EFFECT OF TILLAGE METHODS ON SOIL PHYSICAL AND STRENGTH PROPERTIES UNDER AMARANTHUS HYBRIDUS PRODUCTION IN A SANDY-LOAM ENVIRONMENT

[1*]Dada, P. O. O., [2]Musa, J. J., [1]Adewumi, J. K. and [3]Olla O. O.

[1]*Department of Agricultural and Bioresources Engineering,Federal University of Agriculture, Abeokuta. P.M.B. 2240 Ogun State*
[2]*Department of Agricultural and Bioresources Engineering. Federal University of Technology, Minna, P. M. B. 65. Niger State. Nigeria*
[3]*National Centre for Agricultural Mechanization. P.M.B. 1525. Ilorin- Idofian Road.. Kwara State*
***Corresponding Author:** dadapoo@funaab.edu.ng*
***Phone No:** +234-803-399-9110*

ABSTRACT

Amaranthus hybridus (African Spinach) production is a common vegetable in many southwestern parts of Nigeria. Many farmers grow it for its high source of protein and vitamins under different soil conditions without taking into consideration the tillage method that best gives the highest yield. A field study was conducted on a sandy loam soil in the National Centre for Agricultural Mechanization, Ilorin. Nigeria during the raining season of 2017 to investigate the effect of tillage methods on soil physical properties, penetration resistance and shear strength under Amaranthus hybridus production. The experiment was a completely randomized design with three replications. Tillage methods were disc plough (DP), disc harrow (DH), combination of disc plough and disc harrowing (DPH) and zero tillage (ZT). Soil physical parameters investigated during the growth stages of the crop were soil bulk density, soil moisture content, penetration resistance, shear stress and total porosity. Average bulk density for DP, DPH, DH and ZT were 1.33, 1.30, 1.25 and 1.50 g/cm^3 respectively. Shear stress increased with depth in all the plots. Maximum values at the 14-21 cm depth were 132, 104, 166 and 16 mPa for DP, DPH, DH and ZT respectively. The average penetration resistance on the DP, DPH, DH and ZT at the 14-21cm depth were 84.3, 82, 178 and 97 kPa respectively. Amaranthus hybridus yield was highest on the DPH plots with an average weight of 10 stands weighing 108g. Disc ploughed + harrowing was the best tillage practice considering the soil physical properties, penetration resistance and shear stress of the plots for the optimum yield of Amaranthus hybridus on the sandy loam field.

Keywords: *Amaranthus hybridus, Conservation, Sandy loam field, Tillage*

INTRODUCTION

Amaranthus species is a common green in many Asian, Latino, African, and Caribbean cultures, and competition from imports is extremely minimal. Amaranth leaves are also highly nutritious and often striking in color, qualities that lend favorably to marketing as a novel substitute for more common greens (National Research Council, 2006)

Amaranth is grown and eaten as a vegetable in over 50 countries worldwide, in such geographically diverse locations as South America, Nepal, China, Greece, India, and South Pacific Islands (National Research Council, 2006). Nutritional assessments of common vegetable species (A. blitum, A. cruentus, A. dubius, A. tricolor, and A. viridis) show high protein content and significant levels of essential micronutrients, including beta-carotene, iron, calcium, vitamin C, vitamin A, and folic acid (Achigan-Dako *et al*., 2014; Mziray *et al*., 2001; Teutonico and Knorr, 1985). High nutritional value and tolerance of many biotic and abiotic stresses have made amaranth an especially important vegetable crop in Africa, where some societies derive as much as 25% of their protein intake from amaranth leaves during the production season, and its sale in thousands of tonnes annually has significant economic impact (National Research Council, 2006).

The primary Amaranthus species eaten as a vegetable include A. tricolor, A. cruentus, A. dubius, A. caudatus, A.hybridus, and A. viridis. Amaranth leaves and stems are steamed, used in soups, boiled in several changes of water, or young leaves are eaten raw (Achigan-Dako *et al*., 2014).

In comparison to the deep pool of cultural knowledge surrounding amaranth, intensive production research is lacking. Amaranths are known to tolerate marginal soils, high heat, and drought, and have been reported to display a general resilience and resistance to common pests and diseases (Niveyro *et al*., 2013, Othim *et al*., 2018).

