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Research Article

Yield and Yield Components of Frafra Potato (*Solenostemon rotundifolius* Poir.) as Affected by Organic Fertilizers

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Abstract

Soil fertilization greatly improves the production of root crops. However, its availability and high cost have become a major challenge. This experiment was conducted to determine growth and yield responses of FP to an integrated application of N fertilizer with cow dung for sustainable FP production. Field experiments were carried out on FP during the 2019 and 2020 cropping seasons at the Manga Agricultural Research Station, Manga, in the Upper East Region of Ghana. The experiment was a factorial design with two propagules, (stem cuttings and 'seed' tubers) and six fertilizers (cow dung (CD) and/or inorganic) giving 12 treatment combinations. Data recorded were plant count, days to 50% flowering (DFF), number of branches per plant, canopy spread, plant height, marketable tuber yield and non-marketable tuber yield. In both cropping seasons, the results showed that the interaction of fertilizer type with propagule was not significant ($p > 0.05$) in affecting the parameters studied. The main effects of fertilizer type and propagules showed significant differences ($p < 0.05$) in days to 50% flowering, branching, canopy spread, number of marketable tubers and tuber yield. Plants that were raised from stem cuttings that received combination of 187.5 kg/ha NPK+2.5 t/ha cow dung or 125.0 kg/ha NPK + 5 t/ha cowdung produced the highest tubers which were not significantly ($p > 0.05$) different from those that received sole inorganic fertilizers. These two treatments were therefore recommended to FP farmers as a viable alternative to the use of sole inorganic fertilizers which are not readily available due to their exorbitant prices.

Keywords: FP; Marketable Tubers; Stem Cuttings; Viable Alternative; "Seed" Tubers

Background

Frafra potato (*Solenostemon rotundifolius*) is a native plant to tropical Africa. It is exclusively a small holder crop which makes a versatile family fare. It serves as a good food security crop, which can be dried and stored for future use. Its tubers are high in calories and essential micronutrients with good socio-economic potential for food security [1]. The tubers provide indispensable dietary and energy requirements. The composition of the raw tubers per 100 g edible portion is: water 75.6 g, energy 394 kJ (94 kcal), protein 1.3 g, 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, ascorbic acid 1 mg [2]. Although formerly of considerable importance as a staple foodstuff in tropical Africa, production has extremely declined [3]. Even though FP has the potential to contribute to food and nutrition security, the crop is among neglected and underutilized species. Its production in Ghana is constrained by poor farming practices, poor soil fertility management, high cost of inorganic fertilizers among others. Little or no work has been done to determine the most appropriate combination of organic and inorganic fertilizers for optimum FP yield. [4] reported that variation in the rate of applica-

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tion of organic manure and inorganic fertilizers could influence the yield of potato. Organic manures and composts have also been found to have a direct anti disease effect by stimulating competing micro-organisms and also by inducing resistance to plant diseases [5]. Several studies have shown that N fertilizer applications can increase dry matter content, protein content of potato tubers, total and/or marketable tuber yield [6]. Nitrogen fertilization has also been reported to increase the average fresh tuber, plant height, leaf number and tuber weight per plant [7].

Several FP farmers have realized the need for soil fertilization in the production of the crop. They, however, often cite high cost and non-availability of inorganic fertilizers as reasons for not applying the recommended dosages. In the smallholder system of Tropical Africa, cheaper, readily available organic sources such as cowdung and chicken manure for fertilizing FP are abundant. Sometimes, livestock and poultry farmers even have to burn these manures as a disposal strategy causing environmental hazards. Identification and selection of appropriate combination rates of inorganic and organic fertilizers will increase the production levels of FP in the production communities.

