.f.	15.10	37.15	31.66
Except when comparing means with the same level(s) of			
Gypsum	1.778		2.548
d.f.	36		37.15
K		1.778	
d.f.		36	
Gypsum.K			2.515
d.f.			36
Gypsum.P			2.548
d.f.			37.15

Least significant differences of means (5% level)

Table	Gypsum	K	P	Gypsum K
rep.	32	32	16	16
d.f.	3	6	36	6.13
l.s.d.	4.104	2.287	2.550	3.877

Except when comparing means with the same level(s) of				
Gypsum				5.007
Table	Gypsum P	K P	Gypsum K P	
rep.	8	8	4	
l.s.d.	3.938	4.566	5.939	
d.f.	28.77	25.45	39.71	
Except when comparing means with the same level(s) of				
Gypsum	3.941		6.458	
d.f.	36		25.45	
K		3.941		
d.f.		36		
Gypsum.K			5.573	
d.f.			36	
Gypsum.P			6.458	
d.f.			25.45	

Duncan's multiple range test

P

	Mean	
0 kg/ha	35.19	a
30 kg/ha	36.20	a
10 kg/ha	37.19	ab
20 kg/ha	39.50	b

Except when comparing means with the same level(s) of				
Gypsum				3.235
Table	Gypsum P	K P	Gypsum K P	
rep.	8	8	4	
l.s.d.	4.279	3.649	5.498	
d.f.	15.10	37.15	31.66	
Except when comparing means with the same level(s) of				
Gypsum	3.606		5.161	
d.f.	36		37.15	
K		3.606		
d.f.		36		
Gypsum.K			5.100	
d.f.			36	
Gypsum.P			5.161	
d.f.			37.15	

Duncan's multiple range test

P

	Mean	
0 kg/ha	32.90	a
10 kg/ha	33.63	ab
30 kg/ha	33.83	ab
20 kg/ha	35.85	b

Appendix XI-Analysis of variance for shelling percentage

Analysis of variance- Alati B

Variate: Shelling percentage (%)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
B stratum	3	0.0011610	0.0003870	3.14	
B.Gypsum stratum					
Gypsum	1	0.0056990	0.0056990	46.24	0.007
Residual	3	0.0003698	0.0001233	0.33	
B.Gypsum.K stratum					
K	1	0.0004706	0.0004706	1.26	0.305
Gypsum.K	1	0.0000797	0.0000797	0.21	0.660
Residual	6	0.0022417	0.0003736	1.33	
B.Gypsum.K.P stratum					
P	3	0.0268113	0.0089371	31.77	<.001
Gypsum.P	3	0.0005976	0.0001992	0.71	0.553
K.P	3	0.0002682	0.0000894	0.32	0.812
Gypsum.K.P	3	0.0011906	0.0003969	1.41	0.255
Residual	36	0.0101262	0.0002813		
Total	63	0.0490157			

Analysis of variance- Jeriko

Variate: Shelling percentage (%)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
B stratum	3	0.0036763	0.0012254	102.88	
B.Gypsum stratum					
Gypsum	1	0.0003175	0.0003175	26.65	0.014
Residual	3	0.0000357	0.0000119	0.02	
B.Gypsum.K stratum					
K	1	0.0001025	0.0001025	0.15	0.713
Gypsum.K	1	0.0000134	0.0000134	0.02	0.894
Residual	6	0.0041436	0.0006906	1.06	
B.Gypsum.K.P stratum					
P	3	0.0295243	0.0098414	15.16	<.001
Gypsum.P	3	0.0055951	0.0018650	2.87	0.050
K.P	3	0.0004588	0.0001529	0.24	0.871
Gypsum.K.P	3	0.0006101	0.0002034	0.31	0.816
Residual	36	0.0233630	0.0006490		
Total	63	0.0678404			

Tables of means

Variate: Shelling percentage (%)

