

Original Research Article

EFFECT OF RATE AND TIME OF PHOSPHOROUS APPLICATION AND PLANTING DENSITY ON YIELD AND NET BENEFIT OF GROUNDNUT (*Arachis hypogaea*) PRODUCTION

Comment [H1]:

ABSTRACT

Groundnut yields are relatively very low in Kenya compared to other countries due to use of poor agronomic practices and low soil fertility, with phosphorous (P) being the most limiting factor. This study aimed at determining the effect of rate and time of phosphorous application, and planting densities on yield and net benefit of groundnuts production. The study was conducted in two locations, Chuka University Horticultural Demonstration Farm and Kenya Agricultural and Livestock Organisation, Embu, Kenya between April and August 2018. The study used a 2 x 3 x 3 factorial experiment laid out in a Randomized Complete Block Design with three replications. There were three factors; P application rates (0, 30, and 60 Kg/ha), time of P application (at sowing, and 14 days after sowing), and planting densities (148,149; 213,331 and 333,334 plants per ha). Data on number of kernels per pod, number of empty pods and yield of groundnuts was collected. Data collected was subjected to analysis of variance using Statistical Analysis Software version 9.4. Significant means were separated using Least Significance Difference at 5% probability level. The results of the study showed that rate and time of phosphorous application and planting densities had a significant effect ($p < 0.05$) on yield of groundnuts. The highest kernel yield and net benefit obtained was 1,659.90 and 963.60 Kg/ha while highest net benefit was KSh 8312 and 12403 which was obtained by applying 30 Kg/ha of P applied at sowing with a plant density of 333,334 plants per hectare at Chuka and Embu, respectively. The study showed that use of appropriate agronomic practices can lead to sustainable groundnut production, thus ensuring food security and improved farmers income. The study recommends spacing of 30 x 10 cm and application of 30 Kg/ha of Phosphorous at sowing for sustainable groundnuts production in the study area and within similar agro-ecological zones.

Keywords: Groundnuts, Plant density, Phosphorus, Yield, Net benefit

1. INTRODUCTION

Groundnut (*Arachis hypogaea* L) is a crucial legume oilseed crop cultivated worldwide in tropical, subtropical and warm temperature regions [1]. It is the thirteenth most important food crop in the world, and fourth most important source of edible oil and the third most important source of vegetable protein [2]. Groundnut is a rich source of edible oil, protein, and its seeds contain vitamin B and C [3; 4]. The nuts are eaten raw, roasted, steamed, crushed and added to soups and stews. It may be used for preparing nutritive and tasty milk. Groundnuts are also used to make peanut oil, peanut flour and animal feeds [5]. The by-products from groundnut include fuel, detergents, bleach, ink, shaving cream, face cream, rubber cosmetics, wall board, abrasive, cellulose, shampoo and medicine [6].

In Kenya, the crop is not only an important source of protein but also a major source of small holder cash income. In Western Kenya, groundnuts serve as food and cash crop [7]. Also, being a legume, groundnut biologically fix nitrogen without consuming non-renewable energies and disturbing agroecological balance hence improving the soil quality [8]. The world average yields of groundnuts stand at 1447 Kg/ha, while in Asia is 1798 Kg/ha, in Nigeria and most part of West Africa is 930 Kg/ha, South Africa 2000 Kg/ha, and in Kenya is 575 Kg/ha [9]. This shows that the yield of groundnuts in Kenya is relatively low. The low average yields cause's huge shortfalls in groundnut supply to the market making the demand of the groundnuts increase drastically [10]. Despite the low yields, there are large prospects of groundnuts production in Kenya. This is because farmers are now embracing groundnut farming and ditching unprofitable traditional crops like maize and beans [11]. However, these prospects have not been realized due to several limiting factors.

The main constraints limiting groundnuts production include poor agronomic practices, low soil fertility, unreliable rainfall, and lack of high yielding disease tolerant varieties, poor prices and lack of institutional support [11; 12; 13; 14]. Other constraints include shrinking farm size coupled with a rapid population growth rate, suggesting that agricultural interventions are needed to improve farm productivity per unit area [15; 16]. The groundnuts farming systems are characterized by low use of fertilizers and poor management of the soil fertility leading to deterioration in groundnut production [17]. The nutrient depletion on the farms is due to large crop harvests, elimination of the crop residues in the farms, erosion, leaching and insufficient nutrient replenishment [18]. The knowledge on nutrient constraints in the production of the groundnuts is limited compared to staple crop production [15]. The knowledge on the nutrient depletion, dynamics and its management on groundnut farms is a pre-requisite for designing suitable integrated approaches for effective and sustainable soil nutrient management in production systems [19]. However, information on groundnuts agronomic practices such as application of fertilisers and plant densities are limited.

Nutrient management is an important aspect in cropping system. The productivity of groundnuts will depend on careful selection of varieties, correct fertilizer application and other management practices [20; 21]. Generally, groundnuts are usually sown using a spacing of 45 cm by 15 cm. Studies have shown an increase of pod yield of groundnut of 62 – 100% when density increased from 266,666 to 666,700 per hectare [22]. In peanut, increasing plant densities from 57,000 to 285,000 plants per hectare increase pod yield per plant by 392.7% which demonstrated that planting density plays an important role on growth and yield of plants [23]. However, the information on the effect of plant densities and the optimum plant density required during production of groundnuts are limited. In soybean, yields have been enhanced by having an optimum plant density that helps canopy closure very early [24]. It has been reported that plant density affects light interception, light use efficiency, and yield [25]. Optimising plant density for nitrogen fixing crops would be critical since plant densities have been found to affect the mechanisms of source-sink and photosynthesis-nitrogen fixation [26].

Plant density may affect yield and yield components, canopy development, plant architecture and distribution of pods. Due to the importance of plant density and nutrient availability in crop production, this study aimed at determining the effect of rate and time of P application and plant density on yield and net benefit in groundnut production in Kenya. The information will help the groundnut farmers to know the appropriate application of phosphorus and plant density in order to obtain optimal groundnut production in terms of yield and net benefit.

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2. MATERIALS AND METHOD

2.1 Site Description

The study was conducted in two locations. One site was situated at Chuka University Horticultural Demonstration Farm and the other site was at Kenya Agricultural and Livestock Research Organisation (KALRO) Embu farm. Chuka University Horticultural farm is located in Meru South sub-County, Tharaka-Nithi County, Kenya. It's located along Nairobi-Meru highway approximately 186 kilometres North-East from Nairobi city. The altitude is 1399 m above sea level with an annual mean temperature range of 20.97 °C to 27.25 °C. It receives an annual rainfall ranging from 1200 to 1400 mm which is bimodal falling in two seasons, with the long rains lasting from March to June and short rains from October to December. It's located at south latitudes of 0.33° and East longitude of 37.65°. The area is in upper midlands 2 and 3 (UM2-UM3) agro ecological zones and type of soil experienced in this region is mostly Humic Nitisols [27]. Majority of the farmers in this region practice crop production (maize, coffee, tea, bananas, garlic, sunflower, tobacco vegetables and beans) in small scale and rearing of livestock. Farming accounts for about 80% of employment in Meru south.

