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To cite this article: D. K. Akosah, S. Adjei-Nsiah & F. C. Brentu (2021) Response of Late Valencia Sweet Orange (*Citrus Sinensis* (L.) Osbeck) to Fertilization on Acrisols of the Semi-Deciduous Forest Agro-Ecological Zone of Ghana, Communications in Soil Science and Plant Analysis, 52:11, 1275-1285, DOI: [10.1080/00103624.2021.1879125](https://doi.org/10.1080/00103624.2021.1879125)

To link to this article: <https://doi.org/10.1080/00103624.2021.1879125>



Published online: 19 Feb 2021.



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Response of Late Valencia Sweet Orange (*Citrus Sinensis* (L.) Osbeck) to Fertilization on Acrisols of the Semi-Deciduous Forest Agro-Ecological Zone of Ghana

D. K. Akosah^a, S. Adjei-Nsiah^b, and F. C. Brentu^b

^aCrop Science Department, School of Agriculture, University of Ghana, Accra, Ghana; ^bForest and Horticultural Crops Research Centre, School of Agriculture, University of Ghana, Accra, Ghana

ABSTRACT

We conducted a study to determine the response of Late Valencia sweet orange to organic and inorganic fertilizer application for two seasons in the semi-deciduous forest agro-ecological zone of Ghana. The experiment which was conducted in a randomized complete block design with four replications consisted of six treatments: (1) 9 t/ha oil palm empty fruit bunches (EFB); (2) 4 t/ha poultry manure (PM); (3) NPKZn (90 kg/ha N, 60 kg/ha P, 80 kg/ha K and 4.8 kg/ha Zn); (4) 0.5 EFB (4.5 t/ha) + 0.5 NPKZn (45 kg/ha N, 30 kg/ha P, 40 kg/ha K and 2.40 kg/ha Zn); (5) 0.5 PM (2 t/ha) + 0.5 NPKZn (45 kg/ha N, 30 kg/ha P, 40 kg/ha K and 2.40 kg/ha Zn) and (6) Control. In the 2019 harvest season, the treatment PM+NPKZn recorded the highest yield of 14.7 t/ha while the control recorded the least yield (6.4 t/ha). In the 2020 harvest season, fruit yield ranged from 17.3 t/ha with the NPKZn treated plots to 28.8 t/ha with the EFB treated plots. Economic analysis showed that for the five fertilizer application treatments, the highest benefit/cost ratio was attained with the EFB treatment for the two harvesting seasons combined. Fertilization did not significantly affect leaf nutrient content 253 days after application. However, leaf nitrogen (N) and potassium (K) contents were generally higher 253 days after fertilizer application than the initial levels while phosphorus (P) level did not change. The study suggests the need for farmers to adopt the use of organic wastes as a soil fertility management practice for citrus while at the same time ensuring timely control of diseases to reduce fruit drop and improve fruit yield.

ARTICLE HISTORY

Received 9 October 2020
Accepted 12 January 2021

KEYWORDS

Economic analysis; empty fruit bunches; inorganic fertilizer; integrated soil fertility management; organic fertilizer; poultry manure

Introduction

Citrus is an important tropical and sub-tropical fruit crop. Sweet orange (*Citrus sinensis* (L.) Osbeck) production accounts for over 50% of the world citrus production with annual consumption growing at a rate of 3.5% over the past thirty years (Sawe 2017). Food and Agricultural Organization (FAO) estimate for world total area under cultivation of orange in 2017 was about 3.8 million ha (FAO 2018). The world's total production of orange fruits during the same period was about 73 million metric tons with about 1.3 million tons originating from western Africa. In western Africa, orange forms a major component of the predominantly tree-crop based farming system in the semi-deciduous forest agro-ecological zone. Ghana produces about 53% of the 1.3 million tons of orange fruits produced in western Africa.

