DOI: https://doi.org/10.20372/star.V14.i1.15
ISSN: 2226-7522 (Print) and 2305-3372 (Online)
Science, Technology and Arts Research Journal
Sci. Technol. Arts Res. J., Jan. – March 2025, 14(1), 219-238
Journal Homepage: https://journals.wgu.edu.et

Original Research

Effect of Applying Phosphorus, Potassium, and Farmyard Manure on Yield and Yield Components of Groundnut (*Arachis hypogaea* L.) on Acidic Soils of Bako and Nedjo Districts, Western Ethiopia

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Abstract

In two areas of western Ethiopia, throughout the main growing seasons of 2023, researchers used farmer-owned land and experimental plots to study the effects of inorganic phosphorus, potassium fertilizers, and farmyard manure on groundnut yields and their constituents. The experiment utilized a randomized full-block design with three replications and a factorial layout. The experimental conditions included varying amounts of phosphorus (0, 46, and 92 kg P_2O_5 ha^{-1}), potassium (0, 100, and 200 kg K_2O ha^{-1}), and farmyard manure (0, 5, and 10 t FYM ha^{-1}). Day-to-flower, physiological maturity, branch-to-peg ratio, pod-to-seed ratio, seed yield, total biomass, shelling percentage, hundred seed weight, harvest index, and dry pod weight were all substantially affected by the mixture of phosphorus and potassium fertilizer with farmyard manure. Researchers found that the optimal combination of 92 kg P_2O_5, 100 kg K_2O, and 10 t FYM ha^{-1} had the highest dry pod output (3.01 t ha^{-1}) and seed yield (1.98 t ha^{-1}). Neither FYM nor PK, however, produced the worst results. Cultivators of groundnuts in the study regions and other comparable agro-ecologies should, therefore, apply 92 kg of P_2O_5, 100 kg of K_2O, and 10 tons of FYM per hectare.

Article Information

Article History:
Received: 22-11-2024
Revised : 18-02-2025
Accepted : 30-03-2025

Keywords:
Pod Number, Harvest Index, Pod Yield, Hundred Seeds Weight, Seed Yield, Shelling Percentage

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INTRODUCTION

One of the most widely cultivated crops in the world, groundnuts (*Arachis hypogaea L.*) do best in warm, tropical, and subtropical climates (ICRISAT, 2008). Cultivated in arid and semi-arid regions worldwide (between 40°N and 40°S) with moderate temperate to tropical climates, this perennial herbaceous legume is a popular crop. This annual legume plant self-pollinates and is mostly grown for its oilseeds. Settaluri et al. (2012) state that the crop's production of edible oil and protein makes it a vital crop for both human and animal use. According to Gulluoglu et al. (2016), it contains 20-25% protein, 45-55% oil, 5% minerals, 16-18% carbs, and vitamins. Because it fixes atmospheric nitrogen (N), it helps reduce soil erosion, and it leaves some nitrogen in the soil for subsequent crops, making it an agronomically sound crop rotation tool.

After linseed (*Linum usitatissimum*) and niger seed (*Guizotia abyssinica*), groundnuts are the third most extensively farmed oilseed crop in Ethiopia in terms of both area and output volume. At less than 1.49 t ha^{-1}, Ethiopia's groundnut output is far lower than the world average yield of 1.65 t ha^{-1} (CSA, 2021). It is much lower than the potential yield, which falls between 2.4 and 3.0 t/ha under ideal management conditions (FAO, 2021). Western Ethiopian farmers produce less than the national average, at 0.8 t ha^{-1}. Due to insufficient fertilizer application, poor soil fertility, and less-than-ideal agronomic techniques, the crop's production was reduced.

Ethiopia has long struggled to increase agricultural productivity due to weak agronomic methods and integrated soil fertility management. Because of its acidic soil and restrictions on the use of foreign inputs, Ethiopia often has nutrient shortages, which greatly reduce agricultural output and productivity (Tesfaye et al., 2011). Production was reduced because soil deterioration was worsened by insufficient fertilizers and insufficient biomass return to the soil on farmed land (Samuel, 2013). Soils lacking in K, phosphate, and nitrogen (pH 5.5 or lower) cause pods to not fill as much, which in turn causes peg and pod abortion, which in turn reduces seed yield (Karltun et al., 2013). To maintain or increase their production, smallholder farmers in the research area must address these nutritional deficiencies. Therefore, acidic soil management relies heavily on integrated soil fertility control techniques.

As a legume crop, groundnuts make the most efficient use of nutrients for their expected yield. The following fertilizers are required for a groundnut crop to produce a 2.0-2.5 t ha^{-1} yield: 160-180 kg of nitrogen, 20-25 kg of phosphorus, 80-100 kg of potassium, 60-80 kg of calcium, 15-20 kg of sulfur, and 30-45 kg of magnesium, according to the author. Agricultural output, fertilizer efficiency, and environmental sustainability are all improved by using inorganic and organic fertilizers together. In semiarid regions with sparse and unpredictable precipitation, this method helps to retain soil moisture. Now more than ever, improving soil quality and agricultural output in the study area requires the use of both organic and mineral fertilizers at the same time.

