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Effect Of Nitrogen And Phosphorus Fertilizer Rates On Yield And Yield Components Of Frafra Potato

Solenostemon Rotundifolius Poir

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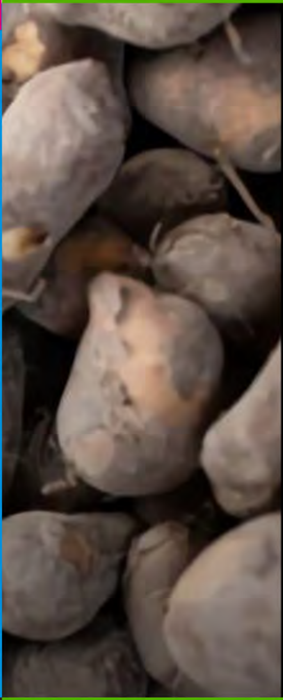

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FARA serves as the technical arm of the African Union Commission (AUC) on matters concerning agricultural science, technology and innovation. FARA has provided a continental forum for stakeholders in AR4D to shape the vision and agenda for the sub-sector and to mobilise themselves to respond to key continent-wide development frameworks, notably the Comprehensive Africa Agriculture Development Programme (CAADP).

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Abstract

Frafra potato (FP) is one of the under-utilized tuber crops but a potentially nutritional food security crop in the Upper Regions of Ghana. Lack of fertilizer recommendation has been one of the causes of low yield of FP on the farmers' field. During the 2019 and 2020 cropping seasons, a study was conducted at the Manga Station of CSIR-SARI using different rates of N and P fertilizers to evaluate the yield response to these rates. The experimental design consisted of 4 × 3 factorial combinations where factor A consist of 4 rates of N (0, 30, 60 and 90 kg/ha) and factor B made up of 3 rates of P (0, 30 and 60 kg/ha) arranged in RCBD in three replications. Data were collected on days to flowering, tuber count, tuber yield, marketable and non-marketable tubers. Interaction effects of N and P had significant ($P<0.05$) effect on days to flowering, tuber yield and market qualities in both years. Tuber yields and marketable tubers increased with increased combination of N and P application from zero to 60-60-0 kg ha-1 N-P2O5-K2O beyond which there was significant ($P<0.05$) yield reduction. The trend on partial budget analysis was consistent in both seasons with the highest yielding treatment (60-60-0 kg ha-1 N-P2O5-K2O) recording the highest net benefit while the control (0-0-0 kg ha-1 N-P2O5-K2O) treatment ranked last (2.16). The application rate of 60-60-0 kg ha-1 N-P2O5-K2O is thus recommended for optimum FP production and productivity.

Keywords: Tuber count, tuber yield, FP, non-marketable yield, productivity.

Background

Frafra potato (FP) is one of the minor but essential food crops in the production areas. Nutritionally, the crop is a carbohydrate food crop but also fairly rich in protein (1.9/100g). Compared with sweet potato ((0.8/100g), yam (1.8/100g), and cassava (0.7/100g). FP ranks highest in protein content among the tuber crops grown in Ghana (GGAP 1977). S. rotundifolius has a high content of protein, calcium, magnesium, fibre, and iron (Gouado et al. 2003; Prematilake 2005). Apart from protein, the composition of raw tubers per 100g edible portion is: water (75.6 g), energy 394 kJ (94 kcal), fat 0.2 g, carbohydrate 21.9 g, fibre 1.1 g, Ca 17 mg, Fe 6.0 mg, thiamin 0.05 mg, riboflavin 0.02 mg, niacin 1.0 mg and ascorbic acid 1 mg (Bremmer and Mulvaney 1982). Besides its nutritional value, FP plays an important role in the social lives of the people in the production areas. It is believed that one can stay without food for a long time after a meal of FP. It is thus, a favourite dish served to hunters or persons engaged in strenuous activities which demand that they stay off food for long period of time. The amount of FP a person can serve to his/her guests at a gathering determines his/her social status and the respect accorded him/her by the community. In Bawku where the study was conducted, Frafra potato (FP) is critical in improving household food security as well as a delicacy particularly for children. It has a high market potential even compared with its counterpart, sweet potato. In spite of the importance of FP, the crop is a relatively under-exploited food crop in the Upper Regions of Ghana where it is mainly produced. Less than 10% farmers ever applied chemical fertilizer (Single supper sulphate) in FP production (Sugri et al., 2013) as there is currently little information on fertilizer recommendation in the study area for optimal FP production; soil nutrient management practices are based on traditional practices. It was discovered that excessive nitrogen application adversely affects crop yield; increase the cost of production and pollutes the environment (Honisch, 2002). The use of lower dose of nitrogen could lead to significant yield reductions. This gives an insight to conduct trials to develop optimum rate of fertilizer application, to enhancing economic return and maintain environmental health. In a similar study on potato

(Solanum tuberosum L.) in Ethiopia, it was reported that lack of optimum nitrogen and phosphorus application rates accounted for low yields of potato. It was further reported that even though the productivity of potato could reach up to 30 t ha-1 attainable yield, its productivity in Ethiopia was very low (below 11.88 t/ha), (CSA, 2016).