In Ghana, only sprouted tubers are planted with the growing end placed above the soil surface, but not covered by soil. Sprouting is delayed by the burying of tubers. According to [2], cuttings, planted in pairs facing opposite directions are also used in FP propagation. The cuttings are placed at a depth of 5 cm, but with the growing point clearly above the soil surface. Stem cuttings collected from the nursery require a spacing of 30 cm x 15 cm (Peter 2007). The tubers are usually planted in mounds or in raised beds separated by ditches to allow water to drain off in heavy rains. The foliage crowds out other plants, so weeding is usually not required. The tubers are harvested about four to five months after planting, after the plants have flowered and the aerial parts have died back. Average yields of 5-15 MT/ha have been reported from the crop in Ghana and Nigeria. According to [8], the potential yield of the crop could be up to 18-20 MT/ha. However, a study in South Africa showed that under optimum conditions of rains, soil fertility and texture, potential yield of 45 MT/ha can be achieved from the crop [2]. Nonetheless, lack of healthy planting materials, rapid tuber deterioration in storage, declining soil fertility, and pests and diseases have been the limiting factors to increasing the production of Frafra potato especially in Ghana [9]. This experiment is based on hypothesis that application of N fertilizer with cowdung will improve the growth and yield of FP. This study, therefore, explored appropriate combination of organic manure (cowdung) and inorganic fertilizers applied to 'seed' tubers and stem cutting for optimum FP production and productivity. The objective of the study was to determine growth and yield response of FP to an integrated application of N fertilizer with cowdung for sustainable FP production

Methodology

Experimental site

The study was conducted during the 2020 and 2021 cropping seasons at the Manga Station (11°01N, 0°16'W)) of CSIR, Manga which is within the Sudan Savannah of the Upper East Region (UER) 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 [10] 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.

Experimental treatments and design

In each year, the experiment was a factorial design with two propagules, (stem cuttings and 'seed' tubers) and six fertilizers (cow dung (CD) and / or inorganic) giving 12 treatment combinations (Table 1) as follows: T1= T1: (SC) (Control), T2: (SC+10 t/ha CD), T3: (SC+250 kg/ha NPK), T4: (SC+187.5 kg/haNPK+2.5 t/ha CD), T5: (SC+125.0kg/ha NPK + 5 t/ha CD), T6: (SC+62.5 kg/ha NPK + 7.5 t/ha CD), T7: (ST) (Control), T8: (ST +10 t/ha CD), T9: (ST +250 kg/ha NPK), T10: (ST +187.5 kg/ha NPK + 2.5 t/ha CD), T11: (ST +125.0 kg/ha NPK + 5 t/ha CD), T12: (ST +62.5 kg/ha NPK + 7.5 t/ha CD). The treatments were replicated three times in a Randomized Complete Block Design (RCBD). Each experimental plot was 3 m wide and 4m long giving a plot size of 12 m2. The distance between replications and plots was maintained at 1m and 50 cm, respectively. The spacing between rows was 0.75 m and between plants within a row 0.30 m.

Table 1: Fertilizer treatment combinations used during the 2019 and 2020 cropping seasons.

Treatments	Inorganic Fertilizer (NPK 15-15-15)	Cow dung (CD)
T1: (SC)	-	-
T2: (SC+10 t/ha CD)	-	10 t/ha
T3: (SC+250 kg/ha NPK)	250 kg/ha	
T4: (SC+187.5 kg/haNPK+2.5 t/ha CD)	187.5 kg/ha	2.5 t/ha
T5: (SC+125.0kg/ha NPK + 5 t/ha CD)	125.0 kg/ha	5 t/ha
T6: (SC+62.5 kg/ha NPK + 7.5 t/ha CD)	62.5 kg/ha	7.5 t/ha
T7: (ST)	-	-
T8: (ST +10 t/ha CD)	-	10 t/ha
T9: (ST +250 kg/ha NPK)	250 kg/ha	
T10: (ST +187.5 kg/ha NPK + 2.5 t/ha CD)	187.5 kg/ha	2.5 t/ha
T11: (ST +125.0 kg/ha NPK + 5 t/ha CD)	125.0 kg/ha	5 t/ha
T12: (ST +62.5 kg/ha NPK + 7.5 t/ha CD)	62.5 kg/ha	7.5 t/ha

SC: Stem Cutting, ST: Seed Tuber, CD: Cow Dung, NPK: Inorganic Fertilizer (NPK 15-15-15)

Note: Recommended rates: NPK (15:15:15) = 250 kg/ha; Cow dung = 10 t/ha.

