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Research Article

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Effects of Application of Farmyard Manure and Inorganic Phosphorus on Tuberous Root Yield and Yield Related Traits of Sweet Potato [*Ipomoea batatas* (L.) Lam] at Assosa, Western Ethiopia

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Abstract

Sweet potato is one the most important root crops produced in western Ethiopia. However, the yield is far below its genetic potential. Lack of recommendation on appropriate rates of fertilizers is one of the problems limiting yield. A study was conducted to determine the effect of application of farm yard manure and inorganic phosphorus on tuberous root yield and yield related traits of sweet potato at Assosa from July to December 2016. The treatment consisted of four levels of farm yard manure (0, 5, 10 and 15 t ha^{-1}) and four levels of P (0, 23, 46 and 69 kg P_2O_5 ha^{-1}). The experiment was laid out as a Randomized Complete Block Design in a factorial arrangement and replicated three times. Analysis of the results showed that the main effect of farm yard manure significantly ($P<0.05$) affected most of the traits studied. The interaction effects of the two also affected most of the growth as well as yield parameters considered. Application of combinations of 15 t ha^{-1} farm yard manure and the highest rate of P_2O_5 resulted in 39.3% faster in bud sprouting. The main effects of farm yard manure affects tuber diameter (20.63 cm), unmarketable tuber yield (1.3 t ha^{-1}), weight of tuber/plant (143 g), weight of marketable tuber/plant (140 g), dry matter content (27.04), specific gravity (1.12), length of tubers(15.68 cm). The highest vine length (139.67 cm), total tuber number per plant (8.0), total tuber yield (24.6 t ha^{-1}), marketable tuber yield (23.65 t ha^{-1}) was recorded at 15 t ha^{-1} farm yard manure+69 kg P_2O_5 ha^{-1} whereas the lowest vine length (45.3 cm), tuber number per plant (2.0), total tuber yield (5.52 t ha^{-1}), marketable tuber yield (3.61 t ha^{-1}) was recoreded at un amended control. The main effects of farm yard manure delayed maturity of the crop where the 15 t ha^{-1} farm yard manure showed delay by about 18 days. Moreover, tuber diameter, length of roots, and weight of tuberous roots exhibited improvement with increment in the amount of applied farm yard manure while none of these parameters were affected by the application of P_2O_5 fertilizer. From this study, the highest net benefit for tuber yield of sweet potato was recorded from the application of manure and P_2O_5 at the combination level of 15 t ha^{-1} farm yard manure+69 kg P_2O_5 ha^{-1} which was 57873 Birr ha^{-1}. Therefore, the doses of 15 t farm yard manure ha^{-1} and 69 kg P_2O_5 ha^{-1} could be integrated and applied for sweet potato crops in the study area. However, it warrants further testing to give conclusive recommendation.

Keywords: Integrated nutrient management; Net benefit; Potato production; Soil fertility

Introduction

Sweet potato (*Ipomoea batatas* (L.) Lam), a member of *Convolvulaceae* family, is a perennial crop usually grown as an annual and a starchy staple food crop in the tropical, sub-tropical and frost-free temperate climatic zones of the world [1]. It ranks fifth as the most important food crop after rice, wheat, maize and cassava in developing countries [2]. In sub Saharan Africa, sweet potato is the third most important root crop after cassava and yam. In this region of Africa, over 7 million tons (5% of global production) of sweet potato is produced annually [3].

The potential of sweet potato to guarantee food security is underestimated as its use is often limited to a substitute food in African countries. Sweet potato is valued for its roots which are boiled, fried, baked or roasted for humans or boiled and fed to livestock as a source of energy. The roots can also be processed into flour for bread making, starch for noodles as well as used as raw material for industrial starch and alcohol [4].

In Ethiopia, sweet potato has been cultivated for many years and is important in diet where population growth is highest, land holding is least and threat of large scale starvation is ever present [5]. The crop is one of the root and tuber crops grown in Ethiopia, and it is the third important root crop next to Enset and Potato [6]. The area covered and production of sweet potato in Ethiopia is increasing from time to time. However, its production is very limited to specific regions, like that of South Nation, Nationalities and Peoples, Oromia, and Amhara regions [7]. Over 95% of the crop is produced in the south west, eastern and southern parts of Ethiopia where it has remained for centuries as one of the major subsistence crops especially in the periods of drought with low production [8]. The national average yield of sweet potato was estimated to 45.65 t ha^{-1}, but the regional average yield of Benisangul Gumuz was 15.4 t ha^{-1} which had 30.25 t ha^{-1} yield gap with the national average yield which implies lower productivity of the crop of the region [9].