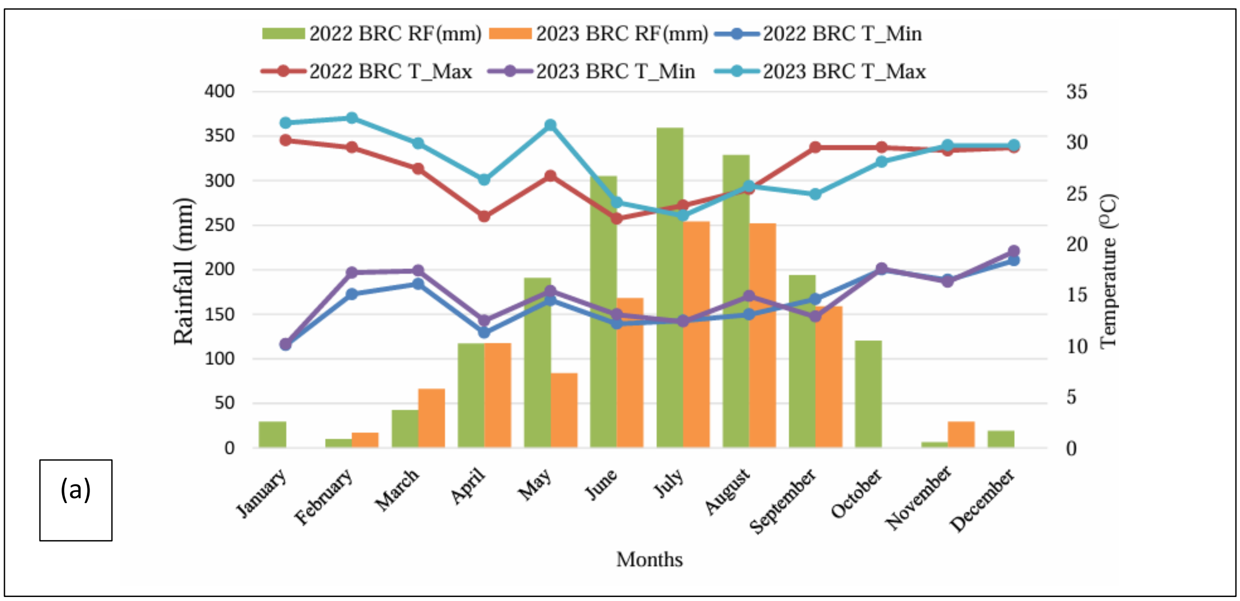
Groundnuts are grown by many farmers in western Ethiopia as a food and income source. According to Asfaw et al. (2011), our understanding of how fertilizer affects groundnuts is lacking. Much of the prior work in Ethiopia has focused on evaluating the flexibility of improved output and aflatoxin control (Gebreselassie et al., 2014; Alemu & Abera, 2014). Melese and Dechassa (2017) looked at how groundnuts in the Babile district of eastern Ethiopia responded to phosphorus and farmyard waste. The crop yielded over 40% more seeds when fertilized with a mix of manure and inorganic phosphorus fertilizer compared to the control group. One way to improve soil fertility, particularly in acidic soils, is to apply PK mineral fertilizer in addition to farmyard manure (Getahun and Tefera, 2017). Argaw (2017) found that using a combination of organic and inorganic fertilizers increased groundnut yield and production by about 45 percent.

The use of a combination of organic and inorganic fertilizers can improve soil fertility, according to researchers (Farah et al., 2014). One known problem that limits agricultural output in western Ethiopia is insufficient soil fertility. Bekele et al. (2023) identified inadequate soil fertility management practices as the primary cause of the lower yield. This is a major problem that restricts groundnut production in Ethiopia, particularly in the western region. The research area has not yet tackled this issue by using integrated farmyard manure and inorganic PK fertilizer for groundnuts, even though groundnuts are a promising oil crop. Therefore, to overcome the challenges of growing groundnuts in acidic soils, a well-planned integrated approach is required to improve the soil's physical, chemical, and biological properties through the nutrient delivery technique. The reaction of groundnuts to fertilizers, especially phosphate, potassium, and farmyard manure, is mostly unknown in the regions of Ethiopia that produce groundnuts. As a result, to maximize crop yields on constrained land, it is crucial to discover agronomic practices that help farmers keep soil fertility high. At the Bako Research Center and in the Nedjo District of western Ethiopia, this study set out to evaluate the effects of several fertilizers on groundnut development, yield characteristics, and yield. The fertilizers tested included potassium, a combination of mineral phosphorus, and farmyard manure.

MATERIALS AND METHODS

Description of Study Areas

Testing took place in the Nedjo region and at the Bako Research Center throughout the main agricultural season of 2023. Latitude: 09º 8'00" N, longitude: 37º 10'00"E, and elevation: 1650 meters above sea level are the coordinates of Bako. Nedjo district is located in western Ethiopia at an elevation of 1735 meters above sea level, with the coordinates of 9°30'N and 35°30'E. The most common soil type in both districts is nitisol, which is defined by a dark reddish-brown color, good drainage, and a high acidity level (pH = 4.45). Phosphorus is solidified and unavailable in these soils due to their high iron and aluminum hydroxide and oxide absorption. Soil aluminum toxicity and phosphorus deficiency are the main causes of stunted plant growth in such areas. In all areas, the mixed crop-livestock farming practices mostly involve growing sugar cane, mango, bananas, common beans, hot peppers, sorghum, and maize.



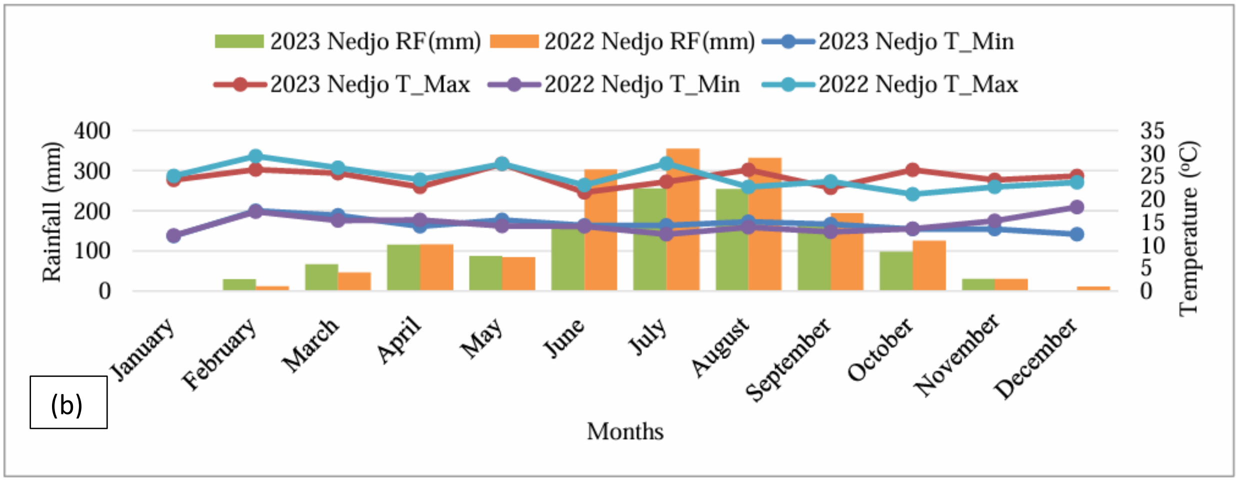


Figure 1. *Rainfall distribution and temperature data of the study area of Bako Research Center (a) and Nedjo district (b) during the 2022/2023 main cropping season, western Ethiopia*

The districts of Bako and Nedjo have a monomodal rainfall pattern, with April through October being the longest rainy season. During the trial period, Nedjo received 1386 mm of precipitation annually, while Bako received 1317 mm. Additionally, the average air temperature at the Bako location is 20.6ºC, with the lowest and greatest temperatures being 14.1ºC and 27.9ºC, respectively. Nedjo experiences temperatures as low as 12°C and as high as 26°C (Figure 1).