Amaranth is especially sensitive to temperature and low relative humidity, making long-distance shipping challenging (Wheeler *et al*., 2015). Competition from imports is therefore minimal, and amaranth is a strong candidate for fresh, direct to consumer sale (NASS, 2012). Efficient production of Amaranth necessitates good tillage practice on the appropriate soil to ensure sufficient yield.

Soil tillage is among the important factors affecting soil physical properties and crop yield. Among the crop production factors, tillage contributes up to 20% (Khurshid *et al*., 2006). According to Hammel (1989), tillage method affects the sustainable use of soil resources through its influence on soil properties. Also, the proper use of tillage can improve soil related constrains, while improper tillage may cause a range of undesirable processes, e.g. destruction of soil structure, accelerated erosion, depletion of organic matter and fertility, and disruption in cycles of water, organic carbon and plant nutrient (Lal, 1993). Use of excessive and unnecessary tillage operations is often harmful to soil. Therefore, there seems to be an interest and emphasis on the shift from the conventional to the conservation and no-tillage methods for the purpose of conserving the soil (Iqbal *et al*., 2005).

Conventional tillage practices have significant influence on the modification of soil structure by changing its physical properties such as bulk density, soil penetration resistance and soil moisture content. According to Rashidi and Keshavarzpour (2007), annual disturbance and pulverization caused by conventional tillage produce a finer and loose soil structure as compared to conservation and no-tillage method which leaves the soil intact.

On the other hand, conservation tillage methods have significant advantages in improvement of soil properties such as pore space (Hill, 1990), It often results in decreased in soil pores, increased soil strength (Bander *et al*., 1981) and stable aggregates (Horne *et al*., 1992). According to Kruger (1996), Franzen *et al*. (1994) and Ferreras *et al*., 2000, in No-till soil, greater soil penetration resistance level was observed, when compared with tilled soils. The pore network in conservationally tilled soil is usually more continuous because of earthworms, root channels and vertical cracks (Cannel, 1985). Therefore, conservation tillage may reduce disruption of continuous pores. Whereas, conventional tillage decreases soil penetration resistance and soil bulk density (Khan *et al*., 1999) especially at the topsoil layer. This also improves porosity and water holding capacity of the soil. Continuity of pore network is also interrupted by conventional tillage, which increases the tortuosity of soil. This all leads to a favorable environment for crop growth and nutrient use (Khan *et al*., 2001). However, the results of no-tillage are contradictory (Iqbal *et al*., 2005), for instance, in arid regions of Iran an adverse effect on crop yields was recorded under no-tillage methods (Hemmat and Taki, 2001), A similar result was observed by Dada *et al*., 2014) on comparison of different conventional and zero tillage methods on maize growth where the yield was significantly reduced under zero tillage compared to disc ploughed and disc harrowed soils. Pierce *et al*. (1994) observed that ploughing when compared with No-till increased micro porosity levels in soils. From the study of Lampurlanes and Cantero-Martizez (2003), the most common variables used to assess soil strength in tillage studies are bulk density and soil penetration resistance. They are interrelated, and use of only one of these variables may lead to misleading results (Campbell and Henshall, 1991). Soil penetration resistance is inversely related to total soil porosity which provides a measure of the porous space left in the soil for air and water movement (Carter and Ball, 1993). Generally, high porosity is associated with poor soil-root contact while low porosity reduces aeration and increases penetration resistance which limits roots growth (Cassel, 1982). Klepper (1990) reported that one of the most important soil physical properties affecting root growth is porosity and this is largely determined by tillage.

The objective of this study is to investigate the effect of different conventional tillage methods on the yield of Amaranthus hybridus under a sandy loam environment.

MATERIALS AND METHODS

Study Site Description*:* The experimental site was located in the National Centre for Agricultural Mechanization (NCAM), Ilorin. Kwara state located in the southern guinea savannah. It lies between latitude 8° 22′ N and longitude 4° 40′ E. The rainfall in the region is about 1200 mm per annum. Vegetation is secondary forest with shrubs scattered around. Mean daily temperature is about 27° C with a range between 20 and 31° C. Bulk density ranges from 1.16 to 1.40 g/cm^3. Moisture content varies from 8.8 to 13 %. The soil in the study site was well drained based on the textural class (Table 1).

Experimental Design: The experiment was a completely randomized design with four tillage methods which consist of disc ploughing, disc ploughing + disc harrowing, disc harrowing and zero tillage (control) replicated three times. Plots sizes were 2.1 by 5m with a buffer zone of 1m between the plots to prevent interaction and overlapping. A New Holland tractor of 65hp was used for the operations. Disc ploughing was done with a three-disc plough while harrowing was done with a 20-disc harrow. The combinations of the treatments are shown in Table 2.