According to Ogedegbe et al., (2015), application of NPK fertilizer significantly influences fresh weight and girth of S. rotundifolius tubers, implying that fertilizer is required to increase the yield of Frafra potato. Adequate NPK fertilizer ensures high yield of potato tubers (Naz et al., 2011) while lower rates of NPK application to potato amplify both fats and ash contents. Also, higher rates increase protein, fibre and dry matter contents of FP (Naz et al., 2011). However, Frafra potato may be produced without NPK fertilizer if soil nitrogen rating is high (Naz et al. 2011). Moreover, according to Gupta (2015), the tuber yield of FP after treatment with 50 kg ha-1 Na and 50 kg ha-1 K fertilizer are statistically superior to tubers which receive absolute K or K and Na in a 100:75 kg ha-1 proportions. This could be attributed to the beneficial interaction of Na and K in plant cells leading to stimulation in all of the cells and tissues.

FP is generally produced under rain-fed agriculture by less than 30% of farmers on less than ¼ hectare per farmer in Ghana. Yield average of 5-15 MT/ha has been reported from the crop in Ghana and Nigeria. According to PROTA (2013), the potential yield of the crop could be up to 18-20 MT/ha. However, a study in South Africa showed that potential yield from the crop may amount up to 45 MT/ha under optimum conditions of rains, soil fertility and texture (Nkansah 2004). Farmers generally do not apply mineral fertilizers to root and tuber crops but rely on natural bush fallow to restore soil fertility (Buri and Issaka 2003). This practice has become unsustainable due to land degradation and increased pressure on land as a result of increased population. Fertilizer use may allow for continuous cultivation in areas where fallowing of farmland is not feasible. Farmers in Ghana apply wood ash and diluted cattle urine prior to planting to promote the growth and development of the crop (Nkansah 2004).

Issaka et al., (2014) studied the effect of missing nutrient on yield and yield components of sweet potato in the site where the current experiments were conducted and reported that in the absence of P (45-0-45 kg/ha N, P2O5, K2O) both tuber and vine production were significantly reduced. According to their findings, tuber size was significantly smaller when P was missing than when N or K was missing. Complete fertilization (45-45-45 kg/ha N, P2O5, K2O) gave similar and/or lower tuber and vine yields as when N or K was missing. They therefore suggested that N and K are less limiting while P is the most limiting nutrient for sweet potato production in these soils.

In 2019 and 2020 cropping seasons, the current study was conducted at the Manga Agric. Station to evaluate the yield response of FP to different N and P rates for optimum production and productivity. Specifically, the objectives of the study were to assess the effect of N and P fertilizers on growth, yield and yield components of FP; determine the optimum rate of N and P fertilizers for FP production and productivity and examine the effect of N and P fertilizers on marketable qualities of FP.

Materials and Methods

Experimental site

The experiment was conducted at Manga Research Station (lies between latitude 11° N and 12° N and on longitude 0°) during the 2019 and 2020 cropping season in the Bawku East district of the Upper East Region of Ghana. The station is situated in the Sudan savannah agro-ecological zone. The area is part of what is sometimes referred to as interior savanna and is characterized by level to gently undulating topography. The annual mean rainfall (2019 and 2020) of the experimental site was 900 mm; it is mono-modal starting in July and ending in October, with a short dry spell in July and the peak in August. The site was on a slope of about 2% and the soil is Plinthic Lixisol (FAO UNESCO 1988) classification and developed from granite. The soil is deep to moderately deep and well drained. Prior to the study, the site was cultivated to maize-cowpea intercrop for three years, with undetermined amount of ammonium sulphate applied to maize during this period.

Table 2: Detailed fertilizer treatment combinations

Nitrogen (N) rates (kg/ha)	**Phosphorus (P) rates (kg/ha)**		
	0	**30**	**60**
0	0N, 0P	0N, 30P	0N, 60P
30	30N,0P	30N,30P	30N,60P
60	60N,0P	60N,30P	60N,60P
90	90N,0P	90N,30P	90N,30P

Experimental Treatments and Design

In each year, the treatments consisted of 4 × 3 factorial combinations of both four levels of N (0, 30, 60 and 90 kg/ha) and three levels of P (0, 30 and 60 kg/ha). The experimental area was ploughed, harrowed and ridged. The experimental design was 4 x 3 factorial in Randomized Complete Block Design (RCBD) with 3 replications. Each experimental plot was 3m wide and 4m long giving a plot size of 12 m^2. The distance between replications and plots was maintained at 1m and 50 cm, respectively. The spacing between rows and plants within a row was 0.75 m and 0.25 m, respectively. Urea (46% N) and Tripple super Phosphate (TSP) (46% P_20_5) were used as source of nitrogen and phosphorus respectively. The plot with zero level of both nitrogen and phosphorus was used as a control treatment. The national fertilizer recommendation for tuber production (P fertilizer as single superphosphate at 40 kg/ ha, K-fertilizer as muriate of potash at 40 kg/ha, and half rate of N-fertilizer as Urea) was applied by hill placement method 2 weeks after germination. The other half rate of N-fertilizer as urea was applied 5-6 weeks later by the same method of application. The treatments were repeated in 2020 cropping season. Composite soil samples per replication were taken before planting in 2019 and individual plots after the 2020 study, and analyzed by standard analytical methods. The FP variety used was the ***Manga Moya*** which was released in 2016 by CSIR-SARI.