The second site was situated at Kenya Agricultural and Livestock Research Organisation (KALRO-Embu). Kenya Agricultural and Livestock Research Organisation are located in Manyatta Sub County, Embu County. It is geographically situated at (0°31'52.03" N 37°27'2.20" E) and on an altitude of 1350 m above the sea level. Mean annual temperature is 21°C. The area is in upper midlands 3 and 4 (UM3-UM4) agro ecological zones and the soils are classified as Humic Nitisols [27]. The mean annual rainfall is 1495 mm per annum which is bi-modal (November–December and March–July). The experiment was carried out during the long rain season (March –July 2018). Majority of the farmers in this region practice crop production such as maize, beans, cowpeas, avocados and citrus fruits. Livestock farming is gaining popularity with the rival of milk cooperatives and investments by the private sectors on milk processing plants.

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2.2 Experimental Design

The study used a 2 x 3 x 3 factorial experiment laid out in a Randomized Complete Block Design (RCBD) and replicated three times. There were three factors, i.e., timing of P application (at sowing, and 14 days after sowing), P fertiliser application (0, 30 and 60 Kg of P/ha of P, 0:18:0) and plant density [148,149 (at spacing of 45 by 15 cm) plants per ha, 213,331 (at spacing of 37.5 by 12.5 cm) plants per ha and 333,334 (at spacing of 30 by 10 cm)

plants per ha]. These resulted in a total of 18 treatments for this study (Table 1).

Table 1: Treatment Coding and their Description

| Treatment Coding | Treatment Description |
|------------------|--|
| F1D1S1 | 0 Kg of P/ha , at sowing,148,149 plants |
| F1D2S1 | 0 Kg of P/ha, 14 days after sowing 148,149 plants |
| F1D1S2 | 0 Kg of P/ha, at sowing, 213,331 plants |
| F1D2S2 | 0 Kg of P/ha, 14 days after sowing, 213,331plants |
| F1D1S3 | 0 Kg of P/ha, at sowing, 333,334plants |
| F1D2S3 | 0 Kg of P/ha, 14 days after sowing, 333,334plants |
| F2D1S1 | 30 Kg of P/ha, at sowing 148,149 plants |
| F2D2S1 | 30 Kg of P/ha,14 days after sowing 148,149 plants |
| F2D1S2 | 30 Kg of P/ha, at sowing, 213,331 plants |
| F2D2S2 | 30 Kg of P/ha, 14 days after sowing, 213,331 plants, |
| F2D1S3 | 30 Kg of P/ha, at sowing333,334plants |
| F2D2S3 | 30 Kg of P/ha, 14 days after sowing, 333,334plants |
| F3D1S1 | 60 Kg of P/ha, at sowing 148,149 plants |
| F3D2S1 | 60 Kg of P/ha, 14 days after sowing148,149 plants |
| F3D1S2 | 60 Kg of P/ha, at sowing, 213,331 plants |
| F3D2S2 | 60 Kg of P/ha, 14 days after sowing, 213,331 plants |
| F3D1S3 | 60 Kg of P/ha, at sowing, 333,334plants |
| F3D2S3 | 60 Kg of P/ha14 days after sowing,333,334plants |

The treatments were randomly applied to the experimental units. Each plot size measured 1 m by 2 m with plant spacing of 45 cm by 15 cm giving 29 plants per plot, spacing of 37.5 cm by 12.5 cm giving 42 plants per plot and spacing of 30 cm by 10 cm giving 66 plants per plot.

2.3 Preparation of Land, Crop Establishment and Management

Land was cleared using a panga and a slasher. First digging was done in March, 2018 to open up the land. Secondary cultivation was then done early on first week of April, 2018 to break the soil clods and create a medium tilth. The experimental plots measured 2 m by 1 m and a path measuring 0.5 m was left between plots and 1 m between the blocks. The blocks measured 12 m by 7.5 m. Holes were made and urea fertilizer was incorporated into the soil at the rate of 15 Kg /ha in each hole. Then two seeds of Virginia variety ICGV-SM 90704 were planted per hole. Thinning was after emergence leaving one seedling per hole. Hand weeding was done thereafter to avoid interference with flowering, pegging and pod formation. Earthing up was done at the onset of peg formation. Pest and diseases were controlled using physical control such as scare crows and chemical method using bestox pesticide. All these management practice were applied uniformly in all experimental plots to ensure that all experimental plots are exposed to uniform conditions. Harvesting was done manually when 50% of the plants had developed pods with testa discoloration.

2.4 Soil Analysis

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Soil sampling was done before planting and after harvesting. Before planting, thirty soil samples were taken randomly using a soil auger in a zig zag sampling design to a depth of 15 cm of the soil profile from the entire experimental site. The soil was broken into small crumbs and thoroughly mixed. From the mixture a composite sample weighing 1 Kg was placed in a manila bag. The samples were transported to Kenya Agricultural and Livestock Research Organization (KALRO) Embu soil science laboratory for analysis. Soil was analysed as per Okalebo [28].

2.5 Data Collection

2.5.1 Effect of Rate and Time of Phosphorous application and Planting Density on Groundnut Yield and Yield Component

Harvesting of the groundnuts was done at 120 days after planting when most of plants had attained the physiological maturity. The pods were hoe-harvested from the randomly selected six selected plants in the middle of each experimental plot to facilitate determination of pod and kernel characteristic such as the yield, number of kernels per pod (shelling) and the number of empty pods.

The harvested pods from experimental plot were placed separately on the ground to facilitate determination of number of pods per individual plant per each experimental plot. Empty pods produced per plant per experimental plot were also counted and recorded. After counting the number of pods per plants, the entire kernels from the randomly selected plants per experimental plot were counted per pod. The kernels were put in a gunny bags and weighed with an electrical weighing balance to determine the yield per experimental plot. The weight obtained per experimental plot was then converted to Kg per hectare.

2.5.2 Effect of Rate and Time of Phosphorous application and Planting Density on on Net Economic Benefit

After harvest, the net economic benefit analysis was computed. The gross field benefit was obtained by multiplying the prevailing market price of groundnuts per Kg with the total groundnut yield in Kg per each treatment [29]. Market price of groundnuts was rather difficult due to fluctuating prices. In cases where the prices keep on fluctuating, it's always advisable to adopt the minimum price. The minimum groundnut price per Kg at Chuka and Embu municipal market was Ksh. 180. These prices were adopted for economic analysis. The gross benefit was the gross income derived from sale of the groundnut and the gross production costs were as indicated (Table 2). The net economic benefit was calculated by deducting the total cost from the gross field benefit per treatment

2.6 Data Analysis

Data was analysed using Statistical Analysis Software (SAS) version 9.4 [30]. Data collected on groundnut growth, yield, net economic benefit and phosphorous use efficiency was subjected to analysis of variance (ANOVA). Significant means were separated using Least Significance Difference (LSD) at 5% probability level.