In Ghana, orange is grown mostly by smallholders in the forest regions mainly in the Eastern, Ashanti, and Central regions where annual rainfall amount exceeds 1000 mm and is distributed in a bimodal fashion (Ofosu-Budu et al. 2007). Sweet orange is an important source of income for over

20,000 farmer members of the Citrus Growers and Marketing Association of Ghana (CIGMAG). Therefore, although not a food security crop, citrus serves as a major source of income for small-scale farmers and is particularly important for women who market the fruit throughout the country (Ofosu-Budu et al. 2007). About 17,604 ha of land was under cultivation in 2017 in Ghana with Late Valencia being the most widely grown sweet orange variety (FAO 2018).

Despite its importance, the citrus industry in Ghana currently has been plagued with some production constraints which has caused it to plummet along with its economic importance to communities that produce the crop and to the country at large. Notable among the production constraints are pests particularly fruit flies and diseases notably citrus black spot (CBS; *Guignardia citricarpa*) and angular leaf spot (*Pseudocercospora angolensis*), limited access to market and low yield (Asare-Bediako et al. 2013), caused by declining soil fertility.

The decline in soil fertility is caused by continuous cultivation without soil replenishment; yields continue to decline on smallholder farmers' fields leading to loss of profit and income (Yeboah et al. 2009). Adoption of organic and inorganic soil fertility management approaches in the context of integrated soil fertility management (Vanlauwe et al. 2015) is considered as the most viable way of addressing the challenge of soil degradation in sub-Saharan Africa (Agyekum 2016). The effective integration of organic manure into soil fertility management can help improve the fertility of the soil at a very low cost (Bayu 2020). Thus, the combination of mineral and organic fertilizer can help improve the yield of oranges (Amankwa 2005). Previous studies on nutrient management in citrus orchards in Ghana have focused either on inorganic fertilizers alone (Ofosu-Budu 1998; Opoku 1971) or organic manure alone (Ofosu-Budu 2003, 2014) with little or no work on the integration of organic and inorganic fertilization. However, studies elsewhere (Quaggio et al. 2006; Ibe, Lawal, and Olaniyan 2011; Srivastava and Singh 2009) have demonstrated that the application of inorganic fertilizers in combination with organic manures has proved superior over conventional inorganic fertilization. Integrated soil fertility management is however an avenue that has not been explored extensively and intensively to improve the productivity of citrus in Ghana. This study was therefore conducted to evaluate the effect of different integrated soil fertility management options on fruit yield and leaf nutrient content to guide smallholder farmers toward a profitable adoption of appropriately integrated soil fertility management options for orange production.

Materials and methods

Study site

The study was carried out at the Forest and Horticultural Crops Research Center (FOHCREC), Okumaning near Kade on a 13-year-old Late Valencia (Late Valencia budded onto Rough lemon rootstock) orchard measuring 1.3 ha. FOHCREC lies within latitude 6° 09' and 6° 06' N and longitude 0° 55' and 0° 49' W in the Demkyembour district of the Eastern Region of Ghana. The Center which is in the semi-deciduous forest agro-ecological zone of Ghana is 135.9 m above sea level. The study site is characterized by a bimodal rainfall pattern with peaks in June and October with a short break in August and a dry season from December to March. The total annual rainfall amount during the experimental period was 1980 mm and 1766 mm for 2018 and 2019 respectively. The soils at the experimental site which are mainly forest oxisol derived from precambrium phyllitic rocks are deep and well-drained and are generally classified as Acrisols in the FAO UNESCO Revised Legend (FAO 1998). The chemical and physical properties of the surface soil of the experimental field are presented in Table 1.

Experimental design and treatments

The experiment was conducted in a randomized complete block design (RCBD) with four replications. Each block measured 144 m by 30 m with a total of 95 trees; each block was separated by 6 m alley. The

Table 1. Initial chemical and physical properties of soil of the experimental site.

Soil depths	pH 1:2.5	O.C (%)	Total N (%)	Ca Mg K Na Exchangeable cations cmol/kg				P ppm	Sand (%)	Silt (%)	Clay (%)
				Ca	Mg	K	Na				
0–30 cm	5.24	1.70	0.17	3.20	1.70	0.33	0.29	22.48	52.00	36.00	12.00
30–60 cm	5.15	0.85	0.11	2.13	0.96	0.34	0.27	19.29	54.00	28.00	18.00

Table 2. Chemical properties of the PM and EFB used in the experiment.