Treatments and Experimental Design

The treatments comprised three levels of phosphorus fertilizer (0, 46, and 92 kg P_2O_5 per hectare), three levels of potassium fertilizer (0, 100, and 200 kg K_2O per hectare), and three levels of farmyard trash (0, 5, and 10 tons per hectare). The study was established using a randomized complete block design (RCBD) in a factorial arrangement with three replications. A total of 81 plots, arranged in a 3 x 3 x 3 configuration, produced 27 treatment combinations. Each block's treatments were chosen at random. Each plot consisted of eight rows of groundnut plants, with each row measuring 2.5 m in length and 1.20 m in width. The distances from the plots to the neighboring blocks were 0.5 m and 1 m, respectively. The distance between rows was 15 cm, while the distance between plants was 25 cm. The total area of the experimental plots used in the study is 500.25 m². There were a total of 80 plants, as each of the eight rows contained 10 plants. To mitigate edge effects, data were collected from the central six rows of plants.

Experimental Procedures and Management

Before the land was plowed, it was selected and cleared of debris. The ground was worked, aerated, and treated with farm tools driven by oxen. Seeds were sown by hand in rows, keeping a distance of 25 to 15 cm within each row and between the rows. Groundnuts were planted on May 9, 2023, and reaped on November 22, 2023. There should be two seeds on each hill, spaced 25 cm apart, and the rows should be 15 cm apart. To offset the loss of seedlings due to insufficient or absent germination and/or emergence, two seeds were planted for each hill. Two plants sprouted, and one was taken out a week later. Further cultural practices, such as weeding and disease prevention, were implemented in line with established regional customs.

Soil Sampling and Analysis

Soil samples were collected randomly from the experimental field with an auger in a zigzag pattern, both before planting and after harvest, to a depth of 0–20 cm. To create a composite sample for analysis, the soil samples were meticulously combined in a bucket. Composite samples from each plot were air-dried at room temperature, ground into powder, and passed through a 2 mm sieve for the analysis of most soil properties. Organic carbon and total nitrogen analyses required additional crushing to pass through a 0.50 mm sieve. The Bako Agricultural Research Center then analyzed soil samples for particular physical and chemical properties. The hydrometer method was used to assess the soil texture (sand, silt, and clay); the pH of the soil in 1:2.5 soil-water suspensions was measured potentiometrically with the standard glass electrode pH method; the Walkley and Black wet digestion method was used to determine organic carbon; and total nitrogen content (%) was evaluated with the Kjeldahl digestion method. Available phosphorus (in mg kg^{-1}) was measured via the Bray II method. The ammonium acetate method was used to evaluate CEC, and the turbidimetric method was employed to measure accessible sulfur (mg kg^{-1}).

Data Collection and Measurements

Crop phenology

The time taken to reach 50% flowering was determined by counting. The period to 50% maturity was calculated from the planting date until half of the plants had reached maturity.

Crop growth parameters

The plant's height in centimeters was measured with a measuring tape from the base at the soil surface to the tip of its last leaf. When the plants reached physiological maturity, the primary branch count was taken on ten plants chosen at random. The total number of nodules was determined by carefully counting them on the roots of 10 randomly selected plants after they were removed from the soil before flowering and rinsed with clean water.

Yield and yield component parameters

Yield component

Before pod setting and following flowering, the roots were excavated and exposed to count the pegs on 10 plants with great care. The number of pod plants per unit area was determined randomly by uncovering the hidden pods from the ground and counting the mature plant pods. To determine the number of seeds per pod, seeds from pods at maturity were counted on ten randomly chosen plants. The weight of a hundred seeds (in grams) was determined by counting the kernels after they had been removed from the dried pods.

Yield and shelling percent

Total seed (t) calculations involved weighing the total seeds after shelling them from the dried pods in the net plot area following the shelling process. To calculate the shelling percentage, one divides the weight of the shelled pods by the weight of the dried pods from which the seeds were taken and then multiplies the outcome by 100.

$$\text{Shelling percentage (SP)} = \frac{\text{Weight of seeds shelled from pods}}{\text{Weight of dried pods from which the seeds were shelled}} \times 100$$

Total dry pod yield and harvest index

Weights of pods harvested from each net plot area were converted to total dry pod yield (t ha^{-1}). Harvest index was calculated as the ratio of seed to above-ground dry weight.

$$\text{Harvest index (HI)} = \frac{\text{Economic yield}}{\text{Biological yield}} \times 100$$

Statistical Data Analysis

The homogeneity test of variances across the location was carried out using the F-test. A combined ANOVA for the two-location data was performed using SAS version 9.4 software, based on the homogeneity of variances (SAS, 2016). After a significant difference was found in the ANOVA, the LSD test was used to compare treatment means at a 5% significance level.

RESULTS AND DISCUSSION

Results

Soil Physical and Chemical Properties of Experimental Site

According to the soil analysis conducted before planting, Bako soil has a sandy loam texture, and Nedjo soil has a sandy clay loam texture (Table 1). At both locations where testing was carried out, the soils' pH levels were in the strongly to very strongly acidic range. The CEC values are low both before and following the harvest. Before planting, both districts exhibited low levels of organic carbon. Before planting, the districts exhibited low total nitrogen concentrations. Before sowing, the levels of exchangeable potassium were moderate, accessible phosphorus was low, and available sulfur was also low. To sustain and enhance groundnut production in the study area, it is necessary to add fertilizers and organic carbon sources due to the soil's inadequate levels of phosphorus, sulfur, potassium, organic carbon, and total nitrogen.