Table 2: Gross cost of groundnut production per hectare

| Variables | No. of units | Unit Cost(Kshs)/ha | Total |
|----------------------------------|--------------|--------------------|--------------------|
| Ploughing | 1 ha | 7,500 | 7,500 |
| Planting (1 ha) | 54 Man-days | 54 | man-days@20,482.20 |
| | | 379.30 | |
| 1 st Weeding(1 ha x2) | 45 Man-days | 45 | man-days@17,068.50 |
| | | 379.30 | |
| Harvesting (1 Ha) | 20 Man-days | 20 | man-days@7,586 |
| | | 379.30 | |
| Threshing/packaging | 72 Man-days | 72 | man-days@27,309.60 |
| | | 379.30 | |
| Inputs | | | |
| P 30Kg/ha | 3 bags | 2,500 | 7,500 |
| P 60Kg/ha | 6 bags | 2,500 | 15,000 |
| Seeds | 10 Kg | 180 | 1,800 |
| Total | | | 104,246.30 |

3. RESULTS AND DISCUSSION

3.1. Soil Analysis Data

After analysis of the soil at KALRO-Embu the pH was 5.31 and 6.33, total nitrogen was 0.23% and 0.03% and the organic carbon content was 2.54% and 2.50%, the available P was 27 ppm and 25 ppm for Chuka and Embu site, respectively (Table 3). The soil pH at Chuka site was strongly while at Embu site was moderately acidic after harvesting. The results showed that the pH of the soil at Chuka is slightly acidic while that at Embu is moderately acidic based on the ranges by Hazelton [31]. The total nitrogen content of the soils at Chuka and Embu are medium and very low, respectively (Table 3). Available phosphorous in the Chuka site was medium while Embu site was low rated based on the ranges of Hazelton [31]. Exchangeable potassium ions of the soil of the two sites were low according to ratings based on the ranges of Hazelton [31].

Table 3: Results of soil analysis from the two experimental sites before planting

| Site | Properties | Value | Range | Class |
|-------|--------------------------|--------|-----------|-------------------|
| Chuka | pH | 5.31 | 4.6-5.5 | Strongly acidic |
| | Nitrogen (N) % | 0.23 | 0.2-0.5 | Medium |
| | Organic Carbon (OC) % | 2.54 | 2.66-5.32 | Adequate |
| | Potassium (K) (cmol/ Kg) | 0.88 | 0.24-1.5 | Adequate |
| | Magnesium (Mg) (cmol/Kg) | 1.28 | 1.0-3.0 | Adequate |
| | Calcium (Ca) (cmol/Kg) | 3 .00 | 2.0-15.0 | Adequate |
| | Manganese (Mn) (ppm) | 73.15 | >60 | Very high |
| | Phosphorus (P) (ppm) | 27 .00 | 26-45 | Medium |
| Embu | pH | 6.33 | 5.6-6.5 | Moderately acidic |
| | Nitrogen (N) % | 0.04 | <0.2 | Very Low |
| | Organic Carbon (OC) % | 2.50 | 2.66-5.32 | Adequate |
| | Potassium (K) (cmol/ Kg) | 0.26 | 0.24-1.5 | Adequate |

| | | | |
|---------------------------|-------|----------|-----------|
| Magnesium (Mg) (cmol/ Kg) | 1.30 | 1.0-3.0 | Adequate |
| Calcium (Ca) (cmol/ Kg) | 2.89 | 2.0-15.0 | Adequate |
| Manganese (Mn) (ppm) | 71.01 | >60 | Very high |
| Phosphorus (P) (ppm) | 25.00 | ≤25 | Low |

Groundnut prefers a neutral soil pH ranging 6.5 – 7.0. If the soil is too acidic or too alkaline it causes slowed growth and late maturity in groundnuts. The study conducted to examine the effects of pH on early seedling growth and reproductive growth of the groundnuts indicated that neutral pH had a major detrimental impact on the seedling survival, growth, pod formation, yield and quality of groundnuts and not germination [32]. Agricultural land is majorly affected by soil acidity which is potentially limiting agricultural productivity and causing environmental challenge. In such cases, liming can increase the crop production.

3.2. Effect of Rate and Time of P Application of Phosphorus, and Plant Density on Yield and Yield Components of Groundnuts

3.2.1. Number of Pods and Empty Pods per Plant, and Number of Kernels per Pod

A test of model adequacy on the number of pods revealed that the fitted model was adequate ($p < 0.05$) for explaining the linear relationship between treatment and number of pod per plant, number of kernels per pod, and number of empty pods per plant of groundnuts. The results of the study showed that there was significant site effect ($p < 0.0001$) and interaction between the site and treatments ($p < 0.05$) on number of pods per plant, number of kernels per pod, and number of empty pods per plant of groundnuts. The results from analysis of the effect of each factor and their combined effect (treatment effect) showed that the factors and treatments had a significant effect ($p < 0.05$) on number of pods per plant, number of kernels per pod, and number of empty pods per plant of groundnuts at both sites (Table 4).

Table 4: Mean for the yield components under different factor levels at two sites.

| Site | Factor | No. of pods | No. of kernel | Empty pods |
|-------|--------|-------------|---------------|------------|
| Chuka | F1 | 15.81c* | 1.58c | 2.57a |
| | F2 | 21.09a | 2.42a | 1.48b |
| | F3 | 17.48b | 1.88b | 1.79b |
| | LSD | 0.35 | 0.126 | 0.52 |
| | S1 | 17.95b | 1.93a | 2.13a |
| | S2 | 17.90b | 1.93a | 2.04a |
| | S3 | 18.58a | 2.03a | 1.70a |
| | LSD | 0.35 | 0.126 | 0.52 |
| Embu | F1 | 11.88b | 1.49b | 1.657a |
| | F2 | 15.06a | 1.73a | 1.18b |
| | F3 | 14.64a | 1.70a | 1.24b |
| | LSD | 0.61 | 0.61 | 0.32 |
| | S1 | 13.93a | 1.57a | 1.449a |
| | S2 | 13.12b | 1.64a | 1.350a |
| | S3 | 14.35a | 1.69a | 1.310a |
| | LSD | 0.61 | 0.13 | 0.32 |

Means followed by same letter for each factor are not significantly different from each other at 5% probability level. F1, F2 and F3 are the levels of P at 0, 30 and 60 Kg per ha respectively; S1, S2, and S3 are the different densities, 148,149, 213,331 and 333,334 plants per ha.

The independent t-test showed that there was significant ($p < 0.05$) for the time of fertilizer application on number of pods, number of kernels and number of empty pods. The mean for the number of pods ranged from 12.53 to 18.6 and 10.21 to 16.3 for Chuka and Embu site, respectively. The mean for number of kernels ranged from 1.50 to 2.00 and 1.30 to 1.80 for Chuka and Embu site, respectively. On the other hand, the mean for the number of empty pods ranged from 1.80 to 2.60 and 1.30 to 2.32 for Chuka and Embu site, respectively. Application of fertiliser at sowing gave better results than application of fertilizer 14 days after sowing at both sites (Table 4).

The analysis of effect of fertiliser application rate showed that the number of pods ranged from 15.81 to 21.09 and 11.88 to 15.06 at Chuka and Embu site, respectively. Application of 30 Kg/ha of P gave the highest number of pods while 0 Kg/ha gave the least number of pods at both sites. The number of kernels ranged from 1.58 to 2.42 and 1.49 to 1.73 at Chuka and Embu site, respectively. Application of 30 Kg/ha gave the largest number of kernels while 0 Kg/ha gave the lowest number of kernels at Chuka and Embu site, respectively. The number of empty pods ranged from 1.48 to 2.57 and 1.18 to 1.65 at Chuka and Embu site, respectively (Table 4). Application of 0 Kg/ha gave the highest number of empty pods while 30 Kg/ha gave the lowest number empty pods at Chuka and Embu site, respectively.

The analysis of effect of plant density showed that the number of pods ranged from 17.90 to 18.58 and 13.12 to 14.35 at Chuka and Embu site, respectively. The plant density of 333,334 plants per hectare gave the highest number of pods while a plant density of 213,331 plants per hectare gave the lowest number of pods at both sites. The number of kernels ranged from 1.93 to 2.03 and 1.57 to 1.69 at Chuka and Embu site, respectively. The plant density of 333,334 plants per hectare gave the highest number of kernels while the plant density of 148,149 plants per hectare gave the lowest number of kernels at Chuka and Embu site, respectively. The number of empty pods ranged from 1.70 to 2.13 and 1.31 to 1.44 at Chuka and Embu site, respectively. The plant density of 148,149 plants per hectare gave the highest number of empty pods while the plant density of 333,334 plants per hectare gave the lowest number of empty pods at Chuka and Embu site, respectively (Table 4).