Management practices

Land preparation was carried out in July each year. Frafra potato variety, ***Manga Moya***, was obtained from Manga Station of Savanna Agricultural Research Institute (SARI) for the experiment. Stem cuttings were used for planting. To produce stem cuttings for propagation, healthy tubers were established in nurseries during the dry season (in March) under irrigation, early enough to produce enough stems for the propagation in the major cropping season (July-October 2019). In the experimental field, these stems were cut and planted manually such that one-half to two-third of its length is beneath the soil surface and at least 2 nodes above the soil surface. The mineral fertilizer was applied two weeks after transplanting and by side placement using Urea (46% N) and Triple Super Phosphate (45% P_2O_5) as mineral sources. Half of the N and the whole P fertilizer rate was applied 2 weeks after planting; and the remaining half of the N dose was applied during the first earthing up (45 days after planting) as side dressing. Lime (CaO: 0.5 t/ha), Muriate of Potash (60% K_2O) and 20 kg/ha $MgSO_4$ were broadcast and worked into the soil two weeks before transplanting. This was necessary for timely mineralization for adequate uptake of the nutrients by the plants. Weeds were managed by hoeing and hand picking. Earthing up was done two times before flowering to initiate tuber bulking and once after flowering to prevent exposure of tubers to direct sunlight. Planting early in the season was necessary to avoid terminal drought since moisture availability is critical at the early and reproductive stages of the crop. Concurrent weeding and earthen up was carried out whenever necessary to facilitate good root establishment which is essential for tuber formation. During tuber formation, weed control was carried out by hand to avoid damage to the tubers. Ridges were occasionally reshaped when washed off by rain and when tubers were exposed for protection against rodent attack. At maturity, 1.0 m^2 area per treatment was demarcated and harvested.

Soil sampling and analysis

The soil characteristics were determined in order to know nutrients status of the experimental site before application of the fertilizers. Three composite soil samples were taken for determination of physical and chemical properties. At the beginning of the experiment (in 2019), 15 samples were randomly collected by using an auger and composited. Then, soil samples were also taken from each treatment at harvesting (in 2020). The samples were air dried, crushed with mortar and sieved to pass through 2 mm mesh. The characteristics analyzed for included; Soil pH, Organic matter, Total Nitrogen, Exchangeable Calcium, Magnesium, Potassium, Sodium and Effective Cation Exchange Capacity, and Bray NO.2 Extractable Phosphorus and Potassium.

The air-dried soil samples were ground at the laboratory and sieved through a 2 mm sieve. Soil pH was determined using a glass electrode (pH meter) in a soil ratio of 1:2.5 as reported by IITA (1979) and Mclean (1982). Soil organic matter was determined by the wet combustion method (Walkey and Black, 1934). Percentage total nitrogen was determined by the micro Kjeldahl-technique (IITA, 1979). The available phosphorus was extracted by the Bray method and determined colorimetrically (Bray and Kurtz 1945). Potassium was determined by flame emission photometry (IITA, 1979). The exchangeable cations calcium, magnesium, potassium and sodium were determined as recommended by IITA (1979) using EDTA Titration after extraction with 0.1N Ammonium Acetate at pH 7. Effective Cation Exchange Capacity (ECEC) was calculated as the sum of the exchangeable bases and exchangeable acidity (IITA, 1979).

Data Collection

Five plants from each treatment plot were randomly sampled and tagged for vegetative data collection. Data recorded were plant count (measured 2 weeks and 3 weeks after planting (WAP)), Days to 50% flowering (DFF), branches per plant, canopy spread (3 months after planting (MAP)) and plant height at monthly intervals. Days to 50% flowering was recorded when the number of days taken for 50 % of the plant population in each plot produced flowers (Shirie-Janagrad ***et al***., 2009). Canopy spread (3MAP) was recorded as an average count of five hills per plot at flowering (Zelalem ***et al***., 2009). Plant height was determined by measuring the height of the plant from the base of the main shoot to the apex at full blooming stage (Zelalem ***et al.,*** 2009).