Fertilizer	% C	% Mg	% N	% P	%K	C:N
PM	6.88	1.62	2.49	1.47	0.08	2.76
EFB	35.0	0.21	0.98	0.12	0.10	35.7

experiment consisted of six treatments: (1) 9 t/ha oil palm empty fruit bunches (EFB); (2) 4 t/ha poultry manure (PM); (3) NPKZn, inorganic fertilizer (N, P, K and Zn) applied at the rate of 90 kg/ha N, 60 kg/ha P, 80 kg/ha K and 4.8 kg/ha Zn (4) 0.5 EFB (4.5 t/ha) plus 0.5 NPKZn (45 kg/ha N, 30 kg/ha P, 40 kg/ha K and 2.4 kg/ha Zn); (5) 0.5 PM (2 t/ha) plus 0.5 NPKZn (45 kg/ha N, 30 kg/ha P, 40 kg/ha K and 2.40 kg/ha Zn); (6) Control. Each treatment consisted of six experimental plants spaced 6 m apart with 6 m between treatments. The poultry manure had 2.48% N, 1.47% P and 0.08% K while the EFB had 0.98% N, 0.12% P and 0.10% K (Table 2).

The inorganic fertilizers were applied in furrows made in a form of a ring around the base of the trees about 100 cm away from the main trunk. The organic fertilizers were applied in a form of a ring spread around the base of the plant about 100 cm away from the main trunk. The organic fertilizers were applied in June 2018. Potassium (in the form of potassium chloride), phosphorus (in the form of triple super phosphate), and Zinc (in the form of Zinc sulfate) were applied in June 2018 while nitrogen (in the form of ammonium sulfate) was split applied in June and September 2018.

Soil and plant analysis

Before the fertilizer application, soil samples were taken from 0–30 cm and 30–60 cm depths and analyzed for physical and chemical properties. Soils were analyzed for pH (H₂O, 1:2.5 soil to H₂O ratio), organic C (Walkley-Black), total N (Kjeldahl), P (Bray-1), and exchangeable K, Ca, and Mg (Ammonium acetate-extractable method).

Leaf samples were taken just before fertilizer application from twenty trees randomly selected from the field; about 8–10 leaves per tree were taken from non-fruiting twigs at the same height of the trees. The leaves taken were 5–7 months old. Leaf samples were also taken 253 days after treatment application from 5–6 months old non-fruiting twigs. Leaf samples were oven-dried at 70°C for 48 hrs and taken to the laboratory for foliar analysis. P was determined by molybdenum blue calorimetric method and N by micro-Kjeldahl method. Potassium was determined using flame photometry while Mg and Ca were determined using the Atomic Absorption Spectrometer (AAS) (IITA 1981).

Cultural practices

Weeding was done on the field as and when necessary. In 2018, weed control was initially done manually by brushing with a cutlass and later with the use of glyphosate and 2, 4-dichlorophenoxyacetic acid. 150 ml of glyphosate and 75 ml of 2, 4-dichlorophenoxyacetic acid were mixed in 15 L of water in a knapsack sprayer and was sprayed on the field.

In 2018, Citrus black spot (*Guignardia citricarpa*) and angular leaf spot (*Pseudocercospora angolensis*) diseases were controlled with the application of fungicides carbendazim (40 mls) plus

Mancozeb (30 g) per 12 liters of water at 4 weekly intervals from the middle of August 2018 until end of December 2018 using mistblowers. In 2019, the field was sprayed against the diseases after petal fall in May 2019 to prevent infection using carbendazim (40 mls) plus Mancozeb (30 g) per 12 liters of water. The application was repeated 2 weeks later after the fruits had formed. In the first week of November 2018 and November 2019, the field was sprayed against fruit flies, termites, and other insects using chlorpyrifos at 75 ml per 12 liters of water. This was followed by the cutting of mistletoes (*Tapinanthus bangwensis*), a plant-parasitic weed normally found on tree crops.