The analysis of treatments effect indicated that the average number of pods per plant ranged from 14 to 22 and 10 to 15 pods for Chuka and Embu sites, respectively (Table 5). The highest number of pods per plant was obtained by applying 30 Kg/ha of P, at sowing and to a plant density of 333,334 plants per hectare at both sites. The least number of pods per plant was obtained from a plant density of 213,334 plants per hectare without P application (0 Kg/ha of P) at both sites. The average number of empty pods per plant in Chuka site ranged from 0 to 3 and 0 to 1 for the Embu site. The highest number of empty pods was obtained at a plant density of 333,334 plants per hectare without P

application. The least number of empty pods was obtained after application of 30 Kg per hectare of P fertilizer at sowing and to a plant density of 333,334 plants per hectare. The average number of kernels per pod ranged from 1 to 2 in both sites. The highest number of kernels per pod was obtained after the application of 30 Kg per hectare of P at sowing and on a plant density of 333,334 plants per hectare. The lowest number of kernels per pod was obtained at a plant density of 333,334 plants per hectare without P application (0 Kg/ha) (Table 5).

The results of this study showed there was a significant effect of rate and time of p application, and plant density on the number of pods per plant of groundnuts production. The highest number of pods per plant was obtained by applying low rate of P at sowing and at a lower density. The highest number of pods was obtained in applying 30 Kg/ha of P at sowing and at a plant density of 333,334 plants per hectare (Table 5). These results are similar to findings by Kamara [33] who found out that increase in application of P rates from 0 Kg/ha to 40 Kg/ha led to a linear increase in the pod yields of groundnuts. Another similar study indicated that pod yield increased with the application of phosphorus [34].

Table 5: Mean for the groundnut yield components under different treatments at two sites.

| Treatment | Number of pods | | Number of kernels | | Number of empty pod | |
|----------------|----------------|-----------|-------------------|---------|---------------------|----------|
| | Chuka | Embu | Chuka | Embu | Chuka | Embu |
| F2D1S3 | 22.33 a* | 15.35a | 2.68 a | 2.00 a | 0.66f | 1.41abc |
| F2D1S2 | 22.78 a | 14.93ab | 2.33 bc | 1.75 ab | 1.08def | 0.88c |
| F2D2S1 | 21.80 a | 15.00 ab | 2.27bcd | 1.77ab | 1.16def | 1.31abc |
| F2D2S2 | 20.46 b | 14.06 abc | 2.26bcd | 1.66ab | 1.60cdef | 1.40abc |
| F2D1S1 | 20.05 b | 15.12 a | 2.38ab | 1.68ab | 1.23def | 1.05bc |
| F3D1S2 | 19.72 b | 14.50 ab | 2.05cde | 1.72ab | 1.77 bcdef | 1.82 abc |
| F3D1S3 | 19.55 b | 15.27 a | 2.00def | 1.72ab | 0.94ef | 1.00bc |
| F3D1S1 | 18.00 c | 16.00 a | 2.00 def | 1.83ab | 0.66f | 1.00bc |
| F2D2S3 | 17.80 c | 15.80 a | 2.10 bcde | 1.80 ab | 1.80 bcdef | 1.10 bc |
| F3D2S3 | 16.04 d | 14.81 ab | 1.86 efg | 1.63 ab | 1.68 bcdef | 1.09 bc |
| F1D2S3 | 16.44 d | 11.55 cd | 1.38 j | 1.40b | 2.94 ab | 1.55 abc |
| F3D2S2 | 16.22 d | 13.05 bcd | 1.83efg | 1.61ab | 2.94 ab | 0.94 bc |
| F1D1S3 | 16.57d | 12.15cde | 1.42 ij | 1.46 b | 3.50 a | 1.66abc |
| F3D2S1 | 16.00 d | 15.27 a | 1.61 ghij | 1.77 ab | 2.61 abc | 1.82abc |
| F1D2S2 | 16.00 d | 10.52 e | 1.72efgh | 1.58ab | 1.16def | 1.00bc |
| F1D2S1 | 15.77 d | 12.35 cde | 1.67fghi | 1.50b | 2.38abc | 1.94ab |
| F1D1S1 | 15.66 d | 12.36 cde | 1.50hij | 1.42b | 2.16abcde | 1.89ab |
| F1D1S2 | 14.61 e | 12.22 cde | 1.42 hij | 1.55 ab | 2.64abc | 2.30a |
| LSD | 0.93 | 2.06 | 0.32 | 0.44 | 1.34 | 1.02 |
| CV | 7.976670 | 15.43131 | 23.754 | 29.109 | 95.788 | 86.511 |
| R ² | 0.837835 | 0.407690 | 0.5721 | 0.2452 | 0.2443 | 0.1867 |

Means followed by same letter for each treatment are not significantly different from each other at 5% probability level. F1, F2 and F3 are the levels of P at 0, 30 and 60 Kg per ha respectively; D1 and D2 are the application time at sowing and 14 days after sowing; S1, S2, and S3 are the different densities, 148,149, 213,331 and 333,334 plants per hectare.

The highest number of pods was obtained on the plant density of 333,334 plants per hectare. Similar findings indicated that pod yield of groundnuts was

found to increase with increase in plant density from 266,666 to 666,700 plants per hectare [22]. A further finding by Kamara [22] indicated that an increase in groundnut pod yield was observed when the plant density was increased from 57,000 plants per hectare to 285,000 plants per hectare. Temegne [35] found similar result and observed that a significant increase in the number of pods was due to P application. Melese [36] also made a finding similar to the one in this study and showed that there was an increase in the number of pods per plant with application of a combination of manure and phosphorus.

The highest number of pods was achieved by applying P at sowing. The requirement of P in nodulating legumes is higher compared to non-nodulating crops as it plays a significant role in nodule formation and fixation of atmospheric nitrogen [37]. Due to the important role played by P in the physiological processes of plants, application of P to soil deficient in this nutrient leads to increase groundnut yield. Phosphorus deficiency results in poor root development, poor pod setting and subsequently reduces pod yield. Phosphorus plays an important role on number of nodules production, nodules dry weight and uptake of N, P and K [38]. Therefore, the above findings are consistent with the findings of this study.

The highest number of kernels per pod was obtained after the application of a lower rate of P, at sowing and at a high plant density. Application of 30 Kg per hectare of phosphorus at sowing gave the largest number of pods. This was a clear indication that phosphorus application at sowing helped to increase the number of kernels per pod in groundnut production. Similar studies have shown that the number of kernels per pod was increased by P application at sowing [39]. Drammeh [40] also made similar findings and stated that when phosphorus was applied to groundnuts at sowing, it resulted to increase growth ancillaries which were due to cell division and rapid development of meristematic tissues which resulted to a greater plant height. Phosphorus deficiency was also noted to result into a decreased shoot length and the number of leaves [40]. Since phosphorus is a vital component of ATP, the ATP forms during photosynthesis, has phosphorus in its structure, and processes from the beginning of seedling growth through to the formation of grain and maturity. Thus, phosphorus is essential for the general health and vigor of all plants and therefore leading to improved flower formation and seed production.