Crop Phenology

Days to 50% flowering

The time taken to reach 50% blooming was significantly affected ($P < 0.05$) by the primary effects of phosphorus, potassium, and farmyard manure (FYM). The interaction effects of fertilizers containing phosphorus, potassium, and farmyard waste had a strong influence on this variable ($P < 0.05$). The location, however, did not affect this variable. Groundnut reached 50% flowering the fastest (in 47.3 days) when application rates were 92 kg P_2O_5 ha^{-1}, 200 kg K_2O ha^{-1}, and 5 t of farmyard waste per hectare (Table 2).

Days to 90 % physiological maturity

The interaction effects of farmyard manure, phosphate, and potassium fertilizers had a significant impact on physiological maturity ($P < 0.05$). Nonetheless, the site had a minor impact on this variable. Without the addition of phosphate and potassium fertilizers, applying 10 t FYM ha^{-1} led to a delay in reaching 90% physiological maturity until day 155.6. The application of 92 kg P_2O_5 ha^{-1}, 200 kg K_2O ha^{-1}, and 5 t ha^{-1} expedited physiological maturity to 148.3 days (Table 2).

Plant Growth Parameters

Plant height

The thorough variance analysis showed that significant ($p < 0.05$) alterations in plant height were due to the main effects of potassium, phosphorus fertilizer, and FYM, as well as the interaction effects of phosphorus and FYM. The three-way interaction had a comparable effect on this variable. Nonetheless, the site and other factors are important.

Table 1

Physical and chemical properties of the experimental site

Soil properties	Bako				Nedjo				References
	Before sowing	Rating	After harvesting	Rating	Before sowing	Rating	After harvesting	Rating	
Clay (%)	33.7		33.7		15		15		
Silt (%)	7.7		7.7		50		50		
Sand (%)	58.6		58.6		35		35		
Textural class	-	Sandy clay loam	-	Sandy loam	-	Sandy clay loam	-	Sandy clay loam	-
pH (1:2.5 H_2O)	5.1	Strong acidic	5.93	Moderately acidic	4.45	Very strong acidic	5.92	Moderately acidic	(Tekalign, 1991)
Organic carbon (%)	1.74	Low	2.12	Moderate	1.85	Low	2.15	Medium	
Total N (%)	0.14	Low	0.22	Moderate	0.13	Low	0.21	Moderate	
Available P (mg P kg $soil^{-1}$)	8.34	Low	14.3	Moderate	6.75	Low	13.4	Medium	(Cottenie, 1980)
Available S (mg P kg $soil^{-1}$)	7.12	Low	19.35	Moderate	6.11	Low	20.15	Medium	(FAO, 2021)
Exchangeable K [($cmol_{(+)}$ kg $soil^{-1}$]	0.43	Medium	0.69	High	0.33	Medium	0.65	High	
CEC [($cmol_{(+)}$ kg $soil^{-1}$]	19.78	Medium	25.30	High	20.18	Medium	22.10	High	(Havlin et al. 1999)

Table 2

Interaction effect of phosphorus, potassium fertilizer, and farmyard manure on day to flowering and days to physiological maturity at Bako and Nedjo (pooled data over two sites)

Fertilizer		DFL			DM		
		Farmyard manure (t ha^{-1})					
Phosphorus (kg P_2O_5 ha^{-1})	Potassium (kg K_2O ha^{-1})	0	5	10	0	5	10
0	0	54.6^{ab}	52.7^{b}	55.3^{a}	154.6^{ab}	153.5^{b}	155.6^{a}
	100	49.3^{c}	50.0^{c}	52.0^{b}	152.5^{b}	152.0^{b}	153.3^{b}
	200	49.0^{c}	49.6^{c}	51.6^{bc}	152.3^{b}	151.8^{c}	152.8^{b}
46	0	50.0^{c}	50.6^{c}	50.3^{c}	151.0^{c}	150.0^{bc}	150.6^{c}
	100	48.3^{de}	49.6^{c}	48.0^{de}	151.1^{c}	150.6^{bc}	151.0^{c}
	200	48.0^{de}	49.0^{c}	49.6^{c}	151.6^{c}	149.6^{d}	150.6^{c}
92	0	50.0^{c}	48.3^{de}	49.3^{c}	150.8^{c}	151.0^{b}	152.3^{b}
	100	48.6^{de}	8.3^{de}	48.6^{de}	151.0^{c}	150.6^{bc}	153.0^{b}
	200	48.0^{de}	7.3^{e}	48.3^{de}	151.8^{c}	148.7^{de}	150.3^{c}
F-test				*			*
CV (%)				2.95			2.77
LSD				0.56			0.45

*Means with the same letter are not significantly different; DFL = days to 50% flowering; DM = days to 50% maturity * = significant at 0.05; LSD = least significant difference; CV = coefficient of variation.*

The tallest groundnut plants, measuring 35.3 cm in height, were achieved with the highest application rates of phosphate, potassium fertilizer, and farmyard manure at 92 kg P_2O_5 ha^{-1}, 100 kg K_2O ha^{-1}, and 10 t FYM ha^{-1}. On the other hand, the plants that were lowest in height were those cultivated with low amounts of phosphate, potassium, and farmyard waste (Table 3). The tallest plants were approximately 120 percent greater than the shortest ones.

Number of Primary Branches per Plant

The number of primary branches per plant was significantly affected ($p < 0.05$) by FYM, phosphorus fertilizer, and potassium, as well as by their interactions. In addition, the site had a considerable effect ($p < 0.05$) on this variable. Bako showed greater overall branch growth than Nedjo. The treatment combination of 92 kg P_2O_5, 100 kg K_2O ha^{-1}, and 10 t FYM ha^{-1} resulted in the greatest number of primary branches per plant. On the other hand, employing FYM and potassium fertilizer while omitting phosphorus led to the fewest primary branches. Fertilized plants developed about 273% more primary branches per plant than those that were not fertilized (Table 3).