Grand mean 0.5856

Gypsum	0 kg/ha	150 kg/ha
	0.5761	0.5950

K	0 kg/ha	20 kg/ha
	0.5829	0.5883

P	0 kg/ha	10 kg/ha	20 kg/ha	30 kg/ha
	0.5578	0.5861	0.6155	0.5829

Gypsum	K	0 kg/ha	20 kg/ha
0 kg/ha		0.5745	0.5777
150 kg/ha		0.5912	0.5988

Gypsum	P	0 kg/ha	10 kg/ha	20 kg/ha	30 kg/ha
0 kg/ha		0.5455	0.5790	0.6029	0.5771
150 kg/ha		0.5700	0.5932	0.6281	0.5886

K	P	0 kg/ha	10 kg/ha	20 kg/ha	30 kg/ha
0 kg/ha		0.5557	0.5864	0.6114	0.5779
20 kg/ha		0.5598	0.5858	0.6197	0.5878

Gypsum	K	P	0 kg/ha	10 kg/ha	20 kg/ha	30 kg/ha
0 kg/ha	0 kg/ha		0.5427	0.5866	0.5942	0.5747
	20 kg/ha		0.5484	0.5715	0.6115	0.5796
150 kg/ha	0 kg/ha		0.5688	0.5863	0.6285	0.5811
	20 kg/ha		0.5713	0.6001	0.6278	0.5961

Tables of means

Variate: Shelling percentage (%)

Grand mean 0.5646

Gypsum	0 kg/ha	150 kg/ha
	0.5624	0.5668

K	0 kg/ha	20 kg/ha
	0.5633	0.5659

P	0 kg/ha	10 kg/ha	20 kg/ha	30 kg/ha
	0.5411	0.5616	0.5994	0.5563

Gypsum	K	0 kg/ha	20 kg/ha
0 kg/ha		0.5616	0.5632
150 kg/ha		0.5651	0.5685

Gypsum	P	0 kg/ha	10 kg/ha	20 kg/ha	30 kg/ha
0 kg/ha		0.5443	0.5639	0.5810	0.5602
150 kg/ha		0.5378	0.5592	0.6178	0.5524

K	P	0 kg/ha	10 kg/ha	20 kg/ha	30 kg/ha
0 kg/ha		0.5376	0.5582	0.6025	0.5550
20 kg/ha		0.5445	0.5650	0.5963	0.5576

Gypsum	K	P	0 kg/ha	10 kg/ha	20 kg/ha	30 kg/ha
0 kg/ha	0 kg/ha		0.5406	0.5590	0.5898	0.5568
	20 kg/ha		0.5481	0.5687	0.5722	0.5636
150 kg/ha	0 kg/ha		0.5346	0.5573	0.6153	0.5532
	20 kg/ha		0.5410	0.5612	0.6204	0.5516

Standard errors of differences of means

Table	Gypsum	K	P	Gypsum K
rep.	32	32	16	16
d.f.	3	6	36	8.71
s.e.d.	0.00278	0.00483	0.00593	0.00557
Except when comparing means with the same level(s) of				
Gypsum				0.00683

Table	Gypsum P	K P	Gypsum K P
rep.	8	8	4
s.e.d.	0.00777	0.00872	0.01168
d.f.	37.65	34.43	44.41
Except when comparing means with the same level(s) of			
Gypsum	0.00839		0.01234
d.f.	36		34.43
K		0.00839	
d.f.		36	
Gypsum.K			0.01186
d.f.			36
Gypsum.P			0.01234
d.f.			34.43

Least significant differences of means (5% level)

Table	Gypsum	K	P	Gypsum K
rep.	32	32	16	16
d.f.	3	6	36	8.71
l.s.d.	0.00883	0.01182	0.01203	0.01267

Standard errors of differences of means

Table	Gypsum	K	P	Gypsum K
rep.	32	32	16	16
d.f.	3	6	36	6.21
s.e.d.	0.00086	0.00657	0.00901	0.00663
Except when comparing means with the same level(s) of				
Gypsum				0.00929