Economic analysis

An economic analysis was performed on the profitability of the use of different fertilizer treatments. The Cost of fertilizer was determined using prices of the different fertilizer treatments and labor costs for fertilizer application were based on the existing labor rates in the study area. The price for the citrus fruits is the market price for February-April 2019 for the 2019 harvesting season and the market price for December 2019-January 2020 for the 2020 harvesting season. All amounts are expressed in US dollars (USD, \$) at the average exchange rate of February-April 2019 (5.4 GHC = 1.00 USD) (Bank Of Ghana 2019). The economic analysis was performed using a Microsoft Excel spreadsheet (version. 2016).

The benefit/cost ratio (BCR) was calculated as shown in Equation (1) (Ross, Westerfield, and Jordan 2001)

Revenue from applying a fertilizer treatment
Cost of fertilizer treatment applied/ha

$$BCR = \frac{B_p}{C_p} \quad (1)$$

B_p = Revenue from applying a fertilizer treatment

C_p = Cost of fertilizer treatment applied per hectare

Sensitivity analysis was conducted to determine the effects of price shock on citrus production in the study area. The sensitivity analysis is based on the premise that within the last five years citrus price has fluctuated between USD 46.30 and USD 69.44 per metric ton while the cost of fertilizer use has increased by about 10%.

Statistical analysis

Data collected on yield and leaf analysis were subjected to analysis of variance (ANOVA) using Genstat statistic software (version 12.0). The standard analysis procedure for a randomized complete block design (RCBD) was followed. The least significant difference (LSD) test at a 5% probability level was used to compare the treatment means.

Results

Effect of fertilization on fruit yield

The results of the effect of fertilizer application on fruit yield of Late Valencia are presented in Table 3. Fruit yield per tree differed significantly ($P < .05$) among the different treatments for both the 2019 and 2020 harvest seasons. In the 2019 harvest season, the mean fruit yield per tree ranged from 22.9 kg with the control treatment to 53.1 kg with trees that received PM+NPKZn. In the 2020 harvesting season, the mean fruit yield per tree ranged from 62.4 kg with the NPKZn treatment to 103.5 kg with the trees that received EFB. According to Table 3, the treatment PM+NPKZn recorded the highest mean yield per hectare of 14.7 tons in the 2019 season followed by EFB (14.31 tons), NPKZn (11.6 tons), NPKZn + EFB (9.6 tons), and then PM (7.1 tons) with the Control recording the least yield of 6.4 tons.

Table 3. Effect of fertilizer application on yield of Late Valencia sweet orange in (a) 2019 and (b) 2020 harvesting seasons.

Fertilizer	Mean number of fruits per tree	Mean fruit yield per tree (Kg)	Mean fruit yield per hectare (t/ha)
2019 harvesting season			
NPKZn+PM	172	53.1	14.4
EFB	184	51.5	14.3
NPKZn	139	41.8	11.6
NPKZn+EFB	114	34.5	9.6
PM	95	25.9	7.2
Control	151	22.9	6.4
LSD _{0.05}	NS	17.6	4.9
(b) 2020 harvesting season			
NPKZn+PM	391	89.3	24.8
EFB	467	103.5	28.8
NPKZn	254	62.4	17.3
NPKZn+EFB	392	88.2	24.5
PM	471	102.9	28.6
Control	308	70.1	19.5
LSD _{0.05}	130	25.6	13.9

However, in the 2020 harvest season, the trees that received EFB alone recorded the highest yield per hectare of 28.8 tons followed by PM (28.6 tons), NPKZn+PM (24.8 tons), NPKZn+EFB (24.5 tons), and the control (19.5 tons) while the treatment NPKZn recorded the least yield of 17.3 tons. Table 3 also shows that in the 2019 harvest season, no significant differences in the number of fruits per tree were observed between treatments although EFB and PM+NPKZn recorded higher mean fruit numbers (184 and 172 for EFB and PM+NPKZn respectively) than the control (151). In the 2020 harvest season, however, significant differences were observed both in the number of fruits and fruit weight per tree between the different treatments with the EFB and PM recording significantly higher number of fruits and higher fruit weight per tree.