Management practices

In March each year, to produce stem cuttings for propagation, healthy tubers were established in nurseries during the dry season under irrigation, early enough to produce enough stems (*Manga Moya* variety) for the propagation in the major cropping season (July-October). The FP variety, was obtained from Manga Station of Savanna Agricultural Research Institute (SARI). In July, the experimental field was prepared when the rains started falling. In the experimental field, the 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. The Cowdung (11% moisture) was 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, $1.0m^2$ 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 2020), 15 samples were randomly collected by using an auger and composited. Then, soil samples were also taken from each treatment at harvesting (in 2021). 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 [11] and [12]. Soil organic matter was determined by the wet combustion method [13]. Percentage total nitrogen was determined by the micro Kjeldahl-technique [11]. The available phosphorus was extracted by the Bray method and determined colorimetrically [14]. Potassium was determined by flame emission photometry [11]. The exchangeable cations calcium, magnesium, potassium and sodium were determined as recommended by [11] 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 [11].

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 [15]. Canopy spread (3MAP) was recorded as an average count of five hills per plot at flowering [6]. 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 [6].

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}) [6]. 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 (> 3.5g). They were further sorted into Marketable (> 2.5 g and good i.e., no cracks, rots etc), Non-marketable tubers (< 2.5 g and good i.e., no cracks, rots etc) and Non-marketable (Bad i.e. 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} [6]. 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 2.

Table 2: 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

The interaction of fertilizer type with propagule was not significant ($p > 0.05$) in affecting the parameters studied. In both cropping seasons, the main effects of fertilizer type and propagules showed significant differences ($p < 0.05$) in days to 50% flowering, branching, canopy spread, number of marketable tubers and tuber yield. Flowering occurred significantly earlier ($P < 0.05$) in plots with stem cuttings and for plants that received organic manure than the control plots (Figure 1). Days to 50% flowering occurred 62-64 days for stem cuttings while the seed tubers took 75-80 days to attain 50% flowering. Earlier flowering in the stem cutting was expected, because unlike the seed tubers, cuttings had the advantage of establishing earlier, taking advantage of the available soil moisture as they did not have to go through a germination process. Among the fertilizer treatments in 2020, flowering was significantly earlier in plants on treated plots than those on the non-treated plots (control). Early flowering in treated plants might be due to optimum P amounts that enhanced early crop development. This observation is in line with report by [16] that optimum P rates enhance early crop development. The observation is at variance with findings by [17,18] who reported that application of inorganic fertilizer and manure prolonged flowering and maturity of potato plants. In their view, the prolonged flowering could be associated with the supply of additional nutrients, that may promote the vegetative growth of the plants that in turn prolonged flowering and maturity of potato plants.

In both cropping seasons, the number of branches per plant were significantly higher ($p < 0.05$) for plants raised from stem cuttings and/or treated with combined use of organic and inorganic fertilizers than the control (Table 3). Plants raised from stem cuttings recorded higher branching than those raised from seed tu-

Figure 1: Effect of fertilizer rate on days to 50% flowering in 2019 (A) and 2020 (B).

bers. Among the plants that were raised from stem cuttings, the highest number of branches were observed in plants that received T3: (SC + 250 kg/ha NPK), T4: (SC + 187.5 kg/haNPK + 2.5 t/ha CD) and T5: (SC + 125.0kg/ha NPK + 5 t/ha CD). The number of branches recorded under these treatments (ranging from 118 branches under T5 in 2020 to 154.1 branches under T4 in 2019) were statistically similar across the treatments but significantly ($p < 0.05$) differed from those of other treatments.

The higher branching among plants that were raised from stem cuttings was expected. This is because unlike the seed tubers, cuttings had the advantage of establishing earlier, taking advantage of the available soil moisture as they did not have to go through a germination process. The higher branching among the plants that were treated with combined use of organic and inorganic fertilizers than the control could be due to adequate supply of nutrients, particularly nitrogen, phosphorus and potassium. These nutrients play major role in cell division, elongation and metabolic processes that enhanced development of branches. These nutrients have a role in vegetative growth and development in accelerating formation of more branches. In a similarly work on sweet potato, [19] observed that nitrogen and potassium were critical to sweet potato production. According to [20], increased branching resulting from fertilizer application could be attributed to nitrogen and other plant nutrients found in fertilizers, which are necessary for plant growth. The fertilizers from organic sources improves the availability of plant nutrients by improving soil pH [21-23]. Studies have also shown that organic fertilizers influence plant growth and production through improving chemical, physical, and biological properties of soils [21,24,25]. Results obtained in the present study are in agreement with those reported by [20,22,23].

