Integrated soil fertility management options as means of improving tomato (*Solanum lycopersicum* L.) production in southeastern Zimbabwe

Tapiwa Kugedera Andrew[1*], Nyasha Sakadzo[2] and Letticia Kokerai Kudzai[3]
1. Department of Agriculture Management, Zimbabwe Open University, Masvingo Region, P. O. Box 1210 Masvingo, ZIMBABWE
2. Department of Agricultural Economics and Development, Manicaland State University of Applied Science, ZIMBABWE
3. Ministry of Land, Agriculture, Water, Climate and Rural Settlement, Masvingo, ZIMBABWE
[*]kugederaandrew48@gmail.com

Abstract
Tomato (Solanum lycopersicum L.) production has been very low in smallholder farming systems and is facing a huge competition from other vegetables which farmers harvest earlier. The objective of this study was to assess the effects of integrated soil fertility management on tomato fruit yields. The experiment of 27 treatments was arranged in a factorial randomized block design with three factors which were Leucaena leucocephala biomass, cattle manure and inorganic fertiliser. A total of 3000 plants were grown. Data collected was subjected to analysis of variance using IBM SPSS version 25 and means were separated using least significant difference.

The results show that increasing application rates of compound S, cattle manure and L. leucocephala biomass increased tomato yields. Control plots recorded the lowest tomato yield of 7.18 t/ha with the highest yield (20.05 t/ha) recorded from a combination of 2.5 t/ha cattle manure, 10 t/ha L. leucocephala biomass and 1000kg/ha compound S. Increasing application rates of compound S fertiliser significantly increased tomato fruit yield by 34.4%. Interactive effects of cattle manure, Leucaena leucocephala biomass and compound S significantly increased tomato fruit yield in all plots. Integrated soil fertility management options improve soil structure, soil fertility, nutrient availability and soil moisture content which significantly improve tomato fruit yields. The use of integrated soil fertility management can be one of sustainable ways which farmers need to adopt to improve home garden production.

Keywords: Integrated, soil fertility, management, *Leucaena leucocephala*, *Solanum lycopersicum* L.

Introduction

Tomato (*Solanum lycopersicum* L.) is one of the most popular and widely consumed vegetable worldwide. It is one of the most important vegetable grown by smallholder farmers in Zimbabwe[3] and is a source of income for the smallholder farmers.[3,9,22]

***Author for Correspondence**

The crop is said to contain lycopene, an antioxidant that significantly prevents cancers of prostrate, lung and stomach.[2] Tomato fruit contains carbohydrates, proteins, vitamins (A, B, C, K, Thiamine, pyridoxine and foliates).[18] This crop has gained considerable health benefits worldwide as it is consumed fresh or mixed in processed food.

Integrated nutrient management options are one of the best methods of improving crop production and food security in dry regions in Sub-Saharan African (SSA) countries.[12,14,15,17,20] Integrated soil fertility management (ISFM) is one of the ways of reducing human poverty,[19,21] improve nutrition, living standards and reduce malnutrition in most smallholder farming areas. Increasing soil fertility in smallholder farming areas improves food availability and reduces food insecurity. Soil infertility has been caused by monoculture, continuous nutrient mining and low use of soil fertility amendments by resource poor smallholder farmers.[1,14]

Some African soils lack essential nutrients as highlighted by studies conducted in Uganda, Kenya and Tanzania where low crop yield was attributed to poor soil fertility.[7] Most farmers are poor and cannot afford to buy large quantities of inorganic fertilisers and to use cattle manure on home gardens due to competition from arable lands.