The highest number of empty pod was obtained at experimental plots that had a high plant density and without P. The least number of empty pods per plant of groundnuts was obtained after application of 30 Kg per hectare of P at sowing and at a plant density of 148,149 plants per hectare on both sites. This showed that application of phosphorus at sowing helped to significantly decrease the number of empty pods. Desmae [41] observed that the number of pods per plant and 100 seed weight increased with lower plant densities. The phosphorous macronutrient is key to photosynthesis, helps plants to convert sunlight into energy [42]. It's also important for respiration, cell division and cell growth things that are integral to the development of the plant

and its fruit. Similar findings were made by Nyuma [39] who also found that application of P significantly decreased the number of empty pods per plant.

3.2.2. Yield of the Groundnuts

A test of model adequacy revealed that the fitted model was adequate ($p < 0.05$) to explain the relationship between treatments and yield of groundnuts at the two sites. The results of the study showed that there was significant site effect ($p < 0.0001$) and interaction between the site and treatments ($p = 0.02$) on yield of the kernel of groundnuts. The results from analysis of effect of each factor and their combined effect (treatments effect) showed that the factors and treatments had a significant effect ($p < 0.05$) on yield of groundnuts at both sites.

The independent t-test showed that there was significant ($p < 0.05$) for the time of fertilizer application on the mean yield of groundnut. The mean for the yield of groundnut ranged from 420.68 to 1009.30 Kg/ha and 350.00 to 500.55 Kg/ha for Chuka and Embu site, respectively. Application of fertilizer at sowing gave better results than application of fertilizer 14 days after sowing at both sites. The analysis of effect of fertilizer application showed that the yield of the groundnuts ranged from 469.82 to 1020.38 Kg/ha and 367.93 to 551.21 Kg/ha at Chuka and Embu site, respectively. Application of 30 Kg/ha gave the highest yield of the groundnuts while 0 Kg/ha gave the lowest yield of groundnuts at both Chuka and Embu site. The analysis of effect of plant density showed that the yield of groundnuts ranged from 431.72 to 1006.09 Kg/ha and 239.62 to 1020.38 Kg/ha at Chuka and Embu site, respectively. The plant density of 333,334 plants per hectare gave the highest yield of groundnuts while a plant density of 148,149 plants per hectare gave the lowest yield at both sites (Table 6).

Table 6: Mean for the yield of groundnuts under different factor levels at two sites

| Site | Factor | Yield of groundnut |
|-------|--------|--------------------|
| Chuka | F1 | 469.82c* |
| | F2 | 1020.38a |
| | F3 | 655.52b |
| | LSD | 133.9 |
| | S1 | 431.72c |
| | S2 | 697.60b |
| | S3 | 1006.09a |
| | LSD | 133.76 |
| Embu | F1 | 367.93c |
| | F2 | 551.21a |
| | F3 | 454.87b |
| | LSD | 63.66 |
| | S1 | 239.62c |
| | S2 | 469.82c |
| | S3 | 1020.38a |
| | LSD | 655.52b |

Means followed by same letter for each treatment are not significantly different from each other at 5% probability level. F1, F2 and F3 are the levels of P at 0, 30 and 60 Kg per ha respectively; S1, S2, and S3 are the different densities, 148,149, 213,331 and 333,334 plants per hectare

The analysis of treatment effect showed that the yield of groundnut ranged from 316.46 to 1659.90 Kg/ha for the Chuka site and 222.25 to 963.60 Kg/ha for the Embu site. The highest yield of groundnut was obtained after the application of 30 Kg per hectare of phosphorus at sowing and at a plant density of 333,334 plants per hectare. The least yield of groundnut was obtained at a plant density of 213,331 plants per hectare without P application. The results of this study showed there was a significant effect on rate and time of P application, and plant density on the yield of groundnuts. The analysis of treatment effect showed that the highest yield of groundnuts was obtained after application of a lower rate of P (30 Kg/ha of P fertiliser) at sowing and at a high plant density (333,334 plants per hectare) (Table 7). This study showed that adequate application of P at sowing increased the yield of groundnuts significantly.

Table 7: Mean for yield of groundnut under different treatments at two sites.

| Treatment | Chuka | Embu |
|----------------|-------------|------------|
| F2D1S3 | 1659.90a* | 963.60a |
| F2D1S2 | 1154.82 b | 515.55cd |
| F2D2S1 | 1136.85b | 316.83ef |
| F2D1S1 | 1075.20bc | 344.38efg |
| F2D2S2 | 957.60bcd | 478.80cdef |
| F3D1S2 | 862.95bcde | 472.50cdef |
| F3D1S3 | 764.17cdef | 619.54b |
| F2D2S3 | 676.50cdefg | 709.50b |
| F3D1S1 | 664.10cdefg | 919.40b |
| F3D2S3 | 628.57defgh | 919.40b |
| F3D2S2 | 545.42fghi | 411.60cdef |
| F1D1S3 | 537.60ghi | 408.59cdef |
| F1D2S1 | 440.40ghi | 232.00fg |
| F3D2S1 | 421.95ghi | 355.25f |
| F1D1S1 | 410.55hi | 318.15ef |
| F1D1S3 | 354.56i | 503.25cde |
| F1D2S2 | 338.21i | 523.05c |
| F1D2S2 | 316.46i | 222.25f |
| LSD | 313.16 | 163.64 |
| CV | 25.46928 | 20.13829 |
| R ² | 0.854653 | 0.863474 |

Means followed by same letter for each treatment are not significantly different from each other at 5% probability level. F1, F2 and F3 are the levels of P at 0, 30 and 60 Kg per ha respectively; D1 and D2 are the application time at sowing and 14 days after sowing; S1, S2, and S3 are the different densities, 148,149, 213,331 and 333,334 plants per hectare

Phosphorus (P) is one of the most essential macro elements, along with nitrogen, required by plants to grow. Adequate P fertilization is essential for effective crop production to attain optimum yields. Phosphorus fertilizer will significantly increase the whole plant growth, leaf photosynthesis and yield [43]. Phosphorus application significantly affected cell division, plant height, root collar diameter, chlorophyll content, root morphology and plant metabolism, acquisition and storage of energy [44; 45]. Therefore, phosphorus is a primary macro nutrient for sustainable plant production and

quality. Studies have shown that phosphorus deficiency disrupts the photosynthetic machinery and the electron transport chain [46; 47]. Consequently, even marginal P deficiency has a major impact on plant growth and development. It has been estimated that 30% of the world's arable soils are deficient in P and require P fertilization to improve yields [48].

The study showed that application of phosphorus at sowing or even after sowing affect plant growth vigour, especially at at early stages of growth, germination, days to flowering and to physiological maturity. Seed germination and vigour size may influence crop yield through both indirect and direct effects. The indirect effects include those on percentage emergence and time from sowing to emergence. These influence yields by altering plant population density, spatial arrangement, and crop duration. Early vigour or faster early leaf area development greatly influences the final yield, since more efficient use of soil moisture at early growing stages (before canopy closure) is considered crucial for higher yields [49; 50]. Greater early vigour leads to faster leaf area development, reduces soil water loss via soil evaporation, increases competition with weeds and improves nutrient uptake [51]. However, greater early growth and water use may also reduce available soil water later in the season to worsen terminal drought, leading to reduced yields. Whether early vigour leads to increased or decreased yield will depend on local climate conditions. In this study the yield at Chuka were higher than at Embu, which can be attributed to the differences in temperature and rainfall during the experimental time.