Amaranthus hybridus seeds were obtained from the local market and they were air-dried and planted by broadcast method and seed germination occurred at one week after planting.

Table 2. Combinations of treatments used

Treatments	Description
DP1	Disc Ploughing with one pass of tractor
DP2	Disc Ploughing with one pass of tractor
DP3	Disc Ploughing with one pass of tractor
DPH1	Disc Ploughing + Harrowing with one pass of tractor
DPH2	Disc Ploughing + Harrowing with one pass of tractor
DPH3	Disc Ploughing + Harrowing with one pass of tractor
H1	Harrowing with one pass of tractor
H2	Harrowing with one pass of tractor
H3	Harrowing with one pass of tractor
C	Zero Tillage (Control Plot)

Sample Protocol:

Soil Bulk density

Soil bulk density was taken at three depths, 0-7, 7-14 and 14-21cm using the core method.

Two points on each plot was randomly selected for sampling twice a week for four weeks till the harvesting of the crop. This was done using a stainless-steel core of dimension 8cm height and diameter of 4cm. Soil samples were oven dried at 105°C for 24 hours and dry weight was determined. Mathematically, bulk density was calculated using the relation:

$$Bd = \frac{Wdry}{Vol} \quad (1)$$

where:

Bd = dry bulk density (g cm^{-3})

Wdry = weight of the dried soil sample (g)

Vol = total volume of the soil core sampler (cm^3) = $\pi r^2 h$.

where r is radius of soil core and h is the height (cm)

Soil Moisture Content

Soil moisture content was also determined from soil samples collected at depths of 0-7, 7-14 and 14-21cm. This was done on all plots on a weekly basis till harvest. The collected soil samples were put into cellophane bags, weighed and oven dried at 105°C for 24 hrs and weights were monitored until constant weight was achieved. Gravimetric moisture content was determined by the equation:

$$\theta g = \frac{Mt - Ms}{Ms} = \frac{Mw}{Ms} \quad (2)$$

Where θg is gravimetric moisture content (%)

Mt is total mass of wet soil (g)

Ms is mass of dry soil (g)

Mw is mass of water (g)

Soil Porosity

This was determined from bulk density values obtained using the standard particle size density of 2.65 g/cm^3. Porosity (Tp) was determined using the relation:

$$Tp = \left(1 - \frac{Bulk{\cdot}density}{Particle{\cdot}density}\right) \times 100 \quad (3)$$

Soil shear stress

This was determined on all plots to give an indication of the shear strength of the soil as affected by the tillage methods. This was investigated on the plots with a shear vane apparatus with a measuring range of 0-240 kPa, torque value of 3.5 N.m. The extension rod has a maximum depth of 300 mm. It was inserted at soil depths of 0-7, 7-14 and 14-21 cm respectively. Measurements were observed and read from the instrument. The units were in kPa. Three points were taken on each of the plots and mean values were recorded.

Soil penetration resistance

A hand held cone penetrologger (Eijkelkamp model) with a maximum penetration of 98 cm was used to monitor soil strength on all plots every week till harvesting of the Amaranthus hybridus. Depth of penetration was 25cm and measurements were recorded in MPa.

Data Analysis

Data were subjected to analysis of variance and means were separated using the Duncan Multiple Range Test at 0.05 level of significance. Minitab Statistical software (version 2017) was used.

RESULTS AND DISCUSSION

Soil physical properties of tillage plots under Amaranthus hybridus growth with respect to depth

Bulk density, soil moisture content, porosity values increased with depth on all plots. Disc ploughed plots showed a higher bulk density than the disc harrowed plots and this can be attributed to the level of pulverization on disc harrowed plots. At the 7-14cm depth on the disc ploughed, disc harrowed, ploughed + harrowed and zero tilled plots, it was observed that there was a reduction in values of bulk density compared to the top 0-7cm depth. This is due to the loose and porous nature of the soil at this depth. There is also the possibility of higher organic matter content at this depth. At the 7-14cm depth there is better aggregation. It is generally known that bulk density typically increases with depth since the subsoil is more compacted.