The use of inorganic and organic fertilisers is one of the major ISFM options adopted by smallholder farmers but high costs of inorganic fertilisers reduce their use in home gardens. Lack of financial incentives to smallholder farmers and weak fertilizer policies have been major draw backs to the use of inorganic fertilisers in Sub-Saharan Africa.[8,10]

If present, such policies in Africa have been inconsistent and effective in their use.[17] Adoption of crop rotation and use of legumes in home gardens have been noted to increase soil fertility through biological nitrogen fixation (BNF), improve soil carbon, soil organic matter and reduce moisture stress.[16]

The commonly legume tree is used by smallholder farmers in *Leucaena leucocephala* but most farmers grow it live fencing and feeding livestock not knowing its BNF capability. The use of *L. leucocephala* in home gardens has the potential to improve soil fertility and act as moisture conservation strategy if farmers incorporate prunings in soil or use them as mulch. *Leucaena* species are some of the widely researched leguminous trees which produce about 10 to 25 t dry matter ha^{-1} yr^{-1} and contain 2.5-4.0 % N in its leaves.[5,11] Incorporation of *Leucaena leucocephala* prunings has the potential of increasing vegetable yields, quality and also improve soil bio-physiochemical properties such as increasing microbial and other organism population in the soils which improve soils aeration, regulate soil pH, reduce leaching of nutrients and improve water retention.[16] ISFM has the potential of bringing in sustainability in crop production[20] and increases other ecosystems in smallholder farming areas.

This may help in reducing frequency of irrigation by farmers and may improve nutrient uptake as well as reducing competition of cattle manure for field crops and vegetables. Tomato production has been very low in smallholder farming systems with most farmers buying tomatoes from local markets. This has increased tomato prices in most dry regions of Zimbabwe with farmers falling to produce high quality and quantity of tomatoes due to poor soil fertility which reduced growth of the plant. The objective of the study was to assess the effects of various integrated soil fertility management options on tomato fruit yield.

Material and Methods

Study area: The experiment was carried out at Chirichoga High School in Masvingo District located 28 km from Masvingo town in the southern part of the province. The area receives 400-500mm per annum depending on the season. The soils are sandy loam soils with a pH of 4.8 and low cation exchange capacity. Soils are very loose and pale coloured showing signs of poor soil fertility and easily drain water when irrigated. The garden is sited where *Eucalyptus* trees were grown and this contributed to poor soil fertility and acidity.

Experimental design: The experiment of 27 treatments was arranged in a factorial randomized block design with three factors which were *Leucaena leucocephala* biomass, cattle manure and inorganic fertilisers. A total of 3000 plants were grown. The amendments were applied in the following rates: *L. leucocephala* biomass (0, 5 and 10 t/ha), cattle manure (0, 2.5 and 5 t/ha) and compound S (0, 500 and 1000 kg/ha) planting as basal fertilisers and 100kg/ha of ammonium nitrate was added as top dressing. Each treatment was replicated three times. Twenty seven (27) treatment combinations were formulated from three levels of each nutrient sources with *L. leucocephala* biomass (L) i.e. L0 (0 t/ha), L5 (5t/ha) and L10 (10t/ha), cattle manure (C) i.e. C0 (0t/ha), C2.5 (2.5t/ha) and C5 (5t/ha) and compound S (F) i.e. F0 (0kg/ha), F5 (500kg/ha) and F10 (1000kg/ha).

Rodade (T49009) variety seedlings were obtained from a local market and planted to a depth of 2-3 cm in each plot measuring 3 m x 2m. Seedlings were irrigated with light irrigation immediately after irrigation. Thinning was done 30 days after planting and all plants were pruned. All plants were sprayed using carbaryl 85 EC to control against cutworms.

Data was subjective to Analysis of Variance (ANOVA) using IBM SPSS version 25 and significant means were separated using least significant different at 5% level.

Results

Interactive effects of cattle manure, *Leucaena leucocephala* biomass and compound-S on tomato yield: The results show that increasing application rates of compound S, cattle manure and *L. leucocephala* biomass increased tomato yields. Control plots recorded the lowest tomato yield of 7.18 t/ha with the highest yield (20.05 t/ha) recorded from a combination of 2.5 t/ha cattle manure, 10 t/ha *L. leucocephala* biomass and 1000kg/ha compound S (Table 1). Results show significant different ($p<0.001$) from the effects of combining three different sources of ISFM amendments. All treatments with 1000 kg/ha compound S yielded the highest tomato fruit yields compared to other treatments. Increasing compound S application from 0 kg/ha to 500kg/ha increased yield by 34.4% (Table 2) under sole effects.