Table 3

Interaction effect of phosphorus, potassium fertilizer, and farmyard manure on plant height and number of primary branches at Bako and Nedjo (pooled data over two sites)

Fertilizers		PH (cm)			NPBP		
		Farmyard manure (t ha^{-1})					
Phosphorus (kg P_2O_5 ha^{-1})	Potassium (kg K_2O ha^{-1})	0	5	10	0	5	10
0	0	2.7^{n}	10.8^{l}	14.6^{ij}	1.5^{e}	2.0^{d}	2.3^{d}
	100	4.7^{m}	16.0^{i}	18.6^{h}	2.5^{d}	3.6^{c}	3.3^{c}
	200	14.5^{ij}	17.1^{hi}	19.7^{h}	3.0^{c}	3.3^{c}	3.3^{c}
46	0	14.0^{ij}	18.0^{h}	21.5^{g}	2.6^{d}	2.8^{c}	2.6^{d}
	100	15.9^{i}	20.6^{gh}	32.2^{c}	2.0^{d}	3.6^{c}	3.6^{c}
	200	15.0^{i}	24.6^{f}	31.1^{c}	3.5^{c}	4.3^{b}	3.6^{c}
92	0	13.8^{k}	22.3^{g}	26.6^{e}	2.6^{d}	3.0^{c}	3.6^{c}
	100	14.8^{ij}	29.3^{d}	35.3^{a}	3.6^{c}	4.1^{b}	5.6^{a}
	200	16.1^{i}	31.2^{c}	33.5^{b}	3.3^{c}	4.1^{b}	4.6^{b}
Site	Bako						4.2^{a}
	Nedjo						2.7^{b}
F-test				*			*
CV (%) =				17.86			21.06
LSD=				1.35			0.28

*Mean with the same letter are not significantly different; PH plant height; NPBP = number of primary branches per plant; * = significant at 0.05; LSD = Least significant difference; CV = Coefficient of variation.*

Yield and Yield Components of Parameters

Number of Pegs per Plant

The variance analysis revealed that the primary effects of fertilizer containing phosphate, potassium, and farmyard manure, as well as their interactions, had a significant impact on the number of pegs per plant ($p < 0.05$). Plants that did not receive fertilizer showed the lowest number of pegs per plant (4.0). The highest number of pegs per plant (15.9) was achieved by applying 10 t FYM ha^{-1}, along with 100 kg K_2O and 92 kg PP_2O_5. As a result, the number of pegs at the combined fertilizer rates surpassed that of plants receiving no fertilizer by more than 65% (Table 4).

Total nodule Number per Plant

The total number of nodules was significantly affected by the main effects of farmyard manure, phosphorus, and potassium fertilizers, as well as their three-way interactions ($p < 0.05$). The total nodule count at the Bako site was the highest (59.6), possibly due to differences in soil texture. Nodules were found in the least amount (25.0) when no fertilizer or farmyard manure was applied. To achieve the maximum total nodules (104.1), 92 kg of P_2O_5, 100 kg of K_2O, and 5 t ha^{-1} of FYM were utilized. The total number of nodules at the two combined fertilizer rates was nearly 75% greater than that of plants that received no fertilizer (Table 4).

Table 4

Interaction effect of phosphorus, potassium fertilizer, and farmyard manure on the number of pegs per plant and Total nodule number per plant in Bako plant Nedjo (pooled data over two sites)

Fertilizers		NNPP			NPPP		
		Farmyard manure (t ha^{-1})					
Phosphorus (kg P_2O_5 ha^{-1})	Potassium (kg K_2O ha^{-1})	0	5	10	0	5	10
0	0	25.0^{j}	31.1^{i}	36.3^{h}	4.0^{h}	5.1^{g}	8.0^{e}
	100	30.0^{i}	34.8^{d}	43.1^{f}	7.2^{e}	7.2^{e}	11.8^{c}
	200	31.1^{i}	37.5^{d}	49.1^{e}	8.3^{e}	8.3^{e}	12.9^{c}
46	0	30.1^{i}	42.6^{f}	47.5^{e}	6.5^{f}	7.8^{e}	8.3^{e}
	100	35.1^{h}	78.6^{c}	97.6^{bc}	8.8^{e}	10.0^{d}	13.0^{b}
	200	36.5^{h}	100.1^{b}	66.6^{d}	10.0^{d}	12.4^{c}	14.6^{b}
92	0	30.0^{e}	64.2^{d}	65.5^{d}	7.5^{e}	8.3^{e}	11.8^{c}
	100	37.1^{g}	104.1^{a}	77.3^{c}	8.3^{e}	11.3^{c}	15.9^{a}
	200	39.5^{g}	77.1^{c}	99.3^{bc}	9.3^{d}	12.5^{c}	12.6^{c}
Site	Bako			59.6^{a}			
	Nedjo			46.7^{b}			
F-test				*			*
CV%=				15.17			14.53
LSD=				5.11			0.45

*Means with the same letter are not significantly different; NNPP = number of nodules per plant; number of pegs per plant; * = significant at 0.05; LSD = Least significant difference; CV = Coefficient of variation.*

Number of pods per plant

The number of pods per plant was significantly affected by the main effects of phosphorus fertilizer and farmyard manure, as well as their interaction ($p<0.05$). Using phosphate, potassium fertilizer, and farmyard manure at the rates of 92 kg PP_2O_5 per hectare, 100 kg K_2O per hectare, and 10 t FYM per hectare resulted in the highest number of pods per plant. As shown in Table 5, this amounted to around 60% more pods per plant than would have been produced without fertilizer.

Number of seeds per pod

Phosphorus and potassium fertilizers, as well as farmyard manure, had significant effects on the seed count per pod, particularly their interactions (notably $p < 0.05$). The highest number of seed pods per hectare was observed when applying 92 kg of P_2O_5 and 100 kg of K_2O, along with 10 tons of FYM. In the absence of fertilizer, the number of seeds per pod was 75% higher (Table 5).