Table 3: Effect of fertilizers and propagules on the number of branches per plant in the 2019 and 2020 cropping seasons.

Treatment	2019	2020
Stem cutting (SC)	**Branches**	**Branches**
T1: (SC)	100.1^{d}	98.9^{e}
T2: (SC + 10 t/ha CD)	121.8^{c}	138.0^{a}
T3: (SC + 250 kg/ha NPK)	147.3^{a}	151.4^{a}
T4: (SC + 187.5 kg/haNPK + 2.5 t/ha CD)	150.0^{a}	154.1^{a}
T5: (SC + 125.0kg/ha NPK + 5 t/ha CD)	149.9^{a}	118.0^{c}
T6: (SC + 62.5 kg/ha NPK + 7.5 t/ha CD)	129.0^{b}	119.0^{c}
Seed tubers (ST)		
T7: (ST)	79.3e	88.1^{e}
T8: (ST + 10 t/ha CD)	98.8^{c}	92.0^{c}
T9: (ST + 250 kg/ha NPK)	129.3^{b}	131.4^{b}
T10: (ST + 187.5 kg/ha NPK + 2.5 t/ha CD)	120.0^{b}	124.1^{b}
T11: (ST + 125.0 kg/ha NPK + 5 t/ha CD)	130.9^{b}	109.0^{d}
T12: (ST + 62.5 kg/ha NPK + 7.5 t/ha CD)	109.0^{d}	108.0^{d}
CV (5%)	10	13

Means in a column followed by the same letter (s) do not differ significantly at 5% level of significance using LSD.

Similar to the branching, canopy spread was significantly ($p < 0.05$) higher in plants that were raised from stem cuttings and/or treated with combined use of organic and inorganic fertilizers than the control (Table 4). Plants raised from stem cuttings recorded higher canopy spread than those raised from seed tubers. Among the plants that were raised from stem cuttings, the highest canopy spread was observed in plants that received T3: (SC+250 kg/ha NPK), T4: (SC+187.5 kg/haNPK+2.5 t/ha CD) and T5: (SC+125.0kg/ha NPK + 5 t/ha CD). The canopy spread recorded under these treatments (ranging from 34.9 cm^2 under T4 in 2020 to 44.5 cm^2 under T3 in 2019) were statistically similar across the treatments but significantly ($p < 0.05$) differed from those of other treatments. The higher canopy spread among plants that were raised from stem cuttings could be due to the high number of branches per plant observed among those plants raised from stem cuttings.

Table 4: Effect of fertilizers and propagule on the canopy spread in the 2019 and 2020 cropping seasons.

Treatment	2019	2020
Stem cutting (SC)	**Canopy spread (cm^2)**	**Canopy spread(cm^2)**
T1: (SC)	14.8^{d}	11.5^{d}
T2: (SC+10 t/ha CD)	25.2^{c}	21.9^{c}
T3: (SC+250 kg/ha NPK)	44.5^{a}	42.9^{a}
T4: (SC+187.5 kg/haNPK+2.5 t/ha CD)	38.1^{a}	34.9^{a}
T5: (SC+125.0kg/ha NPK + 5 t/ha CD)	42.1^{a}	39.8^{a}
T6: (SC+62.5 kg/ha NPK + 7.5 t/ha CD)	33.9^{b}	36.0^{b}
Seed tubers (ST)		
T7: (ST)	10.5^{d}	9.5^{d}
T8: (ST +10 t/ha CD)	20.1^{c}	21.2^{c}
T9: (ST +250 kg/ha NPK)	34.5^{b}	33.9^{b}
T10: (ST +187.5 kg/ha NPK + 2.5 t/ha CD)	32.9^{b}	35.6^{b}
T11: (ST +125.0 kg/ha NPK + 5 t/ha CD)	39.9^{a}	38.1^{a}
T12: (ST +62.5 kg/ha NPK + 7.5 t/ha CD)	31.0^{b}	30.9^{b}
CV (5%)	17	20

Means in a column followed by the same letter(s) do not differ significantly at 5% level of significance using LSD.