Yields were harvested when all the leaves had dried out and stems had withered and there was no more vegetative growth. Parameters taken at harvest (4MAP) from the tubers of the two central rows for each treatment plot were destructively sampled and weighed using an electronic weighing scale. They included total tuber yield per ha, tuber weights (size distribution), marketable tuber yield and unmarketable tuber yield. Mean values per treatment were then estimated. Tuber yield was recorded as the sum of both marketable and unmarketable tuber yields. The total tuber yield (kg/plot) was weighed and converted to tons per hectare (t ha^{-1}) (Zelalem ***et al***., 2009). The total harvest was graded for marketable and unmarketable tubers. It is estimated that FP farmers are likely to store tubers that are healthy but below 2.5g as 'seed tubers' as they are regarded as unmarketable. They will likely sell those that are healthy and weighing 2.5g or more, as these are regarded marketable. Tubers were graded based on size into: Small tubers (<2.5 g); Medium tubers (2.6-3.5 g) and Large tubers (>3.5 g). They were further sorted into Marketable (>2.5 g and good ie no cracks, rots etc), Non-marketable tubers (<2.5 g and good ie no cracks, rots etc) and Non-marketable (Bad ie having cracks, rots etc).

Unmarketable tuber yield: Mean weight of unmarketable tubers produced from middle rows was recorded at harvest and those rotten, turned green and less than 2.5g, were considered non-marketable tuber yield, (kg/plot) and converted into t ha^{-1} (Zelalem ***et al***., 2009). Other parameters considered for grading of tubers were: cracks, rot, sprouts, millipede and weevil infestation. Scoring was done by relating the number of affected tubers to the total number of tubers per treatment plot. The rating scale was as indicated in Table 1:

Table 1: Scoring criteria for Marketable tuber selection

S.No.	Level of damage	Score
1	No damage	1
2	Slight damage	2
3	Moderate damage	3
4	Severe damage	4
5	Very Severe damage	5

Data analysis: For each year, the data collected on different growth and yield parameters were subjected to analysis of variance (ANOVA) by using GenStat 12th Edition. All pairs of treatment means were compared using Least Significant Difference (LSD) test at 5% level of significance.

Economic analysis: Net Benefit (NB) and Benefit-Cost Ratio (BCR) was conducted to determine the profitability of the various treatments. The benefit-cost ratio (BCR) method was used to determine economic analysis of treatments. This involved the determination of variable costs, gross returns and net benefits for all treatments.

Results and Discussion

Results of analysis of soil in the study site at Manga showed that the soil was sandy loam and low to very low available P and exchangeable cations (Ca, Mg) (Table 2). The pH was acidic for the soil at the experimental site (0-20 cm depth). Organic matter content was low while the total N level was high. Exchangeable Ca and K levels as well as available P and K values were also low at the site.

Table 2: Selected Initial Soil Chemical Properties of the Study Site in Manga in 2019 cropping season.

Parameter	Measured Value	Required value @(SRI 2007 guide)
pH (H_2O)	5.1	Acidic: 5.1 – 5.5
Organic Matter (%)	1.0	Low: < 1.5
TN (g kg^{-1})	0.4	High: > 0.2
Ex. Ca {Cmol (+) kg^{-1}}	2.02	Low: < 5.0
Ex. Mg {Cmol (+) kg^{-1}}	0.32	Not available
Ex. K {Cmol (+) kg^{-1}}	0.16	Low: < 0.2
Ex Na {Cmol (+) kg^{-1}}	0.09	Not available
CEC	6.8	Low: < 10
Av. P (mg kg^{-1})	3.8	Low: < 10

Av. K (mg kg^{-1})		Low: < 0.2
Depth (cm)	0-20	-
Texture	Sandy loam	-

@SRI: Soil Research Institute of Ghana

Effect of N and P fertilizer application on growth and development

In both years, the effects of N, P, and N × P were significant ($P< 0.01$) for days to 50% flowering, plant count at establishment, plant height, canopy spread, total number of tubers, total tuber yield, marketable tuber yield and unmarketable tuber yield.

Phenological Parameters

Days to flowering was significantly earlier ($P<0.001$) at 60-60-0 kg ha^{-1} $N-P_2O_5-K_2O$ which was 61days in 2019 and 60 days in 2020. Days to flowering was significantly ($P<0.001$) delayed in the control plots, 78.05 and 79 days in 2019 and 2020, respectively. This could be explained by their higher tendency of initiating vegetative growth such as higher plant height and higher plant count (Tables 3). This result is inconsistent with the findings of Cole (1975) and Zelalem ***et al***., (2009) who reported that application of higher rate of nitrogen fertilizer delayed DFF and maturity in potato. This observation is in line with report by Ekelof (2007) that optimum P rates enhance early crop development.