This was higher compared to when compound S from 500 kg/ha to 1000kg/ha yield increased yields by 4.1%. Effects of increasing compound S from 0 kg/ha to 500 kg/ha were significantly different to effects on yield caused by increasing *L. leucocephala* biomass from 0 t/ha to 5 t/ha which increased yields by 27.7% (Table 2). Combining these three nutrient sources significantly increased tomato fruit yields. Increasing cattle manure from 0 t/ha to 2.5 t/ha does not show significant increase in yield, it increased yield by 0.14% (Table 2).

Results show that the use of ISFM can boost tomato production with higher results obtained from the combination of $C_{2.5}L_{10}F_{10}$ treatments. This shows that the use of high rates of compound S and *L. leucocephala* biomass and 2.5 t/ha cattle manure boosts tomato fruit yields.

Results clearly indicated that the use of 1000 kg/ ha of compound S and 10 t/ha *Leucaena leucocephala* biomass have the potential to produce higher tomato fruits even if used alone. Cattle manure also produced better yields even though they were lower than those from compound S and *Leucaena leucocephala* biomass but cattle manure has the potential to produce higher yields in the long run as it maintains soils CEC, improves water retention, increases availability of nutrients in the root zone throughout the year as it decomposes slowly.

Another issue to note is that cattle manure contains both macro and micro-nutrients needed by tomato plants for growth. From the results in table 2 integration of high levels of all three nutrient sources will produce higher yields in the long run with the potential of improving soil fertility, increasing CEC; improving water retention and microbial activities in the soil. The results were also graphically presented to show clear effects of combining cattle manure, compound S and *L. leucocephala* biomass at different rates. The results are presented in fig. 1, 2 and 3.

Results from fig. 1 and 2 show that interactive effects of compound S and *L. leucocephala* biomass were higher compared to interactive effects of cattle manure and compound-S on tomato fruit yields. Combining compound S and *L. leucocephala* biomass gave better results compared to those from combining compound S and cattle manure. Combining 5 t/ha *L. leucocephala* biomass and 1000 kg/ha compound S yields 18.61 t/ha compared to 17.99 t/ha by combining 1000 kg/ha compound S and 5t/ha cattle manure (Fig. 1 and 2).

Combining *L. leucocephala* biomass and cattle manure showed highly significant differences (p<0.001) among all treatments from the combination although the results were a bit lower to those from combination of compound S and *L. leucocephala* biomass.

Table 1
Interactive effects of cattle manure, *Leucaena leucocephala* biomass and compound-S on tomato yield

Treatment		F_1	F_5	F_{10}	Mean
C_0	L_0	7.18	12.42	15.32	11.64
	L_5	9.09	17.24	17.75	14.69
	L_{10}	9.70	18.77	19.55	16.00
	Mean	*8.66*	*16.14*	*17.54*	*14.11*
$C_{2.5}$	L_0	7.71	8.66	9.00	8.46
	L_5	8.80	19.51	19.75	16.02
	L_{10}	13.80	19.89	20.05	17.91
	Mean	*10.10*	*16.02*	*16.26*	*14.13*
C_5	L_0	10.79	15.96	16.47	14.41
	L_5	14.69	18.04	18.33	17.02
	L_{10}	15.97	18.55	19.15	17.89
	Mean	*13.82*	*17.52*	*17.99*	*16.44*
Interaction					**P-value**
CxL					<0.001
CxF					<0.001
LxF					<0.001
CxFxL					<0.001

C=Cattle manure; F= Compound S and L =*Leucaena leucocephala* biomass
C_0= 0 t/ha cattle manure; $C_{2.5}$= 2.5t/ha cattle manure; C_5= 5t/ha cattle manure; L_0= 0 t/ha *Leucaena leucocephala* biomass; L_5=5 t/ha *Leucaena leucocephala* biomass; L_{10}=10 t/ha *Leucaena leucocephala* biomass; F_1= 0 kg/ha compound S; F_1= 500 kg/ha compound S and F_1= 1000 kg/ha compound S.