The effect of inorganic and organic fertilizer and its combined use significantly ($p < 0.05$) influenced the expression of canopy spread more than the control plot. The increased branching and canopy spread observed in the present study could obviously be due to the nutritional effects of nutrients found in organic and inorganic fertilizers. Thus, the higher canopy spread in the soil-amended plots might be due to the available nutrients supplied by the organic and inorganic fertilizers which in turn might be due to higher nutrient composition and capacity to increase availability of native soil nutrient through higher biological activity [26]. This observation is consistent with the findings of [27] who reported that potassium increased leaf expansion, particularly at early stages of growth and extended leaf area duration. [28] reported that increased supply of phosphorus resulted in increases in shoot dry weight due to photosynthetic products being transferred to the aerial parts.

Marketable tubers

The results of the marketable tubers as influenced by organic and inorganic fertilization showed that in both seasons, the soil-amended plots recorded significantly ($p \leq 0.05$) higher number of marketable tubers than the control plot (Table 5). Plants raised from stem cuttings yielded higher marketable tubers than those raised from seed tubers. Among the plants that were raised from stem cuttings, the marketable tubers observed in plants that received T3: (SC+250 kg/ha NPK), T4: (SC+187.5 kg/haNPK+2.5 t/ha CD) and T5: (SC+125.0kg/ha NPK + 5 t/ha CD) were significantly ($p\leq 0.05$) higher than those observed from other treatments. The marketable tubers recorded under these treatments (ranging from 3320 kg/ha under T4 in 2020 to 3770 under T3 in the same year) were statistically similar across the treatments but significantly ($p < 0.05$) differed from those of other treatments. The higher tuber yield among plants that were raised from stem cuttings could be due to the high number of branches and canopy spread per plant observed among those plants raised from stem cuttings. Type of propagule affected tuber size distribution and tuber yield in both seasons. Flowering was significantly earlier in stem cuttings and it is thus expected that root establishment, tuber initiation and bulking was earlier in stem cuttings than in seed tubers leading to higher tuber yield. The increased branching and canopy spread observed in the present study could obviously improve in tuber yield as increase in canopy spread affects the overall performance as the leaves which serve as the photosynthetic organ for nutrient capture. Increased canopy spread thus 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.

The effect of inorganic and organic fertilizers and their combined use could influence the expression of tuber yield due to the nutritional effects of nutrients found in organic and inorganic fertilizers. The higher tuber yield in the soil-amended plots might be due to the available nutrients supplied by the organic and inorganic fertilizers. Control plots recorded the least branches, canopy spread and tuber yield while those receiving combined use of organic and inorganic fertilizers produced the highest branches, canopy spread and tuber yield which were significantly ($p < 0.05$) higher than the control plots. The significant ($P < 0.05$) increase in canopy spread reflects possible utilization of nutrients which affects the overall photosynthetic performance. Increased canopy spread leads to a 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 an improved yield. [29] reported that, plants absorbed sufficient light and increased their photosynthetic efficiency as a result of increased leaf area. This explains why plots that received combined use of organic and inorganic fertilizers had higher crop performance. Inorganic fertilizer alone or in combination with cowpdung out-yielded the control plots in tuber yield probably due to the contribution of plant nutrients by the cowdung or the NPK fertilizers. [30] attests to this fact that a positive interaction exists between organic and inorganic inputs when applied simultaneously. Fertilizer inputs have added benefits in terms of improved crop yield, soil fertility status or both [31].

Application of organic manure and inorganic fertilizer as sole or in combination has the potential of increasing the yield of frafra potato tuber yield. According to [32], 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 [33]. This might be due to its higher nutrient composition and capacity to increase availability of native soil nutrient through higher biological activity. [26] has reported significant increase in marketable tubers with chicken manure application. Chicken manure in combination with inorganic N was equally reported to give significant marketable tuber yield [34] have reported of significant marketable tuber yield increase in sweetpotato with both chicken manure and inorganic N input. According to them, the yield pattern was similar to N sources and the highest yields were obtained at 100kg N/ha input.