Table 4 shows the number of fruits that dropped as a result of insect pests (fruit flies) and diseases (citrus black spot (*Guignardia citricarpa*) and angular leaf spot (*Pseudocercospora angolensis*)) in each treatment and their corresponding weight in tons/ha. Higher fruits appeared to have dropped in 2019 than in 2020. The fruit drop in 2019 resulted in substantial yield losses ranging between 36 and 54%. However, in the 2020 harvesting season, fruit drop was much lower with no significant differences between treatments. Yield loss as a result of fruit drop ranged between 3.4 and 6.7%.

Table 4. Number and weight of fruits that dropped due to pests and diseases before harvesting of the fruits in 2019 and 2020

Fertilizer	Mean number of fruits drop per tree	Mean weight of fruit drop per tree (kg)	Mean weight of fruit drop per hectare (tons/ha)	% yield loss due to pests and diseases
2019 Harvesting Season				
PM+NPKZn	85	30.2	8.4	36
EFB	119	34.1	9.5	40
NPKZn	100	33.2	9.2	44
NPKZn+EFB	76	24.6	6.8	41
PM	103	30.8	8.6	54
Control	106	22.2	6.2	50
LSD _{0.05}	NS	NS	NS	-
2020 Harvesting Season				
PM+NPKZn	22	4.1	1.1	4.56
EFB	35	5.7	1.6	5.45
NPKZn	27	4.2	1.2	6.70
NPKZn+EFB	19	3.1	0.8	3.43
PM	29	4.4	1.2	4.27
Control	22	4.2	1.2	6.00
LSD _{0.05}	10.5	NS	NS	

Late Valencia sweet orange response to different fertilizer treatments application and benefit/cost ratios for different fertilizer treatments application at FOHCREC, Kade

The current input prices of 222.33, USD 74.32, USD 370.58, USD 222.45, USD and 74.08 USD per ha for PM+NPKZn, EFB, NPKZn, EFB+NPKZn, and PM, respectively, (and labor for fertilizer application of 69.44 USD) and the fruit price of 57.9 USD ton⁻¹ suggest that to break even, the response of citrus to the various fertilizer treatments should at least be 5.04, 2.48, 7.6, 5.04 and 2.48 kg/ha for PM+NPKZn, EFB, NPKZn, EFB+NPKZn, and PM, respectively. These give benefit-cost ratios of 2.5, 6.9, 0.4, 1.6, and 4.0 (Table 5).

Sensitivity analysis indicates that in a situation where the price of citrus fruits falls to USD 46.30 per ton, fertilizer use will be profitable for all the fertilizer treatments except NPKZn treatment. Also, when the cost of fertilizer use is escalated by 10% and the fruit price increases to USD 69.44 per ton, all the treatments will be profitable (B/C >1) except the NPKZn treatment (Table 6).

Effect of fertilization on leaf nutrient content

Table 7 shows the nutrient content of the leaves before the treatment application. According to Obreza and Morgan (2008), the leaf N, P, and K contents which were 2.37%, 0.14%, and 1.20% respectively were medium. The leaf analysis also indicated very low Mg content while Ca content was optimum according to Obreza and Morgan (2008).

Fertilizer application did not significantly affect the level of nutrients (N, P, K, Ca, and Mg) in the leaves 253 days after the application (Table 7). The N and K levels in the leaves increased 253 days after the application of the fertilizer. The N level in the leaves at the start of the experiment was 2.37% compared to an average of about 3% 253 days after application of the fertilizers (Table 7). K level in the leaves also increased from the initial level of 1.2% to an average of 1.5% 253 days after the fertilizer application. The P level in the leaves 253 days after application did not increase from the initial level of

Table 5. The response of late Valencia Sweet Orange to inorganic and organic fertilizers and Benefit/Cost Ratios of application of organic and inorganic fertilizers.