Table 2. Mean shear stress (MPa) under different tillage methods with respect to depth under Amaranthus hybridus growth

Tillage Methods	Plots	Depth (cm)		
		0-7	7-14	14-21
	DP1	14	50	132
Disc Ploughed	DP2	13	26	122
	DP3	6	38	72
	DPH1	2	20	94
Ploughed + Harrowed	DPH2	6	10	102
	DPH3	2	57	104
	H1	6	18	130
Harrowed	H2	8	16	166
	H3	5	54	166
Zero Tillage (Control)	Control	26	36	81

3.3 Penetration resistance with respect to tillage methods under Amaranthus hybridus growth

Penetration resistance which reveals the level of soil strength was generally moderate on the sandy loam soil. It was observed that penetration resistance increased with depth on all the tillage plots. At 0-7, 7-14 and 14-21cm depth values ranged from 14 to 27, 15 to 125 and 60 to 180kPa respectively (Figure 1). There was a significant increase in penetration resistance at the 14 to 21cm depth in all the plots. At this depth range in the soil profile which is around the plough layer, the soil is more compact and there will be greater soil resistance which invariably results in increased soil strength especially when there is mechanized tillage. This is similar to the report by Salako *et al.*, (2007, Dada *et al.*, 2014 where soil strength increased with depth as a result of topsoil removal and tillage practice. On the disc ploughed plots, the mean penetration resistance was 26, 44 and 84kPa at the 0-7, 7-14 and 14-21 cm depth respectively and on the disc ploughed + harrowed plots, penetration resistance was 15, 25 and 82kPa at the 0-7, 7-14 and 14-21 cm depth respectively. The mean penetration resistance at the 0-7, 7-14 and 14-21 cm depth on the disc harrowed plots were 21, 115 and 178kPa respectively. The high values observed on the disc harrowed plots compared to other tillage plots can be attributed to the differential properties of soil which can change as a result of previous soil usage and crop type grown.

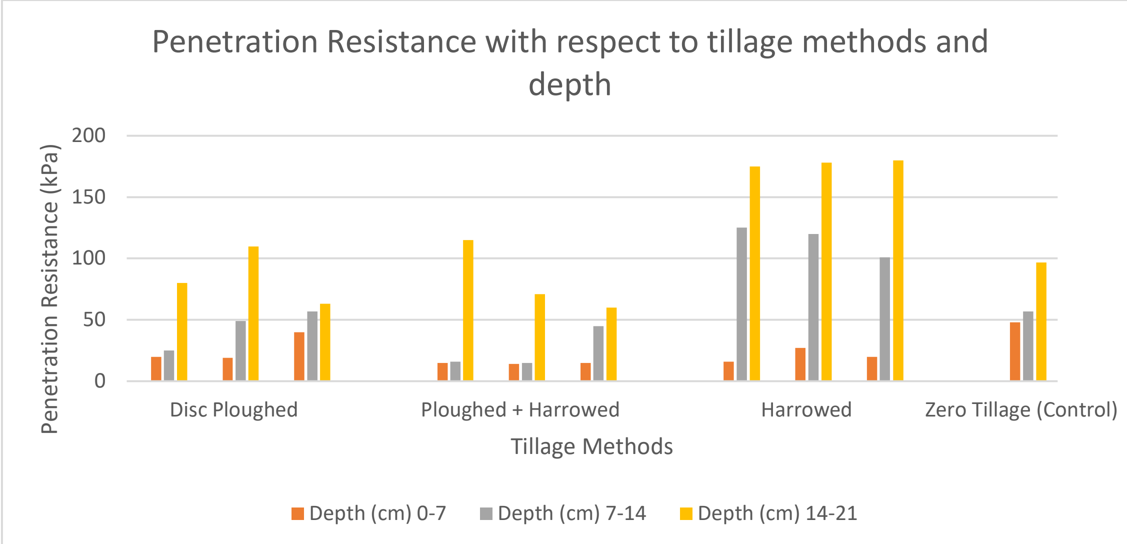

Figure 1. Penetration resistance with respect to tillage methods and depth

Amaranthus hybridus growth and yield in relation to tillage methods

Seedlings started emerging 4 days after planting in most of the plots though the disc ploughed and the zero tillage plots had very poor emergence while the ploughed and harrowed plots had better emergence. The best seedling emergence was on the ploughed and harrowed plots. This is attributed to the fact that the loose nature facilitated by enhanced the mineralization of the organic manure applied. There was a consistent increase in weight of the vegetables as the days increased till harvest (Table 3). Plough + harrowed plots gave the best tillage method in terms of yield compared to other tillage methods. Zero tilled plots had very low yield and this can be attributed to the compact nature of the soil. This further reveal that for crops to have a good yield, there should be some form of tillage activity on the soil to loosen the soil.