Sweet potato is widely accepted and consumed in Benishangul Gumuz regional state, but its production and supply does not match since it is not extensively cultivated. Even among the few growers, sweet potato production is low. The total area of land covered by sweet potato in the region was only 669 ha and the total production was 1032 t (15.4 t ha^{-1}) [9]. Thus, Benishangul Gumuz Regional State is among the least sweet potato producing regions in Ethiopia and local demand is only met by trade from neighbouring Oromia regional state.

The use of organic manure to supplement inorganic fertilizer use helps to reduce the high cost of soil mineral input. A number of studies carried out on organic and inorganic fertilizers combination in sweet potato have attested the positive effects on yield of the crop. In addition, the use of organic fertilizers as a supplement improves the physical properties of the soil [10]. In general, farmers in the study area do not use fertilizers in sweet potato production. Although there are ample amount of FYM in the area, farmers often do not use FYM for sweet potato production and do not know it's possible effect with inorganic fertilizer on the productivity of the crop. Currently, there is no research information on combined use of organic and inorganic fertilizer application pertaining to root yield and yield related traits of sweet potato in the study area. In view of this fact, a systematic investigation of the effect of using mineral fertilizers like Phosphorus and locally available, accessible and affordable FYM is felt to be of paramount importance for increasing the production of sweet potato in the study area. Therefore, to address the problem, study was conducted to assess the effects of FYM and phosphorus fertilizer on yield related traits and tuberous root yield of sweet potato; and to identify economically feasible rates of farm yard manure and phosphorus for sweet potato production in the study area.

Materials and Methods

Description of the study area

The experiment was conducted under rain fed condition at research farm of Assosa Agricultural Research Center (ASARC) during 2016 cropping year from July to December. Assosa Agricultural Research Center is 660 km away from Addis Ababa which is located at latitude of 10002'N and longitude of 34°34'E in western Ethiopia. The altitude of the site is 1553 m asl. Which is in mid altitude and total annual rainfall of the cropping season was 1072.7 mm. The rainy season extends from April to October and maximum rain is received in the months of June to August. It has a warm humid climate with mean maximum and minimum temperatures of 25°C and 16°C respectively. The soil of the site was characteristically reddish brown (Nitosol), which is slightly acidic with pH of 5.7 and texturally clay.

Treatments and experimental design

The treatments consist of 4 × 4 factorial combinations of phosphorus (0, 23, 46 and 69 kg P_2O_5 ha^{-1}) and FYM (0, 5, 10, 15 ha^{-1}). The treatments were arranged in a randomized complete block design (RCBD) with three replications, making a total of 48 experimental plots.

Experimental materials

A sweet potato variety Awassa 83, which was released by Awassa Agricultural Research Centre in 1997, was used for the experiment by collecting vine cuttings from ASARC. The cultivar was selected because of its adaptability, high yield potential, and diseases resistance in the study area. Triple super phosphate (TSP) containing 46% P2O5 was used as inorganic fertilizer sources and well decomposed farmyard manure (FYM) on dry weight basis was used as source of organic fertilizer. The FYM was purchased from farmers in the study area who were trained for the preparation of compost.

Soil and FYM sampling and analysis

In order to determine the physical and chemical properties of the soil, three representative soil samples were taken using auger from the depth of 0 to 30 cm for each block of the experimental site before planting and application of any type of fertilizer. The samples were mixed, after which about 1 kg of a single composite soil sample was prepared. The sample was taken to the ASARC soil testing laboratory and tested for total nitrogen, soil pH, organic carbon, available phosphorus, potassium, Cation Exchange Capacity (CEC) and texture analysis. Soil pH in water was measured potentiometrically using pH meter with combined glass electrode in a 1:2.5 soil to water supernatant suspension. Determination of FYM organic carbon was carried out by oxidizing the organic carbon under standard condition with potassium dichromate in sulphuric acid solution as described by Walkely and Black. Soil total nitrogen and FYM were determined by the Kjeldahl method using micro- Kjeldahl distillation unit and Kjeldahl digestion stand as described by Jackson [11]. Available soil phosphorus was extracted by the Bray II procedure and determined calorimetrically by spectrophotometer. Cation Exchange Capacity (CEC) of the soil was determined by 1 M ammonium acetate (NH4OAc) saturated sample at pH 7 where the standard paste was distilled to estimate the ammonium liberated by titration with acid. Particle size distribution was done by hydrometer method (differential settling within a water column) according to FAO.