Fertilizer treatment	Response (tons ha ⁻¹)			Revenue from fertilizer application (US \$) a	Cost of fertilizer applied (US\$) b	Benefit/Cost Ratio
	2019	2020	Total			
NPKZn+PM	8.4	5.3	13.7	733	292	2.5
EFB	7.9	9.3	17.2	998	144	6.9
NPKZn	5.3	-2.2	3.1	177	440	0.4
NPKZn+EFB	3.2	5.0	8.2	475	292	1.6
PM	0.8	9.1	9.9	574	144	4.0

^aPrices of citrus fruits are estimated at 57.9 USD per ton.

^bIncludes the cost of labor for fertilizer application of 291.77, USD 143.76, USD 440.02, USD 291.89, USD and 143.52 USD per ha for PM+NPKZn, EFB, NPKZn, EFB+NPKZn, and PM, respectively.

Table 6. Sensitivity analysis for the four fertilizer treatment applications at FOHCREC.

Situation	Fertilizer treatment	Revenue from fertilizer application (US \$)	Cost of fertilizer applied (US \$)	Benefit/Cost Ratio
Fruits selling at 46.30USD/ton	NPKZn+PM	586.62	291.77	2.0
	EFB	798.21	143.76	5.6
	NPKZn	141.22	440.02	0.3
	NPKZn+EFB	379.66	291.89	1.3
	PM	458.83	143.52	3.2
Fruits selling at 69.44 USD and Cost of fertilizer Use increased By 10%	NPKZn+PM	879.80	320.95	2.7
	EFB	1197.15	158.14	7.6
	NPKZn	211.79	486.02	0.4
	NPKZn+EFB	569.41	321.08	1.8
	PM	688.15	157.87	4.4

PM =Poultry manure; EFB =Empty fruit bunches

Table 7. Nutrient content of leaf sample of the Late Valencia trees (a) before and (b) after the application of the fertilizer treatments.

	N (%)	P (%)	K (%)	Ca (%)	Mg (%)
(a) Before the application of the fertilizer treatments	2.37	0.14	1.20	2.34	0.43
(b) After the application of the fertilizer treatments					
PM+NPKZn	3.20	0.15	1.46	2.22	0.25
EFB	3.15	0.15	1.84	2.13	0.32
NPKZn	3.11	0.14	1.28	2.33	0.32
NPKZn+EFB	3.08	0.13	1.34	2.19	0.29
PM	3.25	0.13	1.45	2.11	0.38
Control	3.05	0.13	1.48	2.20	0.23
LSD	NS	NS	NS	NS	NS

0.14% while Ca and Mg levels decreased from the initial levels of 2.34 and 0.43% respectively to an average of about 2.19% and 0.29%.

Discussion

Late Valencia sweet orange response to different fertilizer treatments application and benefit/cost ratios for different fertilizer treatments application at FOHCREC, Kade

The yields obtained in this study during the first season were generally low (30–53 kg/tree) compared with what has been obtained at the same location (66–220 kg/tree) by Ofosu-Budu (1998) but compares favorably with the yield of 28–45 kg/tree reported by Yildiz, Demirkeser, and Kaplankiran (2013) in Turkey. The yields obtained in the second season (70–103 kg/tree) however, compare favorably with what has been obtained in Ghana (Ofosu-Budu 1998). The low yield obtained during the first season was partly due to high fruit drop across the treatments due to insect pests (fruit fly) and diseases, particularly citrus black spot (CBS; *Guignardia citricarpa*) and angular leaf spot (*Pseudocercospora angolensis*) (Table 4). Percent yield loss as a result of fruit drop due to insect pests and diseases ranged between 36 and 54% with the PM treatment recording the highest yield loss. Yield loss due to pests and diseases has been observed to be a major threat to the citrus industry in Ghana and yield loss due to the combined damage caused by fruit fly and CBS is as high as 56% (Brentu et al. 2012). The better yields obtained in the second season were partly due to better disease control which resulted in lower fruit drop (3.4–6.7%). During the second season, the trees were sprayed against both citrus black spot and angular leaf spot diseases immediately after petal fall to prevent disease infection. These data suggest that annual savings (the increase in productivity due to better disease management) are 11.47 tons/ha, which is worth 722 USD, which is of the same magnitude as additional revenues due to fertilizer use. This emphasizes the need for adequate disease control measures to ensure the high productivity of citrus orchards in Ghana (Brentu et al. 2012).