Table 3; Interaction effects of N and P Fertilizer on DFF of FP

N (kg /ha)	**P (kg/ha)**					
	2019			**2020**		
	0	30	60	0	30	60
0	78.05^{a}	77.00^{a}	78.01^{a}	79.33^{a}	77.67^{a}	78.00^{a}
30	78.01^{a}	72.00^{b}	76.00^{b}	78.00^{b}	74.00^{b}	75.00^{b}
60	65.00^{b}	62.30^{d}	61.00^{d}	65.33^{c}	63.00^{d}	60.00^{d}
90	64.13^{c}	70.10^{c}	65.60^{c}	63.33^{d}	69.00^{c}	65.67^{c}
LSD (0.05)	1.20			1.19		
CV (5%)	10			8		

Means followed by the same letter within a column for each treatment are not significantly different from each other at 5% level of significant.

Growth Parameters

Plant height: Interaction of N and P was highly significant ($P < 0.01$) on plant height (Table 4). In 2019, plant height ranged from 10.13 cm (under 0-0-0 kg ha^{-1} N-P_2O_5-K_2O) to 19.99 cm (under 90-60-0 kg ha^{-1} N-P_2O_5-K_2O) whilst in 2020 it ranged from 11.03 cm (under 0-0-0 kg ha^{-1} N-P_2O_5-K_2O) to 20.17 cm (under 90-60-0 kg ha^{-1} N-P_2O_5-K_2O). The interaction showed that the plant height increased with combination of N and P application in both seasons. For example, in 2020, the maximum plant height (20.17cm) recorded at 90 kg/ha N and 60 kg/ha P was significantly different from all other treatments whilst the minimum plant height of 11.03 cm was recorded by the control plot (Table.4). In both years, increasing the rates of both N and P from zero to the maximum increased plant height by 97.3% in (2019) and 83.9% (in 2020) over the control. This could be due to stimulation of root growth and development resulting from adequate N supply as well as the uptake of other nutrients (Brady and Weil, 2002). This observation could be as a result of the function of N in promoting vegetative growth which appears to be more enhanced with the P fertilizer application. This is consistent with reports by Sharma ***et al.***, (2014) who reported that plant height increased with increasing fertilizer levels of nitrogen and phosphorus. The reason for this could be due to the availability of nutrients to the crop resulting in increased photosynthetic and metabolic activities. In a similar study on potato, Mulubrhan (2004) and Zelalem ***et al., (***2009) reported that increasing application of nitrogen and phosphorus significantly increased the height of potato plants.

Table 4; Interaction Effect of N and P Fertilizer on plant height (cm) at flowering

N (kg /ha)	**P (kg/ha)**					
	2019			**2020**		
	0	30	60	0	30	60
0	10.13^{d}	11.27^{d}	12.00^{d}	11.03^{d}	12.17^{d}	12.27^{d}
30	12.17^{c}.	13.27^{c}	13.90^{c}	13.27^{c}.	14.17^{c}	14.8^{c}
60	14.30^{b}.	15.17^{b}	17.79^{b}	15.20^{b}.	16.17^{b}	18.33^{b}
90	16.10^{a}.	16.17^{a}.	19.99^{a}	15.70^{a}.	17.17^{a}.	20.17^{a}
CV (5%)	**10**			**14**		

Means followed by the same letter within a column for each treatment are not significantly different from each other at 5% level of significant.

Growth Parameters

Plant count: Plant count per hill at flowering was significantly ($P<0.001$) influenced by the interaction of N and P. (Table 5). The interaction showed that the plant count increased with combination of N and P application in both seasons. In 2019, the minimum plant count of 9.90 (recorded under the control (0-0-0 kg ha^{-1} N-P_2O_5-K_2O) plot) was significantly ($P<0.001$) lower than those of other treatments while the maximum 28.07 (which was significantly ($P<0.001$) higher than other treatments) was recorded under 90-60-0 kg ha^{-1} N-P_2O_5-K_2O. In 2020, the minimum plant count of 10.00 (which was significantly lower than other treatments) was recorded by the control (0-0-0 kg ha^{-1} N-P_2O_5-K_2O) plot while the maximum, 29.67 (which was significantly ($P<0.001$) higher than other treatments) was recorded by 90-60-0 kg ha^{-1} N-P_2O_5-K_2O. In both years, increasing the combination of both N and P from zero to the maximum increased plant count by 183% in (2019) and 197% (in 2020) over the control. The increase in plant count in response to increase in N and P combination might be related to the fact that plant count is mostly dependent on the number of sprouts per tuber. This observation is in line with findings by Rosen and Bierman (2008), who showed that phosphorus applications increased the number of potato stems per hill compared with the zero phosphorus level (control).

Table 5; Interaction effects of N and P Fertilizer on plant count at flowering of FP in Manga, during the 2019 and 2020 cropping season in Ghana

N (kg /ha)	**P (kg/ha)**					
	2019			**2020**		
	0	30	60	0	30	60
0	9.90^{c}	11.80^{d}	13.97^{d}	10.00^{c}	12.00^{d}	14.67^{d}
30	14.07^{b}.	16.93^{c}	17.90^{c}	15.67^{b}.	17.33^{c}	18.00^{c}
60	16.97^{a}.	20.00^{b}	20.96^{b}	17.67^{a}.	20.67^{b}	21.66^{b}
90	14.09^{b}	23.97^{a}.	28.07^{a}	15.60^{b}	24.67^{a}.	29.67^{a}
CV (5%)	5			4.4		

Means followed by the same letter within a column for each treatment are not significantly different from each other at 5% level of significant.