Table 3. Amaranthus hybridus growth and yield with respect to tillage methods.

	Plot	4 DAP	10 DAP	21 DAP	Harvest (g)
		Fresh weight (g) of 10 stands			
	DP1	1.05	9.81	14.64	26.67
Disc Ploughed	DP2	1.15	8.92	16.34	27.01
	DP3	1.21	9.84	17.23	25.09
	DPH1	31.43	33.91	49.87	60.13
Plough + Harrow	DPH2	30.89	35.66	54.89	67.34
	DPH3	32.01	36.74	55.02	61-31
	H1	24.16	31.04	35.86	55.56
Harrow	H2	23.24	32.67	35.23	57.01
	H3	22.31	31.82	36.90	59.69
Zero Tillage	Control	1.10	4.63	6.17	10.18

CONCLUSION

This study considered the effect of different tillage methods on soil physical and strength properties under Amaranthus hybridus production in a sandy-loam environment. Disc ploughed + harrowed plots gave the best yield for the vegetable. For better yield of vegetables, there should be at least minimum tillage done on agricultural soils and bulk density, penetration resistance and shear stress should not be too high. Tillage enhances the flow of water and nutrients into the soil but the level of pulverization should not be too high to forestall soil and nutrient losses.

FUNDING

This research was funded by the Centre for Agricultural Development and Sustainable Development (CEADESE) of the Federal University of Agriculture, Abeokuta (FUNAAB) under the World Bank project.

ACKNOWLEDGEMENTS

The authors acknowledge the National Centre for Agricultural Mechanization at Ilorin, Kwara State. Nigeria for providing the land used for this research. The authors also acknowledge the financial support of the Centre for Agricultural Development and Sustainable Development (CEADESE) for the grant to undertake this Research. The staff and students of NCAM who devoted their time in data collection on the field are also acknowledged. The tractor operators and their supervisors are appreciated for the establishment of the plots and tillage operations.

REFERENCES

Achigan-Dako, E.G., O.E.D. Sogbohossou, and P. Maundu. 2014. Current knowledge on Amaranthus spp.: research avenues for improved nutritional value and yield in leafy amaranths in sub-Saharan Africa. Euphytica. 197(3):303-317.

Bander, J.W., Randall, G.W. and Swan J.B. 1981. Effects of four continuous tillage system on mechanical impedance of a clay-loam soil. Soil Science Society of America. 45:802-806.

Campbell, D.J. and J.K. Henshall, 1991. Soil Analysis; Physical Methods, Bulk Density. In: Smith, K.A. and C.E. Mullins (Eds.), Marcel Dekker, New York, pp:329-366.

Cannel R.Q. 1985. Reduced tillage in north-west Europe- a review. Soil and Tillage Res. 5: 129-177.

Carter,M.R and Ball, B. C. 1993. Soil Sampling Methods of Soil Analysis. Soil Porosity. In: Carter, M.R. (Ed.), Lewis publ, Boca Raton, FL. pp: 581-588.

Cassel, D.K., 1982. Tillage Effects on Soil Bulk Density and Mechanical Impedance. In: Unger P.W. and D.M. Van-Doren, (Eds.), ASA Spec Publ., 44 Madison, W.I. pp: 45-67.

Dada P.O.O., Adewumi, J.K., Ohu, J.O., Salako F.K. and Ayankunle, I.B. 2014. Structural stability response to tillage and depth treatments of a sandy Alfisol in Southwestern Nigeria. Journal of Science, Technology, Mathematics and Education (JOSTMED), Federal University of Technology, Minna. Niger State. 10(2): 38-45.

Ferreras, L.A., J.L. Costa, F.O. Garciaand, C. Pecorari, 2000. Effect of no-tillage on some soil physical properties of a structural degraded petrocalcic paleudoll of the Southern “Pampa” of Argentina. Soil Tillage Res., 54: 31-39.

Franzen, H., R. Lal and W. Ehlers, 1994. Tillage and mulching effects on physical properties of a tropical Alfisol. Soil Tillage Res., 28: 329 - 346.

Hammel J.E. 1989. Long term tillage and crop rotation effects on bulk density and soil impedance in northern Idaho. Soil Sci. Soc. Amer. J. 53: 1515-1519.