Experimental procedures and field management

The experimental land was ploughed disked and harrowed and ridges were prepared manually with traditional hoes. The plot size was 3 m × 3 m. There were five rows in each plot each of which accommodates ten plants with 0.6 m and 0.3 m between rows and plants and distance of 0.8 m and 1.2 m between plots and blocks, respectively. There were 10 plants per row and 50 plants per plot. The net area of the plot was 5.4 m^2 (3 m × 1.8 m).

Uniform sweet potato apical vine cuttings of 30 cm length according to Geleta were taken and planted on July 15/2016 in the experimental plot by burying two thirds of their lengths in to the soil at 450 angles with the recommended spacing of 30 cm between plants and 60 cm between rows on ridges [12]. One vine cutting was planted in each hole of the ridge and replanting was done to substitute the dead vines after one week of planting.

Nitrogen fertilizer was applied uniformly according to recommendation by Ethiopian Institute of Agricultural Research (EIAR) which is 150 kg ha^{-1} in the form of Urea (46% N) [13]. It was applied in two splits ½ of the dose at time of planting and the other ½ of the dose at active vegetative growth stage. All of the TSP fertilizer was applied in band along the rows just before planting the vines and covered with a 5 cm thick soil. FYM was incorporated to their respective plots uniformly two weeks before planting. Hoeing of the experimental plot was done manually and the field was kept free of weeds during the growth period of the plants. Earthing-up was done not to expose the storage roots. Other agronomic practices were applied uniformly according to the recommendation for the crop. The crop was harvested on December 26/2016 when the colour of the leaves completely changed to yellowish.

Data collection and analysis

Data were collected on; days to bud sprouting, Days to physiological maturity, number of primary branches/plant, Vine length, number of roots/plant, marketable root number/plant, total tuber root yield, marketable root yield, average length of tuberous roots, shoot fresh weight, average root number per plant, average tuberous root diameter, average vine length, root dry matter content. All data were subjected to analysis of variance using SAS statistical software (SAS, 2000) version 9.2.

For treatments that were significant, mean separation was done using the Least Significant Difference (LSD) test at 5% probability level.

Results and Discussion

Some soil physico-chemical properties of the experimental site

The soil sample collected from the experimental field before planting was analyzed for some selected soil properties. The data on these soil properties were determined in a laboratory. It has slightly acidic soil reaction with a pH value of 5.7 for the surface of 0-30 cm depth.. Furthermore, the results obtained showed a total nitrogen content of 0.3%, which is medium according to the rating by Landon [14] who classified soils having total N of greater than 1.0% as very high, 0.5-1.0% high, 0.2-0.5% medium, 0.1-0.2% low and less than 0.1% as very low in total nitrogen content. Available phosphorus content of 5.2 ppm which is low according to the rating by Tekalign [15] who described soils with available P content of <10 ppm as low. Thus, soil of the experimental site is very low in available P content (Table 1). The Netherlands commissioned study by Ministry of Agriculture and Fisheries also classify soil with organic carbon contents (%) >3.50, 2.51-3.5, 1.26-2.50, 0.60-1.25 and <0.60 as very high, high, medium, low and very low, respectively. Therefore, the organic carbon content of the soil (1.63%) of the experimental site is medium. This shows that the soil needs additional external organic matter supply to nourish the plant. According to Landon, top soils having CEC greater than 40 Cmol (+)/kg are rated as very high and 25-40 Cmol (+)/kg as high, 15-25, 5-15 and <5 Cmol (+)/kg of soil are classified as medium, low and very low, respectively, in CEC. Thus, the soil of the study site with the CEC of 12.65 Cmol (+)/kg is rated as low. Similarly, the FYM sample applied to the experimental field before planting was analyzed for some selected chemical properties. The data on these chemical properties were determined in a laboratory. It had pH of 6.9 which is neutral. Accordingly, the results obtained were total nitrogen content of 0.479%, available phosphorus content of 38.72 ppm, exchangeable Potassium 0.89%, Organic carbon 2.29%, EC 0.385 mmhos/cm.