Canopy spread

There was significant ($P<0.05$) increase in canopy spread which reflects possible utilization of nutrients (Table 6). In 2019, canopy spread ranged from 14.85 cm^{2} (under the control plot) to 42.11 cm^{2} (under 90-60-0 kg ha^{-1} N-P_2O_5-K_2O. Similarly, in 2020, canopy spread ranged from 15.00 cm^{2} (under the control plot) to 44.51 cm^{2} (under 90-60-0 kg ha^{-1} N-P_2O_5-K_2O. Thus, in both years, increasing the combination of both N and P from zero to the maximum increased canopy spread over the control. The untreated control plants were stunted in growth as they had to rely on the native soil fertility which, was deficient (low) in most essential nutrients apart from N. Increase in canopy spread affects the overall performance as the leaves serve as the photosynthetic organ for nutrient capture. Increased canopy spread leads to greater dry matter accumulation of nutrients per unit of land area, because of better utilization of solar radiation. Also, greater canopy spread favours both photosynthesis and suppression of weeds leading to improved yield.

Table 6; Interaction effects of N and P Fertilizer on canopy spread (cm^2) at flowering of FP in Manga, during the 2019 and 2020 cropping season in Ghana

N (kg /ha)	P (kg/ha)					
	2019			2020		
	0	30	60	0	30	60
0	14.85^{c}	17.70^{d}	20.96^{d}	15.00^{c}	18.00^{d}	22.01^{d}
30	21.11^{b}.	25.41^{c}	26.85^{c}	23.51^{b}.	26.00^{c}	27.00^{c}
60	25.46^{a}.	30.00^{b}	31.44^{b}	26.51^{a}.	31.01^{b}	32.49^{b}
90	21.14^{b}	35.96^{a}.	42.11^{a}	23.40^{b}	37.00^{a}.	44.51^{a}
CV (5%)	**5**			4.4		

Means followed by the same letter within a column for each treatment are not significantly different from each other at 5% level of significant.

Yield parameters

Total Tuber Yields: The interaction of N x P was highly significant ($P<0.001$) for total tuber yield per hectare in both years. Total tuber yields obtained in 2019 were generally lower than those in 2020 (Table 7). The interaction showed that in 2019, tuber yields ranged from 250.00 kg/ha (under 0-0-0 kg ha^{-1} N-P_2O_5-K_2O) to 3980 kg/ha (under 60-60-0 kg ha^{-1} N-P_2O_5-K_2O) whilst in 2020 it ranged from 360.00 kg/ha (under 0-0-0 kg ha^{-1} N-P_2O_5-K_2O) to 4100 kg/ha (under 60-60-0 kg ha^{-1} N-P_2O_5-K_2O). thus, the treated plots recorded higher tuber yield compared to the control. In both seasons, tuber yields increased with increased combination of N and P application from zero to 60-60-0 kg ha^{-1} N-P_2O_5-K_2O beyond which there was yield reduction; optimum yield was thus, attained at 60-60-0 kg ha^{-1} N-P_2O_5-K_2O (Table 7). This could be due to attainment of full potential of tuber yield at 60-60-0 kg ha^{-1} N-P_2O_5-K_2O. Beyond this rate, excess N application could have stimulated shoot growth at the expense of tuber initiation and bulking resulting in yield reduction. This observation could be as a result of the function of N in promoting vegetative growth which appears to be more enhanced with P fertilizer application. Initial soil nutrient analysis at the site indicated low extractable K, Exchangeable cations and effective cation exchange capacity (Table 2). Gollifer (1972), Anderson (1974) and Bourke (1985) have indicated the importance of potassium in tuber development as elicited across all the treatments. The positive response of FP tuber to the fertilizer application could be due to the fact that it enhanced the vegetative growth phase leading to longer growth duration and ensuring higher yield. Significant increases in yield as a result of fertilizer application are likely to persuade resource-poor farmers to buy and use fertilizer on their FP farms as indicated by high tuber yield.

Table 7; Interaction effects of N and P Fertilizer on tuber yield (kg/ha) of FP in Manga, 2019 and 2020

N (kg /ha)	**P (kg/ha)**					
	2019			**2020**		
	0	**30**	**60**	**0**	**30**	**60**
0	250^{e}	280^{e}	300^{e}	360^{e}	390^{e}	410^{e}
30	880^{e}	1400^{c}	2100^{c}	910^{e}	1560^{c}	2320^{b}
60	1460^{c}	2080^{c}	3980^{a}	1580^{c}	2320^{c}	4100^{a}
90	1710^{c}	2520^{b}	3010^{b}	2220^{c}	2650^{b}	3120^{b}
CV (5%)	**6**			**4**		

Means followed by the same letter within a column for each treatment are not significantly different from each other at 5% level of significant.

