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Effect of Rate and Time of Phosphorous Application and Planting Density on Yield and Net Benefit of Groundnut (*Arachis hypogaea*)

Ngari Ann Wanjue [a*], Gathungu Geofrey Kingori [a] and Muraya Moses Mahugu [a]

[a] *Department of Plant Sciences, Chuka University, P. O Box 109-60400, Chuka, Kenya.*

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Groundnut yields are relatively very low in Kenya compared to other countries due to the 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 the rate and time of phosphorous application and planting densities on yield and net benefit of groundnut 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 the number of kernels per pod, number of empty pods and yield of groundnuts were collected and net benefit determined by subtracting the cost of production from the gross product sale price per

**Corresponding author: E-mail: annwanjue@gmail.com;*

unit area. Data collected were subjected to analysis of variance using Statistical Analysis Software version 9.4. Significant means were separated using the Least Significance Difference at a 5% probability level. The results of the study showed that the rate and time of phosphorous application and planting densities had a significant effect ($p < 0.05$) on the yield of groundnuts. The highest kernel yield and net benefit obtained was 1,659.90 and 963.60 Kg/ha while the 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 the 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 groundnut production in the study area and within similar agroecological 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] and is the thirteenth most important food crop globally, 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 vitamins 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, wallboard, abrasive, cellulose, shampoo and medicine [6].

In Kenya, the crop is not only an important source of protein but also a major source of smallholder cash income. In Western Kenya, groundnuts serve as food and cash crop [7]. Also, being a legume, groundnut biologically fixes 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 huge shortfalls in groundnut supply to the market making the demand for groundnuts increase drastically [10]. Despite the low yields, there are large prospects for groundnut production in Kenya. Farmers have embraced groundnut farming after ditching traditional crops like maize and beans [11]. However, the optimal groundnut production has not been realized due to many limiting factors.

The main constraints limiting groundnut production include poor agronomic practices, low soil fertility, unreliable rainfall, lack of high-yielding disease-tolerant varieties, poor prices and lack of institutional support [11-14]. 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]. Groundnut farming systems are characterized by low use of fertilizers and poor management of 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 of nutrient constraints in the production of groundnuts is limited compared to staple crop production [15]. The knowledge of 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 groundnut agronomic practices such as the application of fertilisers and plant densities are limited.

Nutrient management is an important aspect of the 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 peanuts, 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 the growth and yield of plants [23]. However, the information on the effect of plant densities and the optimum plant density required during the production of groundnuts is 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 the rate and time of P application and plant density on yield and net benefit in groundnut production in Kenya. The information will help groundnut farmers to know the appropriate application of phosphorus and plant density to obtain optimal groundnut production in terms of yield and net benefit.

2. MATERIALS AND METHODS

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 [Chuka site] is located in Chuka South sub-County, Tharaka-Nithi County, Kenya. It’s located along the Nairobi-Meru highway approximately 186 kilometres North-East of Nairobi city. The altitude is 1399 m above sea level with an annual mean temperature range of 20.97 ^{o}C to 27.25 ^{o}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 a south latitude of 0.33^{o} and an East longitude of 37.65^{o}. The area is in upper midlands 2 and 3 (UM2-UM3) agroecological zones and the type of soil experienced in this region is mostly HumicNitisols [27].

The second site was situated at Kenya Agricultural and Livestock Research Organisation (KALRO-Embu) [Embu site]. 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 at an altitude of 1350 m above sea level. The mean annual temperature is 21 ^{o}C. The area is in upper midlands 3 and 4 (UM3-UM4) agroecological 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 rainy season (March –July 2018).

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., the 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 a 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).

The treatments were randomly applied to the experimental units. Each experimental plot size measured 1 m by 2 m with a plant spacing of 45 cm by 15 cm giving 29 plants per plot, a spacing of 37.5 cm by 12.5 cm giving 42 plants per plot and a spacing of 30 cm by 10 cm giving 66 plants per plot. Planting holes were made and fertilizer treatments were incorporated into the soil 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. Pests and diseases were controlled using physical control such as scarecrows and chemical methods using Bestox® pesticide. All these management practices 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.

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

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@ 379.30	20,482.20
1st Weeding(1 ha x2)	45 Man-days	45 man-days@ 379.30	17,068.50
Harvesting (1 Ha)	20 Man-days	20 man-days@ 379.30	7,586
Threshing/packaging	72 Man-days	72 man-days@ 379.30	27,309.60
Inputs			
P 30 Kg/ha	3 bags	2,500	7,500
P 60 Kg/ha	6 bags	2,500	15,000
Seeds	10 Kg	180	1,800
Total			104,246.30

2.3 Soil Analysis

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. The soil was analysed as per Okalebo [28].

2.4 Data Collection

2.4.1 Effect of rate and time of phosphorous application and planting density on groundnut yield and yield component

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

The harvested pods from the experimental plot were placed separately on the ground to facilitate the determination of the 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 plant, the entire kernels from the randomly selected plants per experimental plot were counted per pod. The kernels were put in 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.

2.4.2 Effect of rate and time of phosphorous application and planting density 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 treatment [29]. The market price of groundnuts was rather difficult due to fluctuating prices. In cases where the prices keep on fluctuating and it's always advisable to adopt the minimum price. The minimum groundnut price per Kg at Chuka and Embu municipal markets was Ksh. 180. These prices were adopted for economic analysis. The gross benefit was the gross income derived from the 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

2.5 Data Analysis

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

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 the Chuka site was strong while at the 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 is medium and very low, respectively (Table 3). Available phosphorous in the Chuka site was medium while the Embu site was low-rated based on the ranges of Hazelton [31]. The exchangeable potassium ions of the soil of the two sites were low according to ratings based on the ranges of Hazelton [31].