Months	T(°C)		RF(mm)	Rh (%)
	Min	Max		
May	15.4	28.4	123.98	68
June	15.4	26.3	160.7	66
July	14.9	24.6	160.67	75
August	24.5	14.8	265.13	67
September	15	25.6	183.2	76
October	14.5	26.6	160.73	74
November	13.2	28.8	18.3	76
Total	-	-	1072.7	502
Mean	16.13	25.04	-	71.7

Table 1: Meteorological data of Assosa Agricultural Research Centre for 6 years from May-November (2011-2016). Source: ASARC Metrology Station (2017) and personal calculation from collected raw data.

Days to bud sprouting

The main effects of phosphorus and FYM significantly (P<0.05) influenced days to bud sprouting of sweet potato Moreover, this trait was significantly influenced by the interaction effect of FYM and phosphorus (P<0.05). The fastest bud sprouting (8.7 days) was recorded at combination of 15 t ha^{-1} FYM and 69 kg P_2O_5 which was 39.3% faster than the control (0 t ha^{-1} FYM and 0 kg P_2O_5) which may be due to better water holding capacity of the applied FYM around root zone of the cuttings which enables initiation of roots and make the buds to sprout early. Days to budding was delayed at treatments with no fertilizer which indicated that application of FYM/compost is very important for root initiation and prolification which speeds up budding of plants (Tables 2 and 3). This result was in line with the findings of chen [16] who reported that stimulation of root growth (initiation and proliferation of root hair), increased root biomass, enhanced plant growth and development with the application of vermicompost/ farmyard manure, because of the presence of humic acids due to water retention around root area of sweet potato plants which helped the cuttings to bud earlier.

Sizes of soil particles (%)			Texture class	pH	OC (%)	TN (%)	AP (ppm) K (%)	CEC(cmol(+)kg^{-1}
Sand	Silt	Clay						
32.83	9.56	48.8	5.7	1.63	0.3	5.2	1.01	12.65

Table 2: Selected physico-chemical properties of the experimental soil before planting. Key: OC: organic carbon; TN: Total nitrogen; AP: Available Phosphorous; CEC: Cation Exchange Capacity.

pH	AP (ppm)	%K	EC mmhos/cm	%TN	%OC
6.9	38.72	0.89	0.385	0.479	2.29

Table 3: Chemical properties of farmyard manure after analysis. Key: OC: organic carbon; TN: Total nitrogen; AP: Available Phosphorous; EC: Electrical conductivity.

Number of primary branches per plant

The analysis of variance indicated that the number of primary branches per plant was not influenced significantly by the interaction effect of FYM and P. Similarly, the main effects of farmyard manure and phosphorus were not significant. The lack of significance response to the treatments may be due to the inherent genetic characteristics of the crop which stimulates vine number early in buds rather than the amount of fertilizer applied. This result is in line with the findings of Mukhtar [17] who reported no significant effect of using different rates of organic and inorganic fertilizer on vine length, number of leaves, number of branches per plant and total dry matter of sweet potato.

The findings of [18] also showed non-significant increase in stem number per plant of potato in response to fertilization. Similarly, Yen [19] observed that branching is cultivar dependent than applied fertilizer.

Vine length

The vine length was highly significantly ($P<0.01$) affected by the main effect of FYM and significantly by the main effect of phosphorus. Similarly, the interaction effect of FYM and phosphorus was highly significant ($P<0.01$). The highest vine length (139.67 cm) was obtained at combination of 15 t ha^{-1} FYM and 69 kg of P_2O_5 and it was statistically at par with 15 t ha^{-1} FYM and 0 P_2O_5 ha^{-1} while the lowest vine length (45.33 cm) was recorded at 0 t ha^{-1} FYM and 0 kg P_2O_5. With no FYM applied, vine length showed increase with applied P up to the rate of 46 kg P_2O_5 ha^{-1}. However, with further increase of P, vine length of the sweet potato plants reduced. This might indicate that sweet potato benefited little from P to increase its canopy compared to the benefit that it derived from farmyard manure [20].