Table 5

Interaction effects of phosphorus, potassium fertilizer, and farmyard manure on the number of pod plant^{-1} and number of seed pod^{-1} at Bako and Nedjo (pooled data over two sites)

Fertilizers		PNPP			NSPP		
		Farmyard manure (t ha^{-1})					
Phosphorus (kg P_2O_5 ha^{-1})	Potassium (kg K_2O ha^{-1})	0	5	10	0	5	10
0	0	3.1^{f}	4.1^{e}	5.5^{d}	1.0^{g}	1.1^{fg}	1.2^{fg}
	100	5.3^{d}	5.1^{d}	6.1^{d}	1.2^{f}	1.3^{f}	1.8^{e}
	200	5.4^{d}	6.1^{d}	9.1^{c}	1.2^{f}	1.6^{e}	1.9^{e}
46	0	4.3^{e}	5.3^{d}	7.3^{c}	1.2^{f}	1.5^{e}	1.5^{e}
	100	6.3^{d}	7.6^{c}	12.3^{b}	1.5^{e}	2.0^{d}	2.0^{c}
	200	7.5^{c}	10.1^{c}	12.6^{b}	2.0^{d}	2.4^{c}	2.6^{b}
92	0	4.3^{e}	6.3^{d}	5.5^{d}	2.2^{d}	2.0^{d}	1.8^{c}
	100	6.1^{d}	11.6^{c}	16.1^{a}	2.3^{d}	2.6^{b}	2.9^{a}
	200	9.5^{c}	12.0^{b}	13.1^{b}	2.2^{d}	2.5^{b}	2.6^{b}
F-test				*			*
CV (%)				14.54			21.45
LSD				0.56			0.15

*Means with the same letter are not significantly different; NSPP = number of seed per pod; PNPP = pod number per plant; * = significant at 0.05; LSD = Least significant difference; CV = Coefficient of variation.*

Total dry pod yield

The analysis of variance revealed significant ($p < 0.05$) changes in total dry pod yield due to the main effects of location, phosphorus, and potassium fertilizer, as well as their interactions with farmyard manure. The ANOVA results indicated that the total dry pod and seed yield were significantly ($p < 0.05$) higher at both locations. Bako's total dry pod yield was 2.7, surpassing Nedjo's yield of 1.9--(Table 6). After applying 92 kg P_2O_5 ha^{-1}, 100 kg K_2O ha^{-1}, and 10 t ha^{-1} of FYM, growth metrics such as plant height, branch count per plant (Table 4), dry biomass yields (Table 7), and pod count per plant (Table 5) showed an increase. This led to the biggest desiccated pod. The highest recorded pod yields may be attributed to the synergistic effects of FYM and inorganic PK fertilizers on nutrient availability that promotes growth.

Table 6

Interaction effect of phosphorus, potassium fertilizer, and farmyard manure on total dry pod yield and seed yield at Bako and Nedjo (pooled data over two sites)

Fertilizers		TDPY (t ha^{-1})			SY (t ha^{-1})		
		Farmyard manure (t ha^{-1})					
Phosphorus (kg P_2O_5 ha^{-1})	Potassium (kg K_2O ha^{-1})	0	5	10	0	5	10
0	0	1.0^{h}	1.01^{g}	1.05^{g}	0.20^{i}	0.32^{h}	0.35^{h}
	100	1.22^{fg}	1.10^{fg}	1.43^{e}	0.49^{g}	0.43^{g}	0.43^{g}
	200	1.29^{e}	1.33^{e}	1.52^{c}	0.54^{f}	0.88^{d}	0.79^{d}
46	0	1.25^{e}	1.13^{f}	1.60^{c}	0.69^{e}	0.65^{e}	0.51^{f}
	100	1.53^{c}	1.66^{c}	2.25^{b}	0.85^{d}	0.99^{c}	1.10^{b}
	200	1.52^{c}	1.71^{c}	2.36^{b}	0.97^{c}	0.97^{c}	1.31^{bc}
92	0	1.35^{d}	1.30^{d}	1.35^{d}	0.88^{d}	0.66^{e}	0.65^{e}
	100	1.65^{c}	2.25^{b}	3.01^{a}	0.93^{c}	1.40^{bc}	1.98^{a}
	200	1.50^{c}	2.21^{b}	2.41^{b}	0.95^{c}	1.11^{b}	1.41^{b}
Site	Bako			2.7^{a}			0.95^{a}
	Nedjo			1.9^{b}			0.78^{b}
F-test				*			*
CV (%)				22.12			26.18
LSD				0.14			0.08

*Means with the same letter are not significantly different; TDPY = total dry pod yield; SY = seed yield; * = significant at 0.05; LSD = least significant difference; CV = coefficient of variation.*

Seed yield

Location, phosphorus, and potassium fertilizers, as well as the interplay between phosphorus, potassium fertilizers, and farmyard manure, had a significant impact on seed yield ($p < 0.05$). Bako showed the highest seed yield, which was 0.95. Because of differences in soil texture and moisture retention capacity, Bako was more suitable for producing dry pod yield and seed production than Nedjo (Table 6). The maximum seed output of 1.98 was achieved by applying phosphate and potassium fertilizers, as well as farmyard manure, at rates of 92 kg P_2O_5 ha^{-1}, 100 kg K_2O ha^{-1}, and 10 t ha^{-1} FYM.

Total dry biomass yield

Phosphorus, potassium, and farmyard manure, along with their interaction effects, significantly influenced dry biomass ($p<0.05$), as did locations. The total dry biomass production of the Bako district plants was 4.97, exceeding the Nedjo plants' output of 2.12, which meant that Bako's yield was about 134% greater than Nedjo's. The maximum total dry biomass yield of 5.3, which is nearly 430% greater than the total dry matter yield observed without any of the three fertilizers (Table 7), was achieved through the simultaneous application of 92 kg P_2O_5, 100 kg K_2O ha^{-1}, and 10 t FYM ha^{-1}.

Table 7

Interaction effects of phosphorus, potassium fertilizer, and farmyard manure on total dry biomass yield and hundred seed weight at Bako and Nedjo (pooled data over two sites)

Fertilizers		TDB (t ha^{-1})			HSW (g)		
		Farmyard manure (t ha^{-1})					
Phosphorus (kg P_2O_5 ha^{-1})	Potassium (kg K_2O ha^{-1})	0	5	10	0	5	10
0	0	1.0^{g}	1.5^{e}	1.6^{e}	28.5^{h}	31.1^{g}	32.2^{e}
	100	1.2^{f}	1.3^{f}	1.8^{e}	31.3^{e}	30.1^{f}	33.1^{d}
	200	1.2^{f}	1.7^{e}	1.9^{e}	32.1^{e}	32.1^{e}	34.1^{d}
46	0	2.2^{d}	2.1^{d}	2.0^{d}	30.1^{f}	33.3^{d}	33.3^{d}
	100	2.5^{cd}	2.6^{cd}	2.9^{cd}	33.3^{d}	34.6^{c}	36.3^{b}
	200	2.0^{d}	2.9^{cd}	3.3^{b}	35.2^{c}	36.1^{b}	36.6^{b}
92	0	2.2^{d}	2.8^{c}	2.8^{c}	33.5^{d}	33.3^{d}	35.5^{c}
	100	2.4^{cd}	4.1^{b}	5.3^{a}	33.1^{d}	35.2^{c}	38.1^{a}
	200	3.8^{b}	3.2^{b}	3.6^{b}	35.0^{c}	36.1^{b}	36.1^{b}
Site	Bako			4.97^{a}			
	Nedjo			2.12^{b}			
F-test				*			*
CV (%) =				22.95			7.14
LSD=				0.24			0.92