There were significant differences ($P < .05$) in yield among the treatments both in the first and second seasons. In the first season, yield per hectare ranged from 6.3 t/ha with the control treatment to 14.7 t/ha with the treatment that received PM+NPKZn. In the second season, the trees that received only poultry manure or only EFB produced significantly higher yields than the NPKZn only, and the control treatment probably due to the mineralization of nutrients after the first season due to slower decomposition of these materials which had higher organic carbon compared with the NPKZn treatment and the control. The average weight of individual fruits for the first year was around 300 (280–310) g for all treatments except the EFB+NPKZn and control which had 210 (150–270) g. In the second year, there was very little variation in the individual fruit weight which ranged between 220 and 250 g, suggesting that the differences in 2019 are unlikely due to treatment effect.

The higher yield recorded by the EFB treatment both in the first and second seasons in comparison with the other treatments could be because it served also as a mulching material which improved the soil conditions by maintaining soil moisture and minimizing erosion (Molla, Fakhru-Razi, and Alam 2004).

Besides, EFB also slowly released its nutrients to the soil through its decomposition (Rabumi 1998). The appreciable content of N (0.98%) in the EFB and its mulching ability helped increase yield more than the control and other treatments in this experiment. Kheong et al. (2010), reported that the application of EFB to oil palm trees significantly increased root proliferation which in turn increased the yield. However, in our present study, we did not study the rooting system. Future studies should explore the effects of organic manure such as EFB and PM on citrus root growth and development and their subsequent effects on fruit yield. Martinez et al. (2009) reported that organic fertilizer application improved the yield of citrus in South America and manure application is used as sustainable citrus production practice. The slow nutrient releasing nature of organic manures makes consistent availability of nutrients to the plant throughout the growing season (Pachauu, Singh, and Lalthamawii 2019). The low yield (7.2 t ha^{-1}) recorded by the PM during the first season which was not significantly different from the control (6.4 t ha^{-1}) was unexpected since in a similar trial at the same location, Ofosu-Budu (2014), reported a significant increase in fruit yield compared with the control when they applied 5 t ha^{-1} PM. Despite the low yield obtained in the first season, the PM treatment significantly recorded a very high fruit yield (28.4 tons) during the second season probably due to decomposition of the manure.

The EFB treatment had both the highest yield response due to its long-term effects on the productivity of citrus trees and the highest B/C ratio due to its relatively lower cost. The EFB is one of the major waste products generated from the processing of fresh fruit bunch (FFB) in palm fruits processing mills. About 22% of FFB processed into oil end up as EFB (Lim and Zaharah 2000). Currently, Ghana produces about 2,469,763 metric tons of FFB annually (FAO 2018) which when processed generates about 543,348 metric tons of EFB annually. In the large industrial estates, EFB is either incinerated in the mills as a means of getting rid of these wastes as well as, providing energy for the boilers in FFB sterilization. However, the small-scale mills which process about 60% of the total FFB produced in the country (Opoku and Asante 2008) burn the EFB as a means of disposing of them, resulting in heaps of ash dotted around small-scale mills in the major oil palm producing areas in Ghana. These EFB instead of being burned could be used to improve the productivity of citrus in areas where oil palm is produced in large quantities.