In the presence of FYM, however, vine growth showed increasing trend with increasing rate of FYM. The increase in vine length in response to increased rate of FYM may be due to increased availability of water in the root zone of the plants under a soil moisture stress condition, which is quite common in rain-fed farming [21]. Farmyard manure combined with inorganic fertilizers play an important role in better penetrations and establishment of crop roots and the better roots help the plant to utilize water from deeper layers that may have enhanced vegetative growth through increasing cell division and elongation [22]. Similarly, many researchers have indicated that combined application of organic and inorganic amendments significantly increased the vegetative growth of plants [23].

Days to physiological maturity

The two main effects (FYM and P) highly significant ($P<0.01$) on days to maturity of sweet potato. Similarly, it was significantly affected by the interaction effect of the two fertilizers. The highest days to physiological maturity (164.67) was observed at the interaction of 15 t FYM ha^{-1} and 69 kg P_2O_5 ha^{-1}, but the lowest day (154.33) was observed at 0 t FYM ha^{-1} and 0 kg P_2O_5 ha^{-1}. Days to maturity decreased by 11% at the combined application of 15 t FYM ha^{-1}+0 kg P_2O_5 ha^{-1} compared to the control treatment. However, days to maturity obtained from the control was in statistically parity with the result obtained at 5 t FYM ha^{-1}+46 kg P_2O_5 ha^{-1} at combined 23 and 69 kg P_2O_5 ha^{-1} alone and combinations of 5 t FYM ha^{-1} with 69 kg P_2O_5 ha^{-1}.

The result indicated that increasing rate of FYM delayed time of maturity of sweet potato which may be attributed to the role that manure plays significant role in promoting vegetative growth before the start of tuberous root development as nitrogen promotes vegetative and lush growth thereby delaying plant maturity [18]. Fuchs [24] also reported that phosphorus fertilizers enhance the establishment of crops while those from mineralization of organic manure promoted and prolonged vegetative growth and yield when both fertilizers were combined.

Total tuber yield

Total tuber yield of sweet potato was significantly affected by the interaction of farmyard manure and phosphorus. The maximum tuber yield per hectare (24.6 t ha^{-1}) was recorded at 15 t FYM ha^{-1}+69 kg P_2O_5 ha^{-1} and the lowest yield (5.5 t ha^{-1}) was recorded at 0 t FYM ha^{-1}+0 kg P_2O_5 ha^{-1}. The large yield gap between the treatments may be due to the low fertility level of the experimental site which resulted lowest yield at control and at treatments which are treated with low level of FYM combined with phosphorus due to low level of the experimental site which made the yield not consistent but when it was amended with FYM in combination with P, the soil became productive and enabled to give better yield. The highest yield response with highest rates of combined application of P and FYM might be due to an initial fast release of nutrients to plants from the inorganic P, prior to the release of nutrients from the organic sources, thereby, solving the characteristic shortcoming of slow initial release of nutrients from sole organic manure application [25]. The inorganic phosphorus applied might have supplemented the low phosphorus in the applied FYM which increased the available P in the soil. This result agrees with the findings of Murwira [26] and Chung [27] where they have observed that the nutrient use efficiency of a crop increased through a combined application of organic manure and inorganic fertilizer. Furthermore, manure treatments could increase the water holding capacity of the soils which could have resulted in the increase of water and nutrient consumption of the plants which increased Hudson [28] and Amir [29] also stated that plants get nutrients throughout the growing period when there is integrated use of inorganic (immediately available) and organic (slow mineralisation) source of nutrients which leads to higher yield attributes and yield in sweet potato. Patel [30] also reported that farmyard manure improves the physico-chemical properties of the soil, however, unless it is integrated with inorganic fertilizers, the use of farmyard manure alone may not fully satisfy crop nutrient demand, especially in the year of application. Animal manures are also useful in improving the efficiency of nutrient recovery thereby resulting in higher crop yield [31]. According to the reports of Xiao

[32], soil treated with manure was found to be loose, which probably provided adequate aeration and moisture into the soil and improved soil microbial activities which resulted in higher growth and maximum root yield and above ground biomass of crops. Forbes [33] also indicated that when cow dung was fortified with NPK fertilizer and applied to sweet potato, there was higher nutrient uptake. The authors indicated that this consequently lead to resultant increase in crop yield and attributed this to increase in P, K and Ca uptake by sweet potato.