*Means with the same letter are not significantly different; TDB total dry biomass; HSW hundred seed weight; * = significant at 0.05; LSD = Least significant difference; CV = Coefficient of variation.*

Hundred seed weight

At both research sites, the weight of one hundred seeds was significantly ($p<0.05$) influenced by the rates of phosphorus and potassium fertilizers, as well as farmyard manure and their interaction effects. The application of 92 kg P_2O_5 and 100 kg K_2O per hectare, together with 10 tons of FYM per hectare, resulted in a maximum seed weight of 38.1. In contrast, the unfertilized plot had the lowest seed weight of 28.5. As shown in Table 7, the overall application of fertilizer was over 35% higher than that of the unfertilized plot in terms of hundred seed weight. The findings of this study suggest that using both organic and inorganic fertilizers on acidic soil could improve soil fertility by maximizing seed weight.

Shelling percentage

The shelling percentage was significantly influenced ($p<0.05$) by the considerable effects of phosphorus, potassium fertilizer, and farmyard manure, as well as their interactions. With the application of 92 kg P_2O_5, 100 kg K_2O ha^{-1}, and 10 t FYM ha^{-1}, the highest shelling percentage was achieved, which was nearly 85% greater than that of untreated plants (Table 8).

Harvest index

The primary effects of phosphorus and potassium fertilizer, along with farmyard waste, significantly impacted the harvest index. Additionally, the interaction between phosphorus and potassium fertilizer also had a significant effect ($p < 0.05$). The findings show that Bako surpassed Nedjo regarding the harvest index. Table 8 indicates that the highest harvest index was noted at the levels of 92 kg P_2O_5, 100 kg K_2O ha^{-1}, and 10 t FYM ha^{-1}. At these levels of combined fertilizers, absorption partitioning to seeds and pods reached its maximum, resulting in a 20% increase in the harvest index relative to the control (Table 8).

Table 8

Interaction effect of phosphorus, Farmyard manure, and potassium on shelling percentage (%) and harvest index (%) at Bako and Nedjo (pooled data over two sites)

Fertilizers		SH (%)			HI (%)		
		Farmyard manure (t ha^{-1})					
Phosphorus (kg P_2O_5 ha^{-1})	Potassium (kg K_2O ha^{-1})	0	5	10	0	5	10
0	0	33.0^{i}	36.1^{g}	36.0^{g}	30.5^{i}	32.2^{g}	33.1^{g}
	100	34.1^{h}	36.3^{g}	39.8^{e}	31.3^{h}	37.1^{f}	40.1^{e}
	200	35.6 ^{g}	36.6^{g}	40.9^{e}	35.6^{g}	39.1g	41.5^{d}
46	0	35.2^{g}	38.5^{ef}	39.5^{e}	32.8^{h}	39.2^{e}	39.6^{e}
	100	35.5^{g}	42.0^{d}	42.0^{d}	36.4^{g}	42.4^{d}	45.5^{c}
	200	36.0^{g}	45.4^{c}	47.6^{b}	38.3^{f}	44.5^{c}	47.1^{b}
92	0	35.2^{g}	40.0^{e}	43.8^{d}	33.7^{h}	42.1^{c}	44.6^{c}
	100	36.3^{g}	47.6^{b}	50.9^{a}	45.1^{c}	45.2^{c}	48.0^{a}
	200	37.6^{f}	46.5^{c}	48.6^{ab}	37.5^{f}	45.8^{c}	46.5^{b}
Site	Bako						47.7^{a}
	Nedjo						40.5^{b}
F-test				*			*
CV (%)				26.18			12.62
LSD				0.74			1.91

Where Means followed by the same letter within the columns and rows are not significantly different at 5% probability level; SH %= shelling percent; HI = harvest index; * = significant at 0.05; LSD = Least significant difference; CV Coefficient of variation

Discussion

When applying 10 t of FYM ha–1 without potassium and phosphorus fertilizers, relative flowering delays (55.3) were observed (Table 2). It is possible that phosphorus and potassium fertilizers hastened the flowering period by boosting meristematic activities related to flower production; the highest use of FYM, however, lengthened the time to flowering because it encourages vegetative growth rather than reproductive growth through the stimulation of residual soil nutrients. Using a balanced fertilizer can promote the division of plant cells. This shows that using phosphorus and potassium fertilizers shortened the time to flowering, whereas applying the highest amount of FYM prolonged this duration. This is because FYM includes all the vital nutrients needed by soil biota, such as carbon, which offers them energy. This prolongs the time until flowering and maturity by enabling ongoing photosynthesis and vegetative growth. Similarly, Der et al. (2015) discovered that applying potassium fertilizer at a rate of 100 kg

K_2O ha^{-1} could meet the potassium requirements of groundnuts during a critical period of flowering development. As phenological features are mainly determined by genetics (Fattahi et al., 2019), the soil conditions at the experimental sites did not significantly hinder physiological maturity. Applying a combination of P, K, and FYM to soil lacking nutrients fosters growth activity. The maturity period is shortened by applying phosphate and potassium fertilizers and using mild FYM treatment, which can be linked to the nutrients' ability to promote reproductive growth while limiting vegetative growth.

The tallest plant height was reached through the combined effects of farmyard manure and mineral PK fertilizers, applied together with 92 kg P_2O_5 ha^{-1}, 100 kg K_2O ha^{-1}, and 10 t FYM ha^{-1}. When compared to the lack of fertilizer, the integrity of PK fertilizer and farmyard manure promotes vegetative growth. Plant heights were greater when PK fertilizers and FYM were applied together than in conditions lacking phosphorus, potassium, and farmyard manure. According to Kabir et al. (2013), applying 25:50:25 kg N:P: K ha^{-1} in combination with 2.5 t FYM ha–1 leads to a higher yield of groundnut plants.