Groundnut prefers a neutral soil pH ranging from 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 challenges. 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 the number of pods 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 a significant site effect ($p < 0.0001$) and interaction between the site and treatments ($p < 0.05$) on the 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 the number of pods per plant, number of kernels per pod, and number of empty pods per plant of groundnuts at both sites (Table 4).

The independent t-test showed that there was a significant ($p < 0.05$) for the time of fertilizer application on the 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 sites, respectively. The mean for the number of kernels ranged from 1.50 to 2.00 and 1.30 to 1.80 for Chuka and Embu sites, 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 sites, respectively. The application of fertiliser at sowing gave better results than the application of fertilizer 14 days after sowing at both sites (Table 4).

The analysis of the 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 sites, 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 sites, 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 sites, respectively. The number of empty pods ranged from 1.48 to 2.57 and 1.18 to 1.65 at Chuka and Embu sites, respectively (Table 4). Application of 0 Kg/ha gave the highest number of empty pods while 30 Kg/ha gave the lowest number of empty pods at Chuka and Embu sites, respectively.

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

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 the same letter for each factor are not significantly different from each other at 5% probability level.FI, 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 the 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 sites, 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 sites, 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 sites, respectively. The number of empty pods ranged from 1.70 to 2.13 and 1.31 to 1.44 at Chuka and Embu sites, 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 sites, respectively (Table 4).

The analysis of the treatment effects 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 the 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 the 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).

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

	Number of pods		Number of kernels		Number of empty pod	
Treatment	**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 the same letter for each treatment are not significantly different from each other at 5% probability level.FI, 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 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 groundnut production. The highest number of pods per plant was obtained by applying a low rate of P at sowing and a lower density. The highest number of pods was obtained by applying 30 Kg/ha of P at sowing and a plant density of 333,334 plants per hectare (Table 5). These results are similar to findings by Kamara [33] who found that an increase in the 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].

The highest number of pods was obtained on the plant density of 333,334 plants per hectare. Similar findings indicated that the pod yield of groundnuts was found to increase with an 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 a similar result and observed that a significant increase in the number of pods was due to the 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 the 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, the application of P to soil deficient in this nutrient leads to increase groundnut yield. Phosphorus deficiency results in poor root development, and poor pod setting and subsequently reduces pod yield. Phosphorus plays an important role in the 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 in a greater plant height. Phosphorus deficiency was also noted to result in 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 leads to improved flower formation and seed production.

The highest number of empty pods 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 the 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 the 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 and 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 a significant site effect ($p < 0.0001$) and interaction between the site and treatments ($p = 0.02$) on the yield of the kernel of groundnuts. The results from the analysis of the effect of each factor and their combined effect (treatments effect) showed that the factors and treatments had a significant effect ($p < 0.05$) on the yield of groundnuts at both sites.

The independent t-test showed that there was a significant ($p < 0.05$) between 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 sites, respectively. The application of fertiliser at sowing gave better results than the application of fertilizer 14 days after sowing at both sites. The analysis of the effect of fertiliser 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 sites, 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 sites. The analysis of the 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 sites, 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).

The analysis of the 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 the rate and time of P application, and plant density on the yield of groundnuts. The analysis of the treatment effect showed that the highest yield of groundnuts was obtained after the 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.

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, and acquisition and storage of energy [44,45]. Therefore, phosphorus is a primary macronutrient for sustainable plant production and quality. Studies have shown that phosphorus deficiency disrupts the photosynthetic machinery and the electron transport chain [46,47].

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 the same letter for each treatment are not significantly different from each other at 5% probability level. FI, 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*

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 the same letter for each treatment are not significantly different from each other at 5% probability level. FI, 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

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 the application of phosphorus at sowing or even after sowing affects plant growth vigour, especially at early stages of growth, germination, days to flowering and 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 was 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 affects the yield of groundnuts, with the application at sowing giving higher yields. Generally, the finding of this study revealed application of 30 kg/ha P gave higher yields than the application of 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 root growth and promotes vigorous growth in crops and this consequently results in to increase in the biomass of groundnut. Similarly, an increase in the 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 an increase in the application of phosphorus.

The finding of this study also showed that plant density significantly affects the yield and yield components 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 the 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, the planting density of groundnut is often high in farmers' field which result in high yields [54], and therefore there is a need to find the optimum plant density for a given ecological zone. The 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. This increase in plant density had a concurrent increase in the pod yield per hectare. This finding is in agreement with those of Kamara [22] who found that pod yield of groundnut increased significantly with an 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 a significant site effect ($p < 0.0001$) and interaction between the site and treatments ($p = 0.0011$) on the net benefit of groundnuts. The results from the analysis of variance for the effect of factors and their combined effects showed that the treatments had a significant effect ($p < 0.05$) on the 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 sites, respectively. The analysis of the 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 sites, 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 sites, respectively. The analysis of the 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 sites, 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 the same letter for each treatment are not significantly different from each other at 5% probability level. FI, 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 the 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 sites, 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 the 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 a 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 the same letter for each treatment are not significantly different from each other at 5% probability level. FI, 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 the 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 × 10 cm spacing during the dry season. In this study, some treatments gave negative net economic benefits, which indicates that if farmers are not well advised on optimum agronomic practices, they would end up producing at a loss.

4. 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 the 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

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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