Marketable and unmarketable tuber yield

The main effects of FYM, P and the interaction of the two factors were significant (P<0.05) on the marketable yield. The combination of 15 t FYM ha^{-1}+69 kg P_2O_5 ha^{-1} produced the highest marketable root yield (23.65 t ha^{-1}) while the lowest yield (5.6 t ha^{-1}) was from 0 t ha^{-1} FYM+0 kg P_2O_5 ha^{-1}. The highest yield at the highest rates of both FYM and P may be due to the nutrient use efficiency of a crop increased through a combined application of organic manure and inorganic fertilizer as result of positive interaction and complementarities between them.

The yield difference between treatments was in line with the findings of Giller [34] who reported a positive interaction between organic and inorganic inputs when applied simultaneously. Hartemink [35] stated that poultry manure in combination with inorganic fertilizer significantly improved marketable root yield in sweet potato. Saikia [36] also stated that cow dung adds bulks of plant nutrient in the soil and increase availability of nutrients and production of growth hormones that might result in a higher nutrient uptake by the crops and increased bulking of tubers. According to Cheng-Wei [37] nutrient use efficiency of a crop increases through a combined application of organic manure and inorganic fertilizers which increases yield. Sidhu [38] also stated that Fertilizer (Organic and inorganic) inputs have added benefits in terms of improved crop yield, soil fertility status or both and lower cost of production.

The analysed result indicated that the main effect of FYM significant on unmarketable tuber yield. As the rate of FYM increased from 0 t ha^{-1} to 15 t ha^{-1}, unmarketable tuberous root was increased from 0.58 t ha^{-1} to 1.3 t ha^{-1}. The result indicated that as the yield of sweet potato increased due to increasing level of FYM, the amount of unmarketable tuber yield also increased.

This may be due to nutrient addition by applied FYM which enriched the soil for the uptake of macro and micro nutrients which are important for increasing tuber yield. Sidhu [38] reported 29% yield increase (marketable and unmarketable tuber) due to supplementing 50 t FYM ha^{-1} in potato over FYM untreated control. The increase in unmarketable was due to insect pest like beetle which made the tubers shapeless and considered as unacceptable in the market which should be controlled by integrated pest management system.

The result indicated that the sweet potato benefited from FYM in total tuber root yield which also had proportionally high unmarketable roots due to tuber bulking size. Sharma [39] also showed that on the effect of 5 tons of FYM with different phosphorus treatments on potato and reported that the application of FYM increased the potato tuber yield including unmarketable tubers. Hameda [40] evaluating P doses from 0 to 45 kg ha^{-1}, found an increase in total (marketable and unmarketable tuber yield) and commercial yield of sweet potato of 8% and 20% when 15 kg and 45 kg P_2O_5 ha^{-1} were applied, respectively, compared to that obtained without applying Phosphorus.

Tuberous root diameter

The analysis of variance for tuberous root diameter showed that the main effect due to farmyard manure was significant (P<0.05) on tuberous root diameter. But the main effect of P and the interaction effect of FYM and P were not significant on the root diameter of sweet potato. The highest tuber diameter (20.63 cm) was recorded at 15 t FYM ha^{-1} and the lowest diameter (12.73 cm) was observed at unamended plots. Generally, as the rates of FYM increased, the tuberous root diameter was increased which may be due to the fact that FYM improved the fertility of the soil through decomposition by soil microbes making nutrients available for sweet potato uptake which enhances vegetative growth and partitioning of assimilate in storage roots. In agreement with this result, Gezahegn [41] also indicated that FYM at 5 t ha^{-1} produced maximum tuberous root diameter, fresh root yield, and marketable root yield of potato. Similarly, Mujtaba [42] indicated that application of vermicompost led to increase in tuber diameter of sweet potato. For crops that are cultivated for their root and tubers like sweet potato farm yard manure creates the reduction of soil bulk density so that the roots freely extend to scavenge available nutrient and moisture so that it increased its diameter (girth) and length [43].