Hemmat A. and Taki D. 2001. Grain yield of irrigated wheat as affected by stubble tillage management and seeding rates in central Iran. Soil and Tillage Res. 63: 57-64.

Hill R.L. 1990. Long-term conventional and no-tillage effects on selected soil physical properties. Soil Sci. Soc. Amer. J. 54: 161-166.

Horne D.J., Ross C.W. and Hughes K.A. 1992. Ten years of maize/oats rotation under three tillage systems on a silt-loam soil in New Zealand. 1. A comparison of some soil properties. Soil and Tillage Res. 22: 131-143.

Iqbal M., Hassan A.U., Ali A. and Rizwanullah M. 2005. Residual effect of tillage and farm manure on some soil physical properties and growth of wheat (Triticum aestivum L.). Int. J. Agri. Biol. 1: 54-57.

Khan F.U.H., Tahir A.R. and Yule I.J. 1999. Impact of different tillage practices and temporal factor on soil moisture content and soil bulk density. Int. J. Agri. Biol. 3: 163-166.

Khan F.U.H., Tahir A.R. and Yule I.J. 2001. Intrinsic implication of different tillage practices on soil penetration resistance and crop growth. Int. J. Agri. Biol. 1: 23-26.

Khurshid K., Iqbal M., Arif M.S. and Nawaz A. 2006. Effect of tillage and mulch on soil physical properties and growth of maize. Int. J. Agri. Biol. 5: 593-596.

Klepper, B., 1990. Root Growth and Water Uptake. Irrigation of Agricultural Crops. In: Stewart, B.A. and D.R. Nielsen, (Eds.), Agron. Monogr. 30. ASA, CSSA and SSSA, Madison, W.I., pp: 281-322.

Kruger, H., 1996. Soil compaction in haplustolls from the south western part of Buenos Aires, Argentina, Scienc. Suelo., 14: 104-106.

Lal R. 1993. Tillage effects on soil degradation, soil resilience, soil quality and sustainability. Soil and Tillage Res. 51: 61-70.

Lampurlanes, J. and C. Cantero-Matirez, 2003. Soil bulk density and penetration resistance under different tillage and crop management system and their relationship with Barley root growth. Am. Soc. Agron. J., 95: 526-536.

Rashidi M. and Keshavarzpour F. 2007. Effect of different tillage methods on grain yield and yield components of maize (Zea mays L.). Int. J. Agri. Biol. 2: 274-277.

Salako, F.K., Dada, P.O., Adesodun, J.K., Olowokere, F.A., and Adekunle, I.O. 2007. Variation in soil strength, bulk density and gravel concentration along a toposequence in Abeokuta, south-western Nigeria. Australian Journal of Soil Research 45:643–650. DOI:10.1071/SR07057. CSIRO Publishing Australia.

Mziray, R.S., J.K. Imungi, E.G. Karuri. 2001. Nutrient and antinutrient in contents of raw and cooked Amaranthus hybridus. Ecology of Food and Nutrition. 40(1):53–65.

National Agricultural Statistics Service (NASS). 2012. Census of Agriculture Highlights: Farmers Marketing. USDA.

National Research Council. 2006. Amaranth (Amaranthus species). pp. 33-51. In: Lost Crops of Africa: Volume II: Vegetables. National Academies Press, Washington D.C.

Niveyro, S.L., Mortensen, A.G., Fomsgaard, I.S. and Salvo, A. 2013. Differences among five amaranth varieties (Amaranthus spp.) regarding secondary metabolites and foliar herbivory by chewing insects in the field. Arthropo-Plant Interact 7:235-245.

Othim, S.T., Srinivasan, R., Kahuthia-Gathu, R., Dubois, T., Dinssa, F. Ekesi, S., Fiaboe, K. 2018. Screening for pest resistance against important lepidopteran and stem weevil pests attacking amaranth in Tanzania. Euphytica.

Pierce, F.J., M.C. Fortin and M.J. Staton, 1994. Periodic plowing effects on soil properties in a no-till farming system. Soil Sci. Soc. Am. J., 58: 1782-1787.

Teutonico, R.A. and D. Knorr. 1985. Amaranth: Composition, Properties, and Applications of a rediscovered food crop. Food Technology. 39:49-60.

Wheeler, L., L. Kitinoja, and D.M. Barrett. 2015. Use of insulated covers over product crates to reduce losses in amaranth during shipping delays. Agriculture. 2015(5):1204-1223.