The findings of this study showed that the time of application of phosphorus fertiliser significantly affect the yield of groundnuts, with application at sowing giving higher yields. Generally, the finding of this study revealed application of 30 kg/ha P gave higher yields than application 60 kg/ha P fertiliser. This indicates that application of too much P does not result in an increase in groundnut yields. Kamara [33] found out that application of P at sowing stimulates roots growth and promote vigorous growth in crops and this consequently results to increase in biomass of groundnut. Similarly, increase in application of P rates from 0 Kg/ha to 40 kg/ha led to a linear increase in the yield of groundnut of groundnuts. Increasing phosphorus fertilizer rates from 0 to 30 Kg/ha increased all yield components [52]. Ajeigbe [34] found that pod yield increased with increase in the application of phosphorus.

The finding of this study also showed that plant density significantly affects the yield and yield componets of the groundnuts. The highest yield was obtained at a plant density of 333,334 plants per hectare. Though in this study higher plant densities gave better results with respect to yield of groundnuts, optimum plant density in groundnut is expected to vary between environment, cultivars and management practices. However, plant density is an important factor for growth and pod production rates, and kernel yield in groundnut [53]. Moreover, planting density of groundnut is often high in farmers' field which result in high yields [54], and therefore there is need to find the optimum plants density for a given ecological zone. Establishment of optimum population per unit area of the field is essential to get maximum yield [55].

The finding of this study clearly showed that an increase in plant density from 148,149 to 333,334 plants per hectare resulted in a significant increase in yield. These increase in plant density had a concurrent increase in the pod yield per hectare. This finding are in agreement with those of Kamara [22] who found that pod yield of groundnut increased significantly with increase in plant density from 266,666 to 666,700 plants per hectare.

3.3 Effect of Rate and Time of P Application, and Plant Density on Net Benefit of Groundnut Production

A test of model adequacy revealed that the fitted model was adequate ($p < 0.05$). The results of the study showed that there was significant site effect ($p < 0.0001$) and interaction between the site and treatments ($p = 0.0011$) on net benefit of groundnuts. The results from analysis of variance for the effect of factors and their combined effects showed that the treatments had a significant effect ($p < 0.05$) on net benefit of groundnuts at both sites except for the time of application. The independent t-test showed that there was no significant ($p > 0.05$) for the time of fertilizer application on net economic benefit. The range for net economic benefit was 3,360 Ksh to 4,460 Ksh and -767 Ksh to -591 Ksh for Chuka and Embu site, respectively. The analysis of effect of fertiliser application showed that the net economic benefit ranged from 2,124 Ksh to 4,420 Ksh and -5,518 Ksh to 1,029 Ksh at Chuka and Embu site, respectively. Application of 30 Kg/ha gave the highest net economic benefit while 0 Kg/ha gave the lowest net economic benefit at both Chuka and Embu site, respectively. The Analysis of effect of plant density showed that the net economic benefit ranged from -1,700 Ksh to 9,847 Ksh and -4,116 Ksh to 3,125 Ksh at Chuka and Embu site, respectively. The plant density of 333,334 plants per hectare gave the highest net economic benefit while a plant density of 148,149 plants per hectare gave the lowest net economic benefit at both sites (Table 8).

Table 8: Mean for the net economic benefit under different factors on both sites.

| Site | Factor | Net economic benefit (Ksh). |
|-------|--------|-----------------------------|
| Chuka | F1 | 2124b* |
| | F2 | 4420a |
| | F3 | 2821.73b |
| | LSD | 2319 |
| | S1 | -1700c |
| | S2 | 3319b |
| | S3 | 9847a |
| | LSD | 2369 |
| Embu | F1 | -5518b |
| | F2 | 1029a |
| | F3 | -1476b |
| | LSD | 1701 |
| | S1 | -4116c |
| | S2 | -1952b |
| | S3 | 3125a |
| | LSD | 1171 |

*Means followed by same letter for each treatment are not significantly different from each other at 5% probability level. F1, F2 and F3 are the levels of P at 0, 30 and 60 Kg per ha

respectively; S1, S2, and S3 are the different densities, 148,149, 213,331 and 333,334 plants per ha.

The analysis of treatment effect showed that the net economic benefit from the groundnut ranged from Ksh -4,611 to Ksh 20,953 Ksh and Ksh -9,674 to Ksh 84,202 for Chuka and Embu site, respectively (Table 9). The results showed that the treatment with the highest net economic benefit was 30 Kg/ha of P, at sowing with plants 333,334 plants per hectare and the lowest was at a plant density of 148,149 plants per ha without P application (0 Kg/ha). This result preliminarily showed that rate and time of P application, and plant density had a significant effect on the net economic benefit. The highest net economic benefit was obtained by applying a moderate rate of P (30 Kg/ha), at sowing and at a high plant density (333,334 plants per hectare), which was an indication that phosphorus application contributed to an increase in the net benefit but to a certain rate. This is because very high rate of 60 Kg/ha resulted in reduced net economic benefit (Table 9).

Table 9: Means of the net benefit (in Ksh) under different treatments at two sites

| Treatment | Chuka | Embu |
|----------------|-----------|------------|
| F2D1S3 | 20953a* | 84202a |
| F2D1S2 | 11538b | 38464b |
| F2D2S2 | 11112b | 35246bc |
| F3D1S1 | 10429b | 27730bcd |
| F3D1S3 | 8312bc | 12403bcde |
| F2D2S3 | 5058bcd | 8838cde |
| F3D2S3 | 4080cde | 3552def |
| F1D2S3 | 4002cde | -306fgh |
| F2D2S1 | 3029cdef | -820efgh |
| F2D1S1 | 2389def | -1169efghi |
| F1D2S2 | 1642defg | -2265fghij |
| F3D1S2 | 1502defg | -2447fghij |
| F1D1S3 | -7847efgh | -2725ghij |
| F3D2S2 | -17474fgh | -32218hij |
| F3D2S1 | -17932fgh | -3280hij |
| F1D1S2 | -2086fgh | -3998ij |
| F1D1S1 | -3978gh | -41683j |
| F1D2S1 | -4611h | -9674k |
| LSD | 5744 | 2829 |
| CV | 87.34 | 253.96 |
| R ² | 0.8469 | 0.89088 |

Means followed by same letter for each treatment are not significantly different from each other at 5% probability level. F1, F2 and F3 are the levels of P at 0, 30 and 60 Kg per ha respectively; D1 and D2 are the application time at sowing and 14 days after sowing; S1, S2, and S3 are the different densities, 148,149, 213,331 and 333,334 plants per ha

Therefore, good agronomic practices, with optimum rate and time of P application and plant density, are required for economic and sustainable groundnut production. In this study application of P contributed to an increase in the net benefit. Chuma [56] reported that application of diammonium phosphate at all doses was profitable based on the agronomic efficiency and value–cost ratio analyses. Similarly, Desmae [41] reported that the highest dry

pod yield, production value, and net benefit per hectare were obtained from 30 cm x 10 cm spacing during the dry season. In this study some treatments gave negative net economic benefits, which indicate that if farmers are not well advised on optimum agronomic practices, they would end up producing at loss.