Table 5: Effect of fertilizers and propagule on the marketable tuber yield in the 2019 and 2020 cropping seasons.

Treatment	2019	2020
Stem cutting (SC)	**Marketable tubers (kg/ha)**	**Marketable tubers (kg/ha)**
T1: (SC)	1210^{d}	1020^{d}
T2: (SC + 10 t/ha CD)	2201^{c}	2111^{c}
T3: (SC + 250 kg/ha NPK)	3540^{a}	3770^{a}
T4: (SC + 187.5 kg/haNPK + 2.5 t/ha CD)	3490^{a}	3320^{a}
T5: (SC + 125.0kg/ha NPK + 5 t/ha CD)	3480^{a}	3650^{a}
T6: (SC + 62.5 kg/ha NPK + 7.5 t/ha CD)	2866^{b}	2143^{c}
Seed tubers (ST)		
T7: (ST)	890^{e}	880^{e}
T8: (ST + 10 t/ha CD)	1201^{d}	1321^{d}
T9: (ST + 250 kg/ha NPK)	2940^{b}	2784^{b}
T10: (ST + 187.5 kg/ha NPK + 2.5 t/ha CD)	2790^{b}	2890^{b}
T11: (ST + 125.0 kg/ha NPK + 5 t/ha CD)	2880^{b}	2690^{b}
T12: (ST + 62.5 kg/ha NPK + 7.5 t/ha CD)	1266^{d}	1169^{d}
CV (5%)	20	17

Means in a column followed by the same letter(s) do not differ significantly at 5% level of significance using LSD.

Non-marketable (good) tubers as influenced by organic and inorganic fertilization showed that the soil-amended plots recorded significantly ($p \leq 0.05$) higher non-marketable (good) tubers than the control plot (Table 6). Plants raised from stem cuttings generally recorded higher non-marketable (good) tubers than those from seed tubers. Among the plants that were raised from stem cuttings, the non-marketable (good) tubers observed in T3: (SC+250 kg/ha NPK), T4: (SC+187.5 kg/haNPK+2.5 t/ha CD) and T5: (SC+125.0kg/ha NPK + 5 t/ha CD) were significantly higher than those recorded from other treatments in both seasons. The tubers recorded under these treatments (ranging from 420 kg/ha under T4 in 2019 to 431 under T3 in 2020) were statistically similar across the treatments but significantly ($p < 0.05$) differed from those of other treatments. 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 [35]. Similar to the marketable tubers, these non-marketable tubers were statistically similar across the treatments but differed significantly from those of other treatments.

Number of bad tubers was not significantly ($p > 0.05$) different among the propagules nor the fertilizer treatments. This might be due to adequate sanitation measures and manipulative interventions such as prevention and control of pest and disease incidence, recommended harvesting practice, and the like rather than mineral nutrition [35].

Table 6: Effect of fertilizers and propagule on the non-marketable tuber yield in the 2019 and 2020 cropping seasons.

Treatment	2019	2020
Stem cutting (SC)	**Non-marketable Tubers (kg/ha)**	**Non-marketable Tubers (kg/ha)**
T1: (SC)	130^{d}	129^{d}
T2: (SC+10 t/ha CD)	209^{c}	128^{d}
T3: (SC+250 kg/ha NPK)	410^{a}	431^{a}
T4: (SC+187.5 kg/haNPK+2.5 t/ha CD)	430^{a}	420^{a}
T5: (SC+125.0kg/ha NPK + 5 t/ha CD)	420^{a}	430^{a}
T6: (SC+62.5 kg/ha NPK + 7.5 t/ha CD)	250^{b}	266^{b}
Seed tubers (ST)		
T7: (ST)	110^{d}	109^{d}
T8: (ST +10 t/ha CD)	179^{c}	118^{d}
T9: (ST +250 kg/ha NPK)	319^{b}	310^{b}
T10: (ST +187.5 kg/ha NPK + 2.5 t/ha CD)	317^{b}	315^{b}
T11: (ST +125.0 kg/ha NPK + 5 t/ha CD)	320^{b}	310^{b}
T12: (ST +62.5 kg/ha NPK + 7.5 t/ha CD)	190^{d}	166^{c}
CV (5%)	14	25

Means in a column followed by the same letter(s) do not differ significantly at 5% level of significance using LSD.