Table 2
Sole effects of cattle manure, *L. leucocephala* biomass and compound-S on tomato yield

Treatments	Mean (SD) ±SE yield (t/ha)
Leucaena leucocephala biomass (0 t/ha)	11.50 (3.54) ±0.681[a]
Leucaena leucocephala biomass (5 t/ha)	15.91 (4.05)±0.779[b]
Leucaena leucocephala biomass (10 t/ha)	17.27 (3.37)±0.648[c]
P-value	*<0.001*
Cattle manure (0 t/ha)	14.11 (4.46) ±0.857[a]
Cattle manure (2.5 t/ha)	14.13 (45.42)±0.1.043[a]
Cattle manure (5 t/ha)	16.45 (2.48)±0.477[b]
P-value	*<0.001*
Compound S (0 kg/ha)	10.86 (3.07) ±0.591[a]
Compound S (500kg/ha)	16.56 (3.59)±0.691[b]
Compound S (1000kg/ha)	17.26 (3.34)±0.644[c]
P-value	*<0.001*

Superscripts under same treatment which are different show significant different at p=0.05.

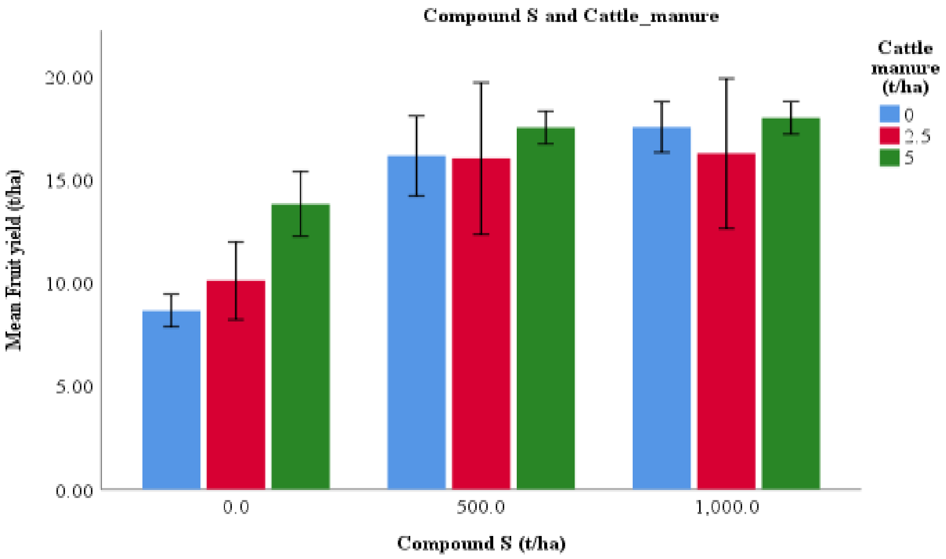

Fig. 1: Interactive effects of compound S and cattle manure on tomato fruit yields