The low B/C ratio obtained with the NPKZn treatment suggests that the application of mineral fertilizer to citrus is not sustainable due to its high cost and short-term effects on the productivity of citrus trees. The sensitivity analysis indicates that at the current interest rate of between 24% and 29% per annum charged by commercial banks and sometimes as high as 50% in the informal sector, all the treatments except the sole NPKZn treatment and NPKZn + EFB can be profitable if orange fruits are sold as low as USD 46.30 per ton. In a situation where the cost of fertilizer use is increased by 10% while orange fruits price increases to USD 66.44/ton, all the fertilizer treatments except the sole NPKZn will be profitable. The study suggests that the benefit/cost ratio will be favorable for most of the improved practices even if the price of fertilizer goes up or if the price of oranges goes down for many of the improved practices. Thus, the financial appraisal of fertilizer-use in sweet orange production shows that fertilizer use in sweet orange production can be profitable in southern Ghana even with adverse price fluctuations. Thus, farmers who use organic fertilizers can increase the profitability of their sweet orange production if efforts are made to control diseases and insect pests. It is hoped that these promising results will encourage sweet orange farmers to adopt the use of organic crop residues as a soil fertility management practice to improve their productivity and increase their profit margin.

Effect of fertilizer application on leaf nutrient content

Generally, there were no significant differences between the treatments for any of the nutrients analyzed in the leaves 253 days after treatment application. The large differences between the control treatments before and after treatments application which was larger than any treatment application effect might be due to the accuracy of the laboratory, differences in sampling time, and random variation. The N content in the leaves of all treatments 253 days after fertilizer

application (3.05–3.20%) was however above optimum (Obreza and Morgan 2008) compared with the initial content in the leaves (2.37%) before the treatment application. Before treatment application, the leaf N/P ratio was 17 which indicates that plant growth was P limited and not N limited. It is therefore not surprising that N increased (luxury uptake) in all treatments apart from the fact N also increased in the control without N application. The higher leaf N content of the treatments that received PM was probably due to the higher N content of the PM. Besides, the increase in the population of micro-organisms as a result of manure application converted the inaccessible form of nitrogen to a readily available form for uptake by the plants (Pachauu, Singh, and Lalthamawii 2019). The EFB and the PM+NPK+Zn treatments also recorded the highest P content (0.15%) in the leaves which was optimum for citrus according to Obreza and Morgan (2008). The 3.11% leaf N content obtained with the sole inorganic treatment of NPK+Zn in this experiment compares favorably with the findings of Li et al. (2019) in China, who recorded lower leaf N content of 2.21% in Satsuma. In our present study, the higher uptake could be possibly due to luxury uptake since the uptake in the control treatment was also quite appreciable and the initial soil analysis suggests that growth of the citrus plants was not limited by nitrogen.

Both Ca and Mg concentrations in the leaves declined from the initial levels of 2.34 and 0.34% respectively to an average of 2.2 and 0.30% for Ca and Mg respectively 253 days after treatments application possibly due to removal from the leaves to satisfy fruit requirements (Zekri and Obreza 2019).

Conclusion

The study has shown a high positive response of sweet orange to organic manures and their combinations with inorganic fertilizer with an average response ranging between 8.2 and 17.2 tons per ha over the two years. Although NPKZn + PM had a higher response (12.2 tons ha⁻¹) compared with sole PM (9.9 t ha⁻¹), the sole PM had higher BCR (4) than the NPKZn + PM (2.5) due to the high cost of NPKZn suggesting that farmers will be better off if they apply only PM or EFB instead of their combination with NPKZn. The study, therefore, suggests that either PM or EFB could be applied to citrus orchards to increase yield and improve soil fertility. Also, to obtain high yields, efforts should be made to control pests and diseases to reduce fruit drop.

Acknowledgments

The authors gratefully acknowledge the financial contribution made towards this work by the Office of Research and Innovation Directorate (ORID) of the University of Ghana, Legon. We thank the Forest and Horticultural Crops Research Centre, Kade for providing Research Field and laboratory space for carrying out the research.

Funding

This work was supported by the Office of Research and Innovation Directorate, University of Ghana, Legon.

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