Partial budget analysis

The economic analysis of the treatments was carried out using benefit-cost ratio (BCR) method. This involved the determination of variable costs, gross returns and net benefits for all treatments. In both seasons, the net benefits (NBs) were generally higher in plots with plants that were raised from stem cuttings and or plots that received application of inorganic fertilizer or in combination with organic manure than the control plots (Table 7). This could be a result of higher tuber yields. 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. Thus, the trend is consistent, with the highest yielding treatment recording the highest NB and BCR. There were no significant differences among plants that received T3: (SC+250 kg/ha NPK), T4: (SC+187.5 kg/haNPK+2.5 t/ha CD) and T5: (SC+125.0kg/ha NPK + 5 t/ha CD) in terms of yield parameters recorded. Their yields were significantly higher than those recoded by plants that received other treatments. T4: (SC+187.5 kg/haNPK+2.5 t/ha CD) and T5: (SC+125.0kg/ha NPK + 5 t/ha CD) are thus recommended for optimum FP production and productivity.

Table 7: 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
T1: (SC)	90.00	79.00	0.88	0.80
T2: (SC + 10 t/ha CD)	244.00	220.00	1.90	1.78
T3: (SC + 250 kg/ha NPK)	333.50	310.50	2.40	2.87
T4: (SC + 187.5 kg/haNPK + 2.5 t/ha CD)	320.90	327.80	2.54	2.78
T5: (SC + 125.0kg/ha NPK + 5 t/ha CD)	319.99	312.00	2.45	2.79
T6: (SC + 62.5 kg/ha NPK + 7.5 t/ha CD)	219.18	220.20	1.30	1.40
T7: (ST)	30.30	28.10	0.90	0.99
T8: (ST + 10 t/ha CD)	118.60	190.70	1.20	1.27
T9: (ST + 250 kg/ha NPK)	290.80	230.19	1.61	1.79
T10: (ST + 187.5 kg/ha NPK + 2.5 t/ha CD)	288.00	240.88	1.89	1.89
T11: (ST + 125.0 kg/ha NPK + 5 t/ha CD)	289.90	235.75	1.73	1.90
T12: (ST + 62.5 kg/ha NPK + 7.5 t/ha CD)	150.80	110.10	1.20	1.12

Conclusion

Generally, Stem cuttings in combination with organic and inorganic fertilizer is necessary for increased FP yield. stem cuttings and fertilizer-treated plots recorded higher tuber yield compared to the control. Plants that received T4: (SC+187.5 kg/haNPK+2.5 t/ha CD) and T5: (SC+125.0kg/ha NPK + 5 t/ha CD) recorded yield parameters that compared favourably with T3: (SC+250 kg/ha NPK). The combination of stem cuttings +187.5 kg/haNPK+2.5 t/ha cow dung or stem cuttings +125.0kg/ha NPK + 5 t/ha cow dung are therefore found to be the most appropriate for the cultivation of FP. Similarity in the performance of the sole inorganic and the combine use of organic and inorganic fertilizers suggests that the use of organic and inorganic fertilizer input combinations for soil fertility improvement in FP production is a better option than either organic or inorganic input applied as sole treatment. This is a viable alternative to the use of sole inorganic fertilizers which are not readily available due to their exorbitant prices. The trend on partial budget analysis was consistent in both seasons with the highest yielding treatments, T4: (SC+187.5 kg/haNPK+2.5 t/ha CD), T5: (SC+125.0kg/ha NPK + 5 t/ha CD) and T3: (SC+250 kg/ha NPK), recording the highest benefit-cost ratio and net benefit while the control (0 kg/ha) ranked last. FP farmers could therefore adopt T4: (SC+187.5 kg/haNPK+2.5 t/ha CD), T5: (SC+125.0kg/ha NPK + 5 t/ha CD) to reduce the cost of inorganic fertilizers required for sustainable FP production.

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