According to the soil study data, the Bako site had a sandy loam texture, while the Nedjo site showed a sandy clay loam texture (Table 1). Groundnuts require adequate soil moisture for their growth and development (Lal et al. 2013). FYM and inorganic PK fertilizers likely increased branch proliferation because of their positive effect on vegetative growth. The peg number per plant may be influenced by the combined effects of PK's inorganic fertilizer and farmyard manure. These not only supply nutrients but also enhance the physical properties of the soil and foster a favorable environment for efficient nutrient absorption. According to Rezaul et al. (2013), applying FYM and inorganic NPK fertilizers at the same time provided balanced nutrients that improved the density of peg plants per acre.

The increase in the number of groundnut nodules was due to the retention of soil moisture, not to soil texture. The number of nodules per plant may have increased because the manure treatment improved the availability of minerals like potassium and phosphorus found in fertilizers. This marks FYM as a nitrogen source for nodulation. The findings of Basu et al. (2007) support the current outcome, demonstrating that using 20:40 kg NP ha^{-1} in conjunction with 2.5 t ha^{-1} of farmyard manure significantly improved nodule formation compared to the use of mineral NP alone. It is possible that using both organic and inorganic fertilizers has increased the number of seed pods per crop, as well as microbial activity and nutrient availability. This might have promoted crop growth and nutrient absorption, as shown by growth indicators. The maximum quantity of seed pods observed may have resulted from the combined effects of inorganic fertilizer and farmyard manure on nitrogen availability, leading to increased production of pods and seed pods. Groundnuts flourish in soil that is both aerated and well-drained; yet, soils that are prone to crusting are inappropriate because they obstruct peg penetration during the flowering phase and diminish harvest yield. The synergistic effects of mineral PK and FYM can be explained, as FYM aids in the initiation of vegetative development for nitrogen fixation. Besides affecting nutrient retention, FYM enhances the soil's physical characteristics, allowing it to retain moisture and thereby promoting growth, pod development, and increased yields. Nucleic acids and phospholipids are formed during the filling of pods and seeds, which leads to improved seed quality and the initiation of metabolic processes necessary for dry matter development. Manure and phosphate have a substantial impact on the agronomic performance and improvement of groundnut seed, in line with the findings of Melese and Dechassa (2017). Throughout the growth period, pods and seeds serve as sinks for groundnut metabolic processes and enhance yields by assimilating dry matter from aboveground sections, making their assimilation significantly beneficial. The difference in peanut biomass production at the two experimental sites could be attributed to differences in the soils' capacity to retain moisture, which is affected by textural variations. Bako, a sandy loam, has better water retention than Nedjo, which is a sandy clay loam with reduced aeration and thus less suitable for abundant pod development (Table 1). For optimal dry biomass yield from groundnuts, the application of 100 kg of K_2O, 10 tons of FYM per hectare, and 92 kg of P_2O_5 was implemented. Due to the low fertility of the soil, it is crucial to manage nutrients in an integrated way. This is illustrated by the rapid delivery of inorganic nutrients in the early stages of crop growth and the gradual, ongoing provision of nutrients from farmyard manure during the entire growth period. As Ramana et al. (2002) note, the positive effect of sufficient nutrition from both organic and inorganic food sources on growth may help explain the increased dry biomass yield of groundnuts. Phosphorus and manure positively influencing soil nutrient quality, along with improved crop growth and dry matter accumulation, likely played a role in achieving the maximum possible seed weight. A significant interaction effect on thousand seed weights was identified by Satyanarayana et al. (2002) between the amounts of inorganic fertilizer and the use of organic manures. The increased shelling percentage stemming from the combination of phosphorus, potassium, and farmyard manure fertilizers may be due to a more efficient distribution of total dry biomass output toward seed yield. The application of manure along with mineral fertilizer led to an effective pod-filling process, as indicated by the shelling percentage, thereby enhancing seed and pod yields. According to Maruthi and Srinivas (2006), the use of manure and mineral fertilizer has led to an increase in the proportion of groundnut shelling by more than 60–70%. In Bako's sandy loam, peg penetration was easier due to its relatively higher water-holding capacity compared to that of Nedjo. According to Caliskan et al. (2008), the variability in the groundnut harvest index is due to environmental factors. The balanced nutrient provision achieved by combining farmyard manure with inorganic phosphorus and potassium fertilizers may have led to the increased harvest indices observed in the current experiment, as this approach promotes ongoing development, boosts photosynthesis, and aids resource transfer into economic sinks.

CONCLUSION

According to the study's findings, using farmyard manure along with inorganic phosphate and potassium fertilizers led to considerable improvements in yield, growth, and yield components. When compared to the equivalent control treatment, phosphorus, potassium fertilizer, and farmyard manure showed an interactive effect on the time taken to reach 50% flowering and physiological maturity. Additionally, they demonstrated an interaction effect on growth variables, improving yield components and augmenting seed and dry pod yield. Treating 92 kg P_2O_5, 100 kg K_2O, and 10 t FYM ha^{-1} resulted in the highest number of branches per plant, as well as increased plant height, pods, and seed yield. The optimal application rates for achieving the maximum productivity of the Werer-963 groundnut variety in the study area and comparable agro-ecologies are 92 kg P_2O_5, 100 kg K_2O, and 10 t FYM ha^{-1} of phosphorus, potassium fertilizer, and farmyard manure, respectively.

Recommendations

It is necessary to conduct additional research to ascertain locally appropriate rates of these fertilizers for the various agroecological zones of Ethiopia. As a result, groundnut farmers in the studied areas should use 92 kg of P_2O_5, 100 kg of K_2O, and 10 tons of FYM for each hectare.

CRediT authorship contribution statement

Askalu Dessalegn: Writing - Original Draft, Writing - Review & Editing **Nigussie Dechassa:** Formal analysis, Investigation, Resources, **Lemma Wogi:** Data curation and visualization.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Data availability statement

Data will be made available on request.

Acknowledgments

The authors would like to express their gratitude to the Ministry of Science and Higher Education (MoSHE) for awarding the first author a scholarship to pursue a PhD study at Haramaya University, which ultimately led to the completion of this research paper. Additionally, the authors are thankful to Salale University for their financial support. Furthermore, the authors extended their appreciation to the Bako Research Center for providing the experimental land for conducting this research as well as for offering the required facilities and technical assistance during soil analysis.

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