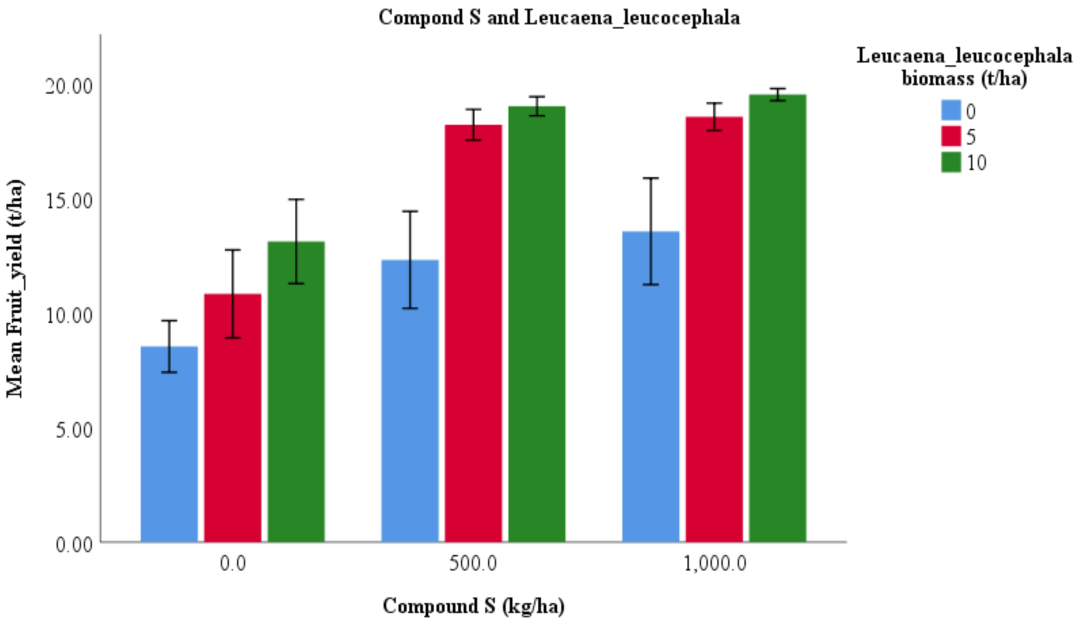

Fig. 2: Interactive effects of compound S and *L. leucocephala* biomass on tomato fruit yields

Discussion

The use of integrated soil fertility management increased tomato fruit yield to improve nutrient availability in the plant root zone, to improve soil structure, to regulate pH and to increase soil organic matter.[12,13] Combining cattle manure, *L. leucocephala* biomass and inorganic fertiliser increases nutrient uptake due to increased nutrients released from all sources. Higher yields were obtained from the interaction of these nutrient sources because cattle manure and *L. leucocephala* biomass release micronutrients which boost crop growth parameters such as roots, leaves and stems. Cattle manure and *L. leucocephala* biomass increase microbial population in the soil of which some are important in nitrogen fixation, improving soil aeration leading to better soil structure for improved yields. Cattle manure releases nutrients slowly in the soil which boosts nutrient availability during the growing cycle and this improves crop yields.[19,20]

Combining inorganic and organic fertilisers significantly increases soil fertility and crop growth,[12] this concurs with results from this study. Results from this study also agree with findings by Vanlauwe et al[20] who indicated that ISFM improves soil fertility and improved crop production in smallholder farming systems in SSA. The use of legumes as components of ISFM has been widely done in SSA to improve soil fertility and crop yields,[6] this is confirmed by improved tomato fruit yields obtained from this study.

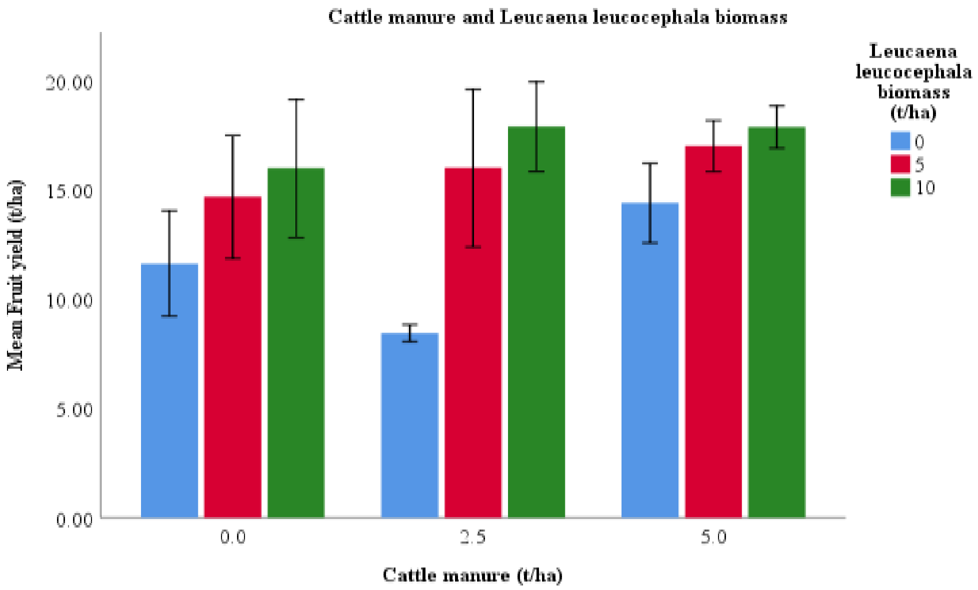

Fig. 3: Interactive effects of *L. leucocephala* biomass and cattle manure on tomato fruit yield