Marketable tuber yields: As with the tuber yield, the marketable tubers increased with increased combination of N and P application from zero to 60-60-0 kg ha^{-1} $N-P_2O_5-K_2O$ beyond which there was reduction. Marketable tuber yields obtained in 2019 were generally lower than those in 2020 (Table 8). The interaction of nitrogen and phosphorus was highly significant ($P<0.001$) in affecting marketable tubers per hectare in both cropping seasons. The interaction showed that in 2019, yields of marketable tubers ranged from 220.00 kg/ha (under 0-0-0 kg ha^{-1} $N-P_2O_5-K_2O$) to 3540.00 kg/ha (under 60-60-0 kg ha^{-1} $N-P_2O_5-K_2O$) whilst in 2020 it ranged from 320 kg/ha (under 0-0-0 kg ha^{-1} $N-P_2O_5-K_2O$) to 3650 kg/ha (under 60-60-0 kg ha^{-1} $N-P_2O_5-K_2O$). The increase in marketable tuber yield with increasing N and P application was associated with increase in the weight of individual tubers. The increase in marketable tuber yield with increasing N and P application was associated with increase in weight of individual tubers. As expected, the weight of individual tubers could be due to stimulation of root growth and development resulting from adequate N supply as well as the uptake of other nutrients (Brady and Weil, 2002). Increasing the rate of phosphorus application linearly and significantly increased the marketable tuber number. This observation is in line with reports by Mulubrhan (2004) who noted in potato production, that marketable tuber numbers increased with increasing rate of nitrogen fertilizer. Israel ***et al.,*** (2012) reported that increasing N rate from 0 to 165 kg N per hectare increased potato marketable tuber number per hill. Similarly, Simret ***et al.***, (2010) also reported that marketable tuber yield increased with N rate from 0 to 100 kg ha^{-1} beyond which yield reduced. Increasing the P rate from 0 to 135 kg P per hectare also increased potato marketable tuber number per hill over the control.

Table 8; Interaction effects of N and P Fertilizer on marketable tubers (kg/ha) of FP in Manga, during the 2019 and 2020 cropping season in Ghana

N (kg /ha)	**P (kg/ha)**					
	2019			**2020**		
	0	**30**	**60**	**0**	**30**	**60**
0	220^{e}	250^{e}	270^{e}	320^{e}	350^{e}	360^{e}
30	700^{e}	1250^{c}	1870^{c}	810	1390^{c}	2060^{b}
60	1300^{c}	1850^{c}	3540^{a}	1410^{c}	2060^{b}	3650^{a}
90	1520^{c}	2240^{b}	2680^{b}	1980^{c}	2360^{b}	2860^{b}
CV (5%)	15			17		

Means followed by the same letter within a column for each treatment are not significantly different from each other at 5% level of significant.

Non-marketable (good) tuber yield: In both years, the non-marketable (good) tuber yield was significantly affected by the interaction effects of nitrogen and phosphorus (Table 9). As with previous trends, non-marketable tuber yield increased with increased combination of N and P from 0 to 60-60-0 kg ha^{-1} N-P_2O_5-K_2O beyond which it reduced. The interaction showed that in 2019, yields of non-marketable tubers ranged from 30 kg/ha (under 0-0-0 kg ha^{-1} N-P_2O_5-K_2O) to 400.00 kg/ha (under 60-60-0 kg ha^{-1} N-P_2O_5-K_2O) whilst in 2020 it ranged from 40 kg/ha (under 0-0-0 kg ha^{-1} N-P_2O_5-K_2O) to 410 kg/ha (under 60-60-0 kg ha^{-1} N-P_2O_5-K_2O). This observation indicates that non-marketable tubers may be controlled more importantly through manipulating other factors such as pest and disease incidence, harvesting practice, and the like rather than mineral nutrition (Berga ***et al.***, 1994a).

Table 9; Interaction effects of N and P Fertilizer on non-marketable (good) tubers (kg/ha) of FP, 2019 and 2020

N (kg /ha)	P (kg/ha)					
	2019			2020		
	0	**30**	**60**	**0**	**30**	**60**
0	30^{e}	30^{e}	30^{e}	40^{e}	40^{e}	40^{e}
30	90^{e}	140^{d}	210^{c}	90^{e}	160^{d}	230^{c}
60	150^{d}	210^{c}	400^{a}	160^{d}	230^{c}	410^{a}
90	170^{d}	250^{c}	300^{b}	220^{c}	270^{c}	320^{b}
CV (5%)	**7**			**8**		

Means followed by the same letter within a column for each treatment are not significantly different from each other at 5% level of significant