5.2 CONCLUSION

The highest yield obtained was 1,659.90 and 963.60 Kg/ha which was obtained by applying 30 Kg/ha of P applied at sowing with a plant density of 333,334 plants per hectare at Chuka and Embu, respectively. The highest net economic benefit of KSh 8312 and 12403 was obtained with application of 30 Kg/ha of P, at sowing and at a plant density of 333,334 plants per hectare and the lowest of KSh -4611 and -9674 was at a plant density of 148,149 plants per ha without P application (0 Kg/ha) at Chuka and Embu, respectively

REFERENCES

- [1]. Nazir, R., Sayedi, S. A., Zaryal, K., Khaleeq, K., Godara, S., Bamboriya, S. D., & Bana, R. S. (2022). Effects of phosphorus application on bunch and spreading genotypes of groundnut. *Journal of Agriculture and Ecology*, 14, 26-31.
- [2]. Meresa, H., & Tsehaye, Y. (2020). Interaction of phosphorus and foliar zinc on seed quality and aspergillus infection on groundnut (*Arachis hypogaea* L.) genotypes in dryland area of TanquaAbergelle, Ethiopia. *Int. J. of Life Sciences*, 8(1), 59-69.
- [3]. Ajanaku, K. O., Ajanaku, C. O., Edobor-Osoh, A., & Nwinyi, O. C. (2012). Nutritive Value of Sorghum Ogi Fortified with Groundnut Seed (*Arachis hypogaea*). *Nutritive Value of Sorghum Ogi Fortified with Groundnut Seed (Arachis hypogaea)*, 7(2), 82-88.
- [4]. Jelliffe, J. L. (2020). An Economic Analysis of Smallholder Groundnut Production in Selected African Countries.
- [5]. Taru, V. B., Khagya, I. Z., Mshelia, S. I., & Adebayo, E. F. (2008). Economic efficiency of resource use in groundnut production in Adamawa State of Nigeria. *World Journal of Agricultural Science*, 56: 4896 – 900.
- [6]. Ihejirika, G.O., Nwufo, M. I., Obilo, O. P., Ogbeye, K. O., Onyia, V.N., & Oputa, E. (2006). Effects of NPK fertilizers rates and plant population on foliar diseases, insect's damage and yield of groundnut. *Journal of Plant Sciences*, 1:362-367.
- [7]. Melese, B., & Dechassa, N. (2017). Seed yield of groundnut as influenced by phosphorous and manure application at Babile, Eastern Ethiopia. *International Journal of Advanced Biological and biomedical Research*, 6:399-404.
- [8]. Shikha, F. S., Rahman, M. M., Sultana, N., Mottalib, M. A., & Yasmin, M. (2023). Effects of biochar and biofertilizer on groundnut production: a perspective for environmental sustainability in Bangladesh. *Carbon Research*, 2(1), 10.
- [9]. FAOSTAT, (2019). Statistical Pocketbook World Food and Agriculture.

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- [10]. Purbajanti, E. D., Slamet, W., & Fuskhah, E. (2019, March). Effects of organic and inorganic fertilizers on growth, activity of nitrate reductase and chlorophyll contents of peanuts (*Arachis hypogaea* L.). In *IOP Conference Series: Earth and Environmental Science* (Vol. 250, No. 1, p. 012048). IOP Publishing.
- [11]. Ndisio, B. O. (2015). *Assessment of Locally Cultivated Groundnut (*Arachis hypogaea*) Varieties for Susceptibility to Aflatoxin Accumulation in Western Kenya*. (Doctoral dissertation, University of Nairobi).
- [12]. Bucheyeki, T.L., Shenkalwa, M. E., Maponda, T., & Matata, W.L. (2010). The groundnuts client oriented research in Tabora, Tanzania. *African Journal of Agricultural Research*, 3:531-536.
- [13]. Muhati, S. I., Shepherd, K. D., Gachene, C. K., Mburu, M. W., Jones, R., Kironchi, G. O., & Sila, A. (2011). Diagnosis of soil nutrient constraints in small-scale groundnut (*Arachis hypogaea* L.) production systems of Western Kenya using infrared spectroscopy. *Journal of Agricultural Science and Technology A*, 1, 111-127.
- [14]. Ayesi, L.S., & Ogboru, J.O. (2016). Groundnut production and consumption rate in Ejigbo local government area of Osun, Nigeria. *Greener Journal of Agricultural Sciences*, 6:145-150.
- [15]. Kipkoech, A. K., Okiror, M. A., Okalebo, J. R., & Maritim H. K. (2007). Production efficiency and economic potential of different soil fertility management strategies among groundnuts farmers of Kenya. *Science Journal*, 2:51714-77951.
- [16]. Thuo, M., Bell, A. A., Bravo-Ureta, B. E., Okello, D. K., Okoko, E. N., Kidula, N. L., & Puppala, N. (2013). Social network structures among groundnut farmers. *The Journal of Agricultural Education and Extension*, 19(4), 339-359.
- [17]. Place, F., Adato, M., Hebinck, P., & Omosa, M. (2005). *The impact of agroforestry-based soil fertility replenishment practices on the poor in western Kenya* (Vol. 142). Intl Food Policy Res Inst.
- [18]. Vanlauwe, B., Tittonell, P., & Mukalama, J. (2007). Within-farm soil fertility gradients affect response of maize to fertiliser application in western Kenya. In *Advances in integrated soil fertility management in sub-Saharan Africa: Challenges and opportunities* (pp. 121-132). Springer, Dordrecht.
- [19]. Pannell, D. J., & Glenn, N. A. (2000). A framework for the economic evaluation and selection of sustainability indicators in agriculture. *Ecological economics*, 33(1), 135-149.
- [20]. Lourduraj, A. C. (1999). Nutrient management in groundnut (*Arachis hypogaea* L.) cultivation. *Agricultural Reviews - Agricultural Research Communications Centre India*, 20, 14-20.
- [21]. Afridi, M. Z., Jan, M.T., Ahmad, I., & Khana, M. A. (2002). Yield components of canola response to NPK nutrition. *Journal of Agronomy*, 1:133-135.
- [22]. Kamara, A.Y., Ewansiha, S.U., Bohahen, S., & Tofa, I. A. (2014). Agronomic response of soybean varieties to plant density in Guinea Savannas of Nigeria. *Agronomy Journal*.
- [23]. Onat, B., Bakal, H., Gulluoglu, L., & Arioglu, H. (2017). The effects of row spacing and plant density on yield and yield components of peanut

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grown as a double crop in Mediterranean environment in Turkey. *Turk J Field Crops*, 22: 71-80.