Conclusion

Application of cattle manure at a rate of 5t/ha in combination with 1000 kg/ha compound S and 10 t/ha *L. leucocephala* biomass yields higher tonnage of tomato fruits compared to all other treatments. ISFM of using cattle manure, compound S and *L. leucocephala* biomass in tomato production can be a better option for smallholder farmers to use as means of improving tomato fruit yields. Using compound S, cattle manure and *L. leucocephala* biomass as sole amendments does not give proper yields since there is need to supplement nutrients in these sources.

Using compound S in sole application needs other sources to be added to increase availability of micronutrients which can be supplied by cattle manure and *L. leucocephala* biomass. Cattle manure releases both major and minor nutrients slowly in the soil maintaining availability of nutrients in the soil.

Recommendation

Smallholder farmers are recommended to use cattle manure and *L. leucocephala* biomass or growing *L. leucocephala* in home gardens as means of improving home garden production. The use of cattle manure and *L. leucocephala* biomass can be a better option for smallholder farmers who are poor and are unable to buy large quantities of inorganic fertilisers. The use of cattle manure and *L. leucocephala* improves soil structure, total porosity, soil organic matter, microbial population and cation exchange capacity of the soil which leads to higher soil fertility, high quality crops and better yields. This can finally reduce poverty, food insecurity and can improve food availability for smallholder farmers.

References

1. Bationo A., Hartemink A., Lungu O., Naimi M., Okoth P., Smaling E. and Thiombiano L., African soils: Their productivity and profitability of fertiliser use, In Kihara J., Fatondji D., Jones J.W., Hoogenboom G., Tabo R. and Bationo A., Eds., Improving soil fertility recommendation in africa using decision support system for agrotechnology transfer, New York: Springer, https://doi. org/10.1007/978-94-007-2960-5, 19–42 **(2012)**

2. Canene-Adams K., Campbell J.K., Zaripheh S., Jeffery E.H. and Erdman J.W., *The Journal of Nutrition*, **135(5)**, 1226-1230 **(2005)**

3. Chandiposha M., Mudani S., Gwazane M. and Kudzipanga N.N., The Effects of Trellising Methods on Determinate Tomato Varieties' Yield in Zimbabwe, *International Journal of Plant and Soil Science*, **4(4),** 411-416 **(2015)**

4. Chibi F.I., Mushayabasa T. and Magejo E., Evaluation of hybrid indeterminate tomato (*Solanum lycopersicum* L.) varieties for commercial greenhouse production, *Annals of Biological Research*, **6(6)**, 65-68 **(2015)**

5. Delve R.J., Cadish G., Tanner J.C., Thorpe W., Thome P.J. and Giller K.E., Implications of livestock feeding management on soil fertility in the smallholder farming systems of sub-Saharan Africa, *Agriculture, Ecosystems and Environment*, **84**, 227-243 **(2001)**

6. Franke A.C., Brand G.J. and Van D., Sustainable intensification through rotations with grain legumes in sub-Saharan Africa: a review, *Agric Ecosyst Environ*, **261**, 172–185 **(2018)**

7. Keino L., Baijukya F., Ng'etich W., Otinga A.N., Okalebo J.R., Njoroge R. and Mukalama J., Nutrients Limiting Soybean (*glycine max l*) growth in acrisols and ferralsols of Western Kenya, *PLoS ONE*, **10(12)**, 1–20 **(2015)**

8. Liverpool-Tasie L.S.O., Omonona B.T., Sanou A. and Ogunleye W., Is increasing inorganic fertiliser use in Sub- Saharan Africa a profitable proposition? Evidence from Nigeria, Evidence from Nigeria (February 1, 2015), World Bank Policy Research Working Paper (7201) **(2015)**

9. Mariatou D. and Kwaramba J., Review of vegetable IPPM in Zimbabwe: A case study of Mashonaland East Province, Working document for the FAO IPPM Global Facility Network **(1999)**