Table	Gypsum P	K P	Gypsum K P
rep.	8	8	4
s.e.d.	0.01106	0.01284	0.01695
d.f.	36.43	37.65	42.19
Except when comparing means with the same level(s) of			
Gypsum	0.01274		0.01816
d.f.	36		37.65
K		0.01274	
d.f.		36	
Gypsum.K			0.01801
d.f.			36
Gypsum.P			0.01816
d.f.			37.65

Least significant differences of means (5% level)

Table	Gypsum	K	P	Gypsum K
rep.	32	32	16	16
d.f.	3	6	36	6.21
l.s.d.	0.00275	0.01608	0.01827	0.01608

Except when comparing means with the same level(s) of

Gypsum				0.01672

Table	Gypsum P	K P	Gypsum K P
rep.	8	8	4
l.s.d.	0.01574	0.01772	0.02354
d.f.	37.65	34.43	44.41
Except when comparing means with the same level(s) of			
Gypsum	0.01701		0.02506
d.f.	36		34.43
K		0.01701	
d.f.		36	
Gypsum.K			0.02405
d.f.			36
Gypsum.P			0.02506
d.f.			34.43

Duncan's multiple range test
P

	Mean	
0 kg/ha	0.5578	a
30 kg/ha	0.5829	b
10 kg/ha	0.5861	b
20 kg/ha	0.6155	c

Except when comparing means with the same level(s) of

Gypsum				0.02273

Table	Gypsum P	K P	Gypsum K P
rep.	8	8	4
l.s.d.	0.02243	0.02600	0.03420
d.f.	36.43	37.65	42.19
Except when comparing means with the same level(s) of			
Gypsum	0.02583		0.03677
d.f.	36		37.65
K		0.02583	
d.f.		36	
Gypsum.K			0.03653
d.f.			36
Gypsum.P			0.03677
d.f.			37.65

Duncan's multiple range test
P

	Mean	
0 kg/ha	0.5411	a
30 kg/ha	0.5563	ab
10 kg/ha	0.5616	b
20 kg/ha	0.5994	c

Appendix XII-Emergence percentage

Emergence percentage on site 1(Alati B village)

Treatment #	Treatment Code	Emergence %			
		Replication			
		1	**2**	**3**	**4**
1	G0 K0 P0	89	81	77	77
2	G0 K0 P1	83	81	83	88
3	G0 K0 P2	83	88	81	105
4	G0 K0 P3	87	84	81	90
5	G0 K1 P0	95	80	88	84
6	G0 K1 P1	77	90	94	82
7	G0 K1 P2	83	87	81	74
8	G0 K1 P3	83	80	73	87
9	G1 K0 P0	77	80	81	79
10	G1 K0 P1	97	74	84	91
11	G1 K0 P2	92	78	83	93
12	G1 K0 P3	81	83	83	71
13	G1 K1 P0	84	84	88	92
14	G1 K1 P1	80	78	81	70
15	G1 K1 P2	83	86	74	74
16	G1 K1 P3	88	76	81	85

Emergence percentage on site 2 (Jeriko village)

Treatment #	Treatment Code	Emergence %			
		Replication			
		1	**2**	**3**	**4**
1	G0 K0 P0	81	30	89	73
2	G0 K0 P1	72	59	74	74
3	G0 K0 P2	91	47	86	82
4	G0 K0 P3	77	67	77	62
5	G0 K1 P0	88	56	71	58
6	G0 K1 P1	88	43	75	68
7	G0 K1 P2	78	52	73	65
8	G0 K1 P3	66	47	68	84
9	G1 K0 P0	68	70	78	60
10	G1 K0 P1	82	47	89	63
11	G1 K0 P2	80	71	74	67
12	G1 K0 P3	86	57	82	71
13	G1 K1 P0	84	50	64	71
14	G1 K1 P1	82	72	58	71
15	G1 K1 P2	59	69	69	73
16	G1 K1 P3	77	54	85	66