- [24]. Rahman, M. M., & Hossain, M. M. (2011). Plant density effects on growth, yield and yield components of two soybean varieties under equidistant planting arrangement. *Asian Journal of Plant Sciences*, 10: 278-286.
- [25]. Zhang, D., Zhang, L., Liu, J., Han, S., Wang, Q., Evers, J., Liu, J., Van der Werf, W., & Liu, L. (2014). Plant density affects light interception and yield in cotton grown as companion crop in young jujube plantations. *Field Crops Research*, 169: 1-150.
- [26]. De Luca, M. J., & Hungria, M. (2014). Plant densities and modulation of symbiotic nitrogen fixation in soybean. *Sci. Agric*, 71: 181 – 187.
- [27]. Jaetzold, R., & Schmidt, H. (1983). Farm Management Handbook of Kenya (Vol. II, Part C): Natural Conditions and Farm Management Information, East Kenya.
- [28]. Okalebo, J. R., Gathua, K. W., & Woomer, P. L. (2002). Laboratory methods of soil and plant analysis: a working manual second edition. *Sacred Africa, Nairobi*, 21, 25-26.
- [29]. Berche, J., Asumadu, H., Yeboah, S., Agyeman, K., & Acheampong, P. (2013). An Evaluation of the Effects of Yara Fertilizers on the Growth and Yield Performance of Maize (*Zea-mays* and its Economic Implications to Farmers in Ghana. *International Journal of Science and Advanced Technology*, 3(8), 1-12.
- [30]. SAS Institute. (2012). *SAS/OR 9.3 User's Guide: Mathematical Programming Examples*. SAS institute.
- [31]. Hazelton, P., & Murphy, B. (2007). Interpreting soil test results: what do all those numbers mean.
- [32]. Cheng, F., & Cheng, Z. (2015). Research progress on the use of plant allelopathy in agriculture and the physiological and ecological mechanisms of allelopathy. *Frontiers in plant science*, 6, 1020.
- [33]. Kamara, A.Y., Ekeleme, F., Kwari, J. D., Omoigui, L.O., & Chikoye, D. (2011). Phosphorous effect on growth and yield of groundnut varieties in the tropical savanna of North Eastern Nigeria. *Journal of Tropical and Soil Science*, 49:25-30.
- [34]. Ajeigbe, H. A., Kamara, A. Y., Kunihya, A., Inuwa, A. H., & Adinoyi, A. (2016). Response of groundnut to plant density and phosphorous application in the Sudan Savanna zone of Nigeria.
- [35]. Temegne, N. C., Taffouo, V. D., Tadoh, T. C., Guertoumbo, W. F., Wakem, G. A., Nkou, F. T. D., & Youmbi, E. (2019). Effect of phosphate fertilization on growth, yield and seed phosphorus content of Bambara pea (*Vignasubterranea*) land races. *JAPS: Journal of Animal & Plant Sciences*, 29(3).
- [36]. Melese, B. (2011). Seed Yield and Quality of Groundnut (*Arachishypogaea* L.) as Influenced by Phosphorus and Manure Application at Babile, Eastern Ethiopia MSc Thesis in Agriculture. *Haramaya University, Haramaya Ethiopia*.
- [37]. Brady, S. M., Callan, J. J., Cowan, D., McGrane, M., & O'Doherty, J. V. (2002). Effect of phytase inclusion and calcium/phosphorus ratio on the performance and nutrient retention of grower–finisher pigs fed barley/wheat/soya bean meal-based diets. *Journal of the Science of Food and Agriculture*, 82(15), 1780-1790.

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- [38]. Mouri, S. J., Sarkar, M. A. R., Uddin, M. R., Sarker, U. K., & Hoque, M. M. I. (2018). Effect of variety and phosphorus on the yield components and yield of groundnut. *Progressive Agriculture*, 29(2), 117-126.
- [39]. Nyuma H. T. (2016). Response of Three Groundnut (*Arachis Hypogaea* L.) Genotypes to Calcium and Phosphatic Fertilizers. <https://n2africa.org/sites/default/files/M.Sc.%20Thesis%20Nyuma%20Henry%20Tamba-0.pdf>
- [40]. Drammeh, K. M. (2016). Rate and time of phosphorus application on growth, n-fixation, seed yield of groundnut (*Arachis hypogaea* L.) and residue fertility on maize production (Doctoral dissertation).
- [41]. Desmae, H., Sako, D., & Konate, D. (2022). Optimum Plant Density for Increased Groundnut Pod Yield and Economic Benefits in the Semi-Arid Tropics of West Africa. *Agronomy*, 12(6), 1474.
- [42]. Ellah, M. M., Aondo, T. O., Ellah, J. N., & Obasi, M. O. (2018). Phosphorus Rates, Intra-Rowing Spacing and Variety of Bambara Groundnut (*Vigna subterranean* (L.) Verdc) in Makurdi Ecological Zone. *Asian Journal of Research in Crop Science*, 1-6.
- [43]. Taliman, N., Dong, Q., Echigo, K., Raboy, V., & Saneoka H (2019) Effect of Phosphorus Fertilization on the Growth, Photosynthesis, Nitrogen Fixation, Mineral Accumulation, Seed Yield, and Seed Quality of a Soybean Low-Phytate Line
- [44]. Epstein, E., & Bloom AJ. (2004) Mineral nutrition of plants: Principles and perspectives (Second Edition). Sunderland, MA: Sinauer Associates, Inc.; 402p.
- [45]. Razaq, M., Zhang, P, Shen, H.I., & Salahuddin (2017). Influence of nitrogen and phosphorus on the growth and root morphology of Acer mono. *PLoS ONE* 12(2): e0171321. doi:10.1371/journal.pone.0171321
- [46]. Frydenvang J, van Maarschalkerweerd M, Carstensen A, Mundus S, Schmidt SB, Pedas PR, Laursen KH, Schjoerring JK and Husted S (2015) Sensitive detection of phosphorus deficiency in plants using chlorophyll a fluorescence. *Plant Physiol* 169: 353–361
- [47]. Carstensen A, Herdean A, Schmidt SB, Sharma A, Spetea C, Pribil M, and Husted S (2018) The Impacts of Phosphorus Deficiency on the Photosynthetic Electron Transport Chain. *Plant Physiology*. 177: 271-284
- [48]. MacDonald GK, Bennett EM, Potter PA and Ramankutty, N. (2011). Agronomic phosphorus imbalances across the world's crop lands. *Proc Natl Acad Sci USA* 108: 3086–3091
- [49]. Zhao, Z., Rebetzke, G., Zheng, B., Chapman, C., & Wang, E. (2019). Modelling impact of early vigour on wheat yield in dryland regions. *Journal of Experimental Botany*, 70(9): 2535–2548
- [50]. Ebone, L.A., Caverzan, A., Tagliari A, Chiomento JLT, Silveira, D.C., & Chavarria G (2020) Soybean Seed Vigor: Uniformity and Growth as Key Factors to Improve Yield. *Agronomy*, 10:545-560
- [51]. Ryan, P., Liao, M., Delhaize, E., Rebetzke, G., Weligama, C., Spielmeyer, W., & James, R. (2015). Early vigour improves phosphate uptake in wheat. *Journal of Experimental Botany*, 66:7089–7100.
- [52]. Gobarah, M. E., Mohamed, M. H., & Tawfik, M. M. (2006). Effect of phosphorus fertilizer and foliar spraying with zinc on growth, yield and

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quality of groundnut under reclaimed sandy soils. *J App Sci Res*, 2(8), 491-496.

Comment [H7]: Full form of Journal

- [53]. Silvertooth, J.C., Edmistem, K.L., & McCarty, W.H. (1999). Production practices of groundnut. *Technology and Production*, 451-483.
- [54]. Gabisa, M., Tana, T., & Urage, E. (2017). The effect of planting density on yield component and yield of groundnut. *International Journal of Scientific Engineering and Applied Science*.
- [55]. Bell, M. J., Muchow, R. C., & Wilson, G. L. (1987). The effect of plant population on peanuts (*Arachis hypogaea*) in a monsoonal tropical environment. *Field Crops Research*, 17(2), 91-107
- [56]. Chuma, G. B., Mulalisi, B., Mondo, J. M., Ndeko, A. B., Bora, F. S., Bagula, E. M., ... & Civava, R. (2022). Di-ammonium phosphate (DAP) and plant density improve grain yield, nodulation capacity, and profitability of peas (*Pisum sativum* L.) on ferralsols in eastern DR Congo. *CABI Agriculture and Bioscience*, 3(1), 65.

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