Partial budget analysis: In both seasons, application rate of 60-60-0 kg ha^{-1} N-P_2O_5-K_2O recorded the highest net benefit (NB) and benefit-cost ratio (BCR) while the control treatment recorded the lowest (Table 10). This could be a result of higher tuber yields and number of marketable tubers in the treated plots. Thus, differences in NBs and BCRs among treatments were basically as a result of differences in tuber yield and number of marketable tubers obtained from the different treatments. This is supported by the fact that, treated plots with the highest tuber yields consistently also accounted for the highest NBs and BCRs. As stated earlier (under Tables 7 and 8), in both seasons, tuber yields and marketable tubers increased with increased combination of N and P application from zero to 60-60-0 kg ha^{-1} N-P_2O_5-K_2O beyond which there was yield reduction. Thus, the trend is consistent, with the highest yielding treatment recording the highest NB and BCR. The application rate of 60-60-0 kg ha^{-1} N-P_2O_5-K_2O is thus recommended for optimum FP production and productivity.

Table 10: Net Benefit and Benefit Cost Ratio of various treatments during the 2019 and 2020 cropping season

Treatment combination (Kg N-P_2O_5 ha^{-1})	Net Benefit (NB) (GHC)		Benefit Cost Ratio (BCR)	
	2019	2020	2019	2020
0-0	100.00	80.00	2.16	2.17
0-30	299.00	109.00	2.29	2.22
0-60	303.50	290.50	2.39	2.37
30-0	630.88	530.80	2.90	2.88
30-30	779.00	779.00	3.80	3.76
30-60	812.38	820.20	4.30	4.40
60-0	300.30	298.10	1.70	1.59
60-30	798.60	690.70	3.90	3.17
60-60	924.80	930.10	4.60	4.70
90-0	670.00	650.90	3.00	2.99
90-30	675.90	605.70	2.70	2.95
90-60	650.80	610.10	2.50	2.72

Conclusions

The study showed that N and P had significant effect on days to flowering, tuber yield and market quality in both years. Days to flowering was significantly earlier at 60-60-0 kg ha^{-1} N-P_2O_5-K_2O than it was in other treatments and was significantly delayed in the control plots in both years. Both tuber yields and marketable tubers increased with higher doses of N and P attaining their optimal levels at the application rate of 60-60-0 kg ha^{-1} N-P_2O_5-K_2O which also accounted for the highest NB and BCR among the treatments. Thus, application rate of 60-60-0 kg ha^{-1} N-P_2O_5-K_2O is optimal for production of FP in the study area and hence is recommended for optimal FP production and productivity.

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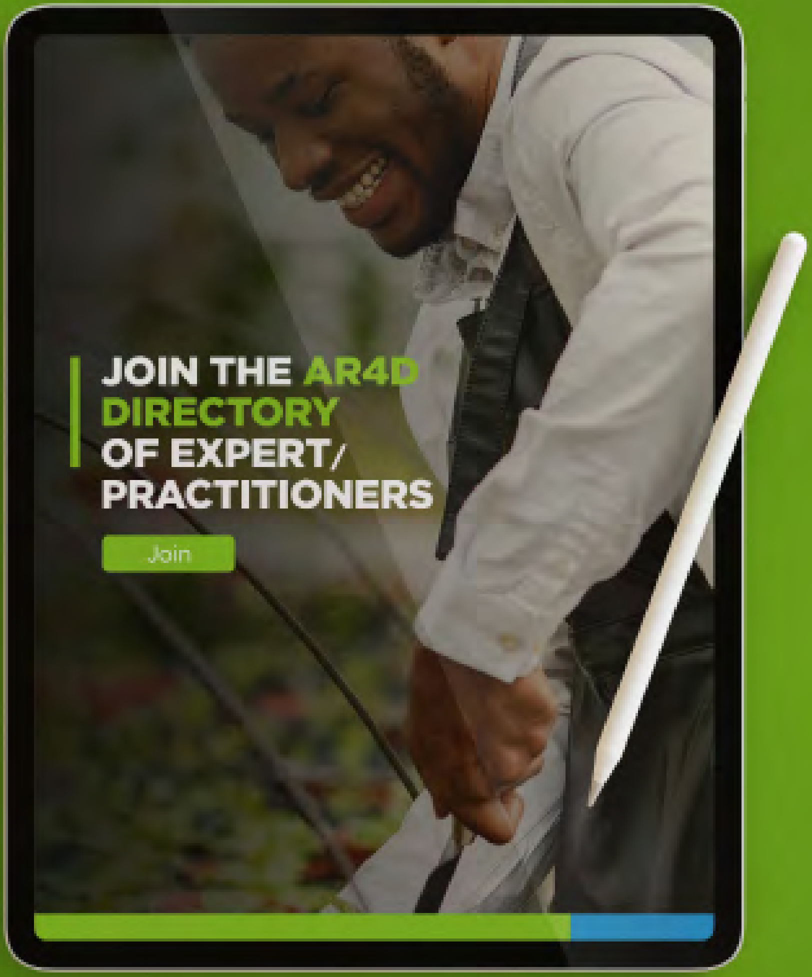

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