10. Minde I., Jayne T.S., Crawford E., Ariga J. and Govereh J., Promoting fertiliser use in Africa: Current issues and empirical evidence from Malawi, Zambia and Kenya, Food Security International Development Policy Syntheses, 54509, http://pdf.usaid.gov/pdf docs/ PNADS615.pdf **(2008)**

11. Mugwe J.N., An evaluation of integrated soil fertility management practices in Meru south district, Kenya, D.Phil thesis, Kenyatta University **(2007)**

12. Mugwe J.N., Ngetich F. and Otieno E.O., Integrated Soil Fertility Management in Sub-Saharan Africa: Evolving Paradigms toward Integration, *Springer Nature Switzerland AG*, 1-13, https://doi.org/10.1007/978-3-319-69626-3_71-1 **(2019)**

13. Nyambati R.O., Odhiambo D.G., Serrem C.K., Othieno C.O. and Mairura F.S., Effects of Integrated Use of *Calliandra calothyrsus* and Maize Stover with Urea on Soil Mineral Nitrogen, Striga Infestation and Maize Yields in Western Kenya, *Journal of Experimental Agriculture International*, **42(1)**, 1-11 **(2020)**

14. Raimi A., Adeleke R. and Roopnarain A., Soil fertility challenges and Biofertiliser as a viable alternative for increasing smallholder farmer crop productivity in sub-Saharan Africa, *Cogent Food & Agriculture*, https://doi.org/10.1080/23311932. 2017.1400933 **(2017)**

15. Rashid M.I., Mujawar L.H., Shahzad T., Almeelbi T., Ismail I.M. and Oves M., Bacteria and fungi can contribute to nutrients bioavailability and aggregate formation in degraded soils, *Microbiological Research*, **183**, 26–41, https://doi.org/10.1016/ j.micres.2015.11.007 **(2016)**

16. Shelton M. and Dalzell S., Production, economic and environmental benefits of *leucaena* pastures, *Tropical Grasslands*, **41**, 174–190 **(2007)**

17. Sommer R., Bossio D., Desta L., Dimes J., Kihara J., Koala S. and Winowiecki L., Profitable and sustainable nutrient management systems for East and Southern African smallholder farming systems- challenges and opportunities: A synthesis of the Eastern and Southern Africa situation in terms of past experiences, present and future opportunities in promoting nutrients use in Africa, Cali Colombia, CIAT, The University of Queensland, QAAFI & CIMMYT, http://hdl.handle. net/10883/4035 **(2013)**

18. Suárez M.H., Rodríguez E.M.R. and Romero C.D., Chemical composition of tomato (*Lycopersicon esculentum*) from Tenerife, the Canary Islands, *Food Chemistry*, **106**, 1046–56 **(2008)**

19. Vanlauwe B., Bationo A., Chianu J., Giller K.E., Merckx R., Mokwunye U., Ohiokpehai O., Pypers P., Tabo R., Shepherd K., Smaling E., Woomer P. and Sanginga N., In Integrated soil fertility management: Operational definition and consequences for implementation and dissemination, The 19th World Congress of Soil Science, Soil Solutions for a Changing World August 1–6, Brisbane, Australia, 194-197 **(2010)**

20. Vanlauwe B., Descheemaeke K. and Giller K.E., Integrated soil fertility management in sub-Saharan Africa: unravelling local adaptation, *Soil*, **1**, 1239–1286 **(2015)**

21. Vanlauwe B., Diels J., Aihou K., Iwuafor E.N., Lyasse O., Sanginga N. and Merckx R., Direct interactions between N fertilizer and organic matter. Evidence from trials with 15N-labeled fertilizer, In Vanlauwe B., Diels J., Sanginga N. and Merckx R., eds., Integrated Plant Nutrient Management in Sub-Saharan Africa, from concepts to practice, CAB International, Wallingford **(2002)**

22. Zitsanza E.S., Ecological studies on *Herlicoverpa armigera* (Lepidoptera: Nocutuidae) in Intensive Cropping Systems in Zimbabwe, Ph.D. Thesis, Imperial College London, University of London **(2000)**.

(Received 29th July 2020, accepted 19th October 2020)