Tuber dry matter content

Analysis of variance revealed that the main effect of FYM and Phosphorus showed significant difference on tuber dry matter content of sweet potatoes at P<0.05 level of significance.

The highest percent dry matter response was recorded at the two main effects of FYM and P_2O_5 ha^{-1} which was (27.02) and (26.2) and the least dry matter content 22.58 and 23.42 was recorded at 0 t ha^{-1} FYM and 0 kg P_2O_5 ha^{-1} respectively. The highest dry matter percent at the highest rates of FYM might be due to that Potato shoot dry matter increased by compost application, due to improved soil structure and aeration, and thereby tubers increased in the better soil bed. Soil resistance against to tubers growth was reduced by compost [44]. Emin [45] reported that the application of farmyard manure significantly increased the dry matter of tuber. Rembialkowska [46] reported that potatoes produced with FYM are healthier and have increased dry matter content than potatoes produced using conventional methods. Isiaka [47] indicated that. application of phosphorus lead to trapping enough solar energy for higher food production which will finally be translocated to the roots for appreciable tuber development, better root dry matter and bulking which is the ultimate target of crop production.

Specific gravity of tubers

The analysis of variance showed that the main effects of FYM and phosphorus were highly significant (P<0.01), but, the interaction effects of FYM and phosphorus was not significant. The highest specific gravity (1.12) was recorded at 15 t ha^{-1} of FYM and the lowest (0.65) recorded at control. The result indicated that, the specific gravity of sweet potato roots was increased with increased rate of FYM [48].

Increasing rate of application of FYM did not bring negative effect on specific gravity of sweet potato. The result indicated that sweet potato has good response to FYM. This result is in line with the findings of Nyathi [49] who found that application of cattle with chicken manures increased specific gravity of sweet potato. Similarly, Teshome [18] revealed the importance of farmyard manure than P_2O_5 to produce sweet potato with high specific gravity as specific gravity is a good indicator of sweet potato tuberous root quality for industrial purposes.

Harvest index

Similar to other parameters, analysis of variance showed that the main effects of FYM has affected harvest index of sweet potato at P<0,05 level of significance while effect of Phosphorus was not significant. The highest harvest index (0.43) was obtained at 15 t ha-1 FYM whereas the lowest (0.26) was recorded at 5 t ha-1 FYM. The result showed that at higher level of FYM application, harvest index was increased by 38.5% over the control. The highest harvest index at the highest rate of FYM may be suggested as manures like FYM are good enhancer of soil fertility by adding essential nutrients in available form for plant uptake for better vegetative growth and the result agrees with the findings of Nyathi [49] who stated that applying manure increased the uptake of N, P, K, Ca, and Mg by plants, indicating that organic fertilizers are good enhancer of soil fertility. Besides furnishing plant nutrients, FYM provides decomposable organic matter and hence increases soil aggregation, which in turn improves physico-chemical condition of the soil like water holding capacity of light soil creates conducive environment for better root development in the tilth of heavy soil and improve soil fertility for increased yields [50].

Partial budget analysis of FYM and phosphorus application

The highest tuber yield (23.65 t ha^{-1}) was recorded at 15 t FYM ha^{-1}+69 kg P_2O_5 ha^{-1}. Similarly, the adjusted tuber yield (23.65 t ha^{-1}) according to CIMMYT (1988) was high when 15 t FYM ha^{-1}+69 P_2O_5 kg ha^{-1} was applied. The partial budget analysis indicated that the highest net benefit of 57873 Birr ha^{-1} was recorded at 15 t FYM ha^{-1}+69 kg P_2O_5 ha^{-1}. From the above results, it was apparent that the treatment with 15 t FYM ha^{-1}+69 kg P_2O_5 ha^{-1} was more profitable than other treatment combinations [51].

Marginal rate of tuber analysis was performed on non-dominated treatments to identify treatments with the optimum return to the farmers' investment. In order to consider a treatment as worthwhile option to farmers, 100% marginal rate of return (MRR) is minimum acceptable rate of return. MRR at 15 t FYM ha^{-1} + 69 kg P_2O_5 ha^{-1} gave a value that was higher (3448%) indicating that 15 t FYM ha^{-1}+69 kg P_2O_5 ha^{-1} used in this study was the economic optimum rate for the crop.

Therefore, application of 15 t FYM ha^{-1}+69 kg P_2O_5 ha^{-1} remains profitable and can be recommended for farmers in Assosa district and other areas with similar agro ecological condition

Summary and Conclusion

The major constraints of sweet potato production in Benishangul Gumuz include erratic rainfall, poor agronomic practices, low soil fertility and low use of inputs such as poor planting materials, poor diseases and pest management practices. The low soil fertility resulted in low sweet potato yield since the farmers do not use the inorganic and organic fertilizer. Besides, farmers in the study area have no awareness of using farm yard manure in combination with inorganic fertilizer and the 40 appropriate rate. In view of this, an experiment was conducted during the 2016 cropping season in Assosa Western Ethiopia. The objective of the study was to assess the effects of FYM and phosphorus fertilizer on yield related traits and tuberous root yield of sweet potato and to identify economically feasible rates of FYM and phosphorus for sweet potato production in the study area. The experiment was laid out in randomized complete block design in factorial arrangement with four rates of FYM (0,5,10 and 15 t ha^{-1}), and four rates of P_2O_5 (0,23,46 and 69 kg P_2O_5 ha^{-1}) in three replications. The result of the experiment indicated that the main effect of FYM significantly (P<0.05) affected number of branches per plant, tuber diameter, unmarketable tuber yield, weight of tuber per plant, weight of marketable tuber per plant and unmarketable tuber number per plant, average tuberous root length, harvest index, and specific gravity. But the main effect of P was non-significant (P<0.05) on all parameters except average specific gravity and dry matter content. The highest mean tuber diameter (20.63 cm), unmarketable tuber yield (1.3 t ha^{-1}), and weight of marketable tuber yield/plant (140g) were recorded at 15 t FYM ha^{-1} and the lowest tuber diameter (12.73 cm), unmarketable tuber yield (0.584), weight of marketable tuber yield/plant (56 g) were recorded at 0 t FYM. In the same manner the significant weight of tuber /plant (143 g), harvest index (0.43), root length (15.68 cm), specific gravity (1.12) were obtained at 15t FYM ha^{-1} whereas the lowest weight of tuber /plant (83g), weight of marketable tuber /plant (56 g), root length (11.7 cm), specific gravity (0,65) were obtained at 0 t FYM ha^{-1}. On the other hand, the interaction effects of FYM and P significantly (P<0.05) influenced days to bud sprouting, tuberous root dry matter, average vine length, days to maturity, total tuber yield, tuber number per plant and marketable tuberous root yield.

The combination of 15 t FYM ha^{-1} and 69 kg P_2O_5 ha^{-1} gave the highest total tuber yield (24.6 t ha^{-1}) and the highest average vine length (136.7 cm) the highest marketable tuber yield (23.65 t ha^{-1}) Days to maturity (164.7), Days to budding (8.7) dry matter content (27.04) and the lowest total tuber yield (5.53) the lowest vine length (45.33 cm) the lowest marketable tuber yield (3.6t ha^{-1}) and lowest dry matter (22.58) was observed at control.

Though most of the sweet potato growth parameters showed good response to farm yard manure, promising yield was observed when farm yard manure was combined with inorganic fertilizers. Thus, unless it is integrated with inorganic fertilizers, the use of farmyard manure alone may not fully satisfy crop nutrient demand especially in the year of application. The highest net benefit (57873 Birr ha^{-1}) for tuber yield of sweet potato was recorded from the application of (15 t FYM ha^{-1})+69 kg P_2O_5 ha^{-1}). Therefore, as a recommendation, cash incomes of small holder sweet potato farmers of the study areas could be significantly enhanced if doses of 15 t FYM ha^{-1} and 69 kg P_2O_5 ha^{-1} are integrated and applied to sweet potato crops. Moreover farmers in the study areas should be encouraged to use integrated nutrient management system rather than inorganic fertilizer alone since such system helps not only supply nutrients but also improves physicochemical properties of the soil, thereby significantly enhances yield and quality of crops. However, as this experiment was done for one season at one location, it is important to repeat the experiment on more locations and seasons with consideration of the long term effect of FYM on the soil as well.

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