Conservation Agriculture for Sustainable Cotton Production in Africa

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Cotton is a commercial crop sustaining the livelihoods of millions of farmers on the African continent (FAOSTAT, 2017). However, there is a concern among cotton growers due to stagnating yields over the past few years. What ails the cotton grower in this part of the world? Low yields in the region reflect that the African cotton-based systems are far from the best management practices (BMPs) (Tripp, 2009).

Soil is the foundation upon which rests the sustainability of crop production. However, land degradation is now a serious threat and a cause for declining productivity in most of the cotton-growing countries in Africa. This stems from intensive tillage operations and limited crop residue recycling as manure, due to its competing uses – fuel and animal feed. Such practices result in a decline in the soil organic carbon (SOC) and also loss of topsoil ultimately leading to loss of soil fertility (Bolliger *et al*., 2006). Loss of topsoil has been established in Africa in the 1980's (Elwell and Stocking, 1988; Lal, 1985). Further, the topsoil on removal gets transported to streams and lakes polluting the surface waters (Heathcote *et al*., 2013). The CO_2 released to the atmosphere, by way of excessive cultivation of crops including cotton, has implications on global climate change (IPCC, 2013).

Can we arrest the degradation and improve cotton productivity in the cotton growing countries of Africa? Yes, surely, we can arrest land degradation by adopting the 'BMPs'. Lessons can be learnt from the rest of the world as to how cotton is grown successfully with high fibre quality at high productivity levels. The BMPs, for improving soil health, are discussed here specifically for the cotton growing countries in Africa, where farmers own small land holdings and cotton cultivation is mostly rainfed. Thus, moisture is a major limiting

Soil erosion after heavy rain shower – main cause of soil degradation in the tropics

factor affecting crop yields apart from the poor soil fertility. In addition, because of the small land holdings, most of the farmers are resource-poor with limited capacity for investments. Thus, conservation agriculture (CA) is a BMP that holds the key to not only improving but also sustaining cotton production in Africa.

Conservation Agriculture (CA)

CA is an integration of ecological management with scientific and modern techniques tempered with traditional knowledge gained from generations of successful farmers (Dumanski and Peiretti, 2013). CA revolves around three basic principles: (i) minimising tillage, (ii) including a permanent cover and (iii) rotation crops. This system is more sustainable and has a wider adaptation because it improves soil quality (Thierfelder *et al*., 2009, 2010) and crop productivity. These three technologies in combination result in synergism. Thus, CA becomes more than the sum of an individual practice. These systems are best suited to the African countries since soil and water is conserved and contributes to improvement in the livelihoods of the farmers (Kassam *et al*., 2016).

Tillage

Presently, farmers practice intensive tillage operations with two main objectives (i) prepare a good seed bed and (ii) provide effective weed control. However, such practices lead to oxidation of the organic matter and a decline in soil organic carbon content. To mitigate C loss, conservation tillage practices are recommended. Conservation tillage denotes soil management systems that result in at least 30% of the soil surface being covered with crop residues after seeding of the subsequent crop. To achieve this level of ground cover, conservation tillage normally involves some degree of tillage reduction and the use of non-inversion tillage methods such as no-till, minimum till or reduced till. A substantial reduction in total soil loss and soil quality improvement was reported following the adoption of modern agricultural technologies such as conservation tillage (Montgomery, 2007). According to a study done by the Cotton Incorporated, USA, two-thirds of the cotton growers adopt some form of conservation tillage in the USA (Nyakatawa *et al*., 2001; Boquet *et al*., 2004; Reed *et al*., 2009). Similarly, conservation tillage practices are followed by cotton growers in Australia (Hulugalle *et al*., 1997), Brazil (Casao *et al*., 2012) and Turkey (Mert *et al*., 2006). Conservation tillage practices have been found to produce cotton yields greater than the conventional tillage treatments in West Africa (Baudron, 2007), Cameroon (Naudin *et al*., 2010) and Zambia (Haggblade and Tenbo, 2003).

Under the sustainable land management programmes, conservation tillage practices are promoted in Africa to a greater extent in food crops. A summary of the results of experiments conducted on cotton with different forms of conservation tillage are presented in Table 1. In Sub-Saharan Africa, the principal factor limiting the area of cropped fields is weeding. Where herbicides have been adopted in reduced tillage, farmers have increased their crop area by over 140% from 1.1 to 2.7 hectares (Haggblade and Plerhoples, 2010). Giller *et al.* (2009) compared two case studies of Africa - West Africa and Central Africa and observed differences in the response of cotton to the CA practices and also the mindset of the people in the region. In southern Zambia, conservation tillage did not perform well because the coarse textured soils are prone to crusting (Baudron *et al*., 2012). Under such situations, CA was perceived as a water shedding technology and not a water harvesting one (Thierfelder and Wall, 2009). Thus, ploughing was considered a better option on such soils to improve water infiltration. Mavukidnadze *et al*. (2017), reported similar seed cotton yields under the conservation and conventional till systems in Zimbabwe. On the other hand, in Cameroon, conservation till systems were better

Table 1. Effect of conservation tillage vs. conventional till systems across the different countries

S. No.	Location	Soil Type	Yield (kg/ha)		% Yield Change	Reference
			Conventional till	Conservation till		
1	Alabama, USA	Silt loam	2660	3130	17.7	Schwab *et al*. (2002)
2	Alabama, USA	Coastal loamy sand	1176	1415	20.3	Watts *et al*. (2017)
3	Dera Ismail Khan, Pakistan	Silty clay soil	*2289	*2124	-	Usman *et al.* (2013)
4	Ladhowal, India	Sandy loam	*2555	*2640	3.3	Chaudhary *et al*. (2016)
5	Kadoma, Zimbabwe	Ustopept	*1715	*1717	--	Mavunganidze *et al.* (2014)
6	Turkey	Vertisol	1941	2050	NS	Mert *et al*. (2006)
7	Cameroon	Fluvisols, Luvisols, Vertisols	*1220	*1390	13.9	Naudin *et al.* (2010)
8	Sikasso, Mali	Ferruginous	*1825±104	*1666±105	-8.7	Sissoko *et al*. (2013)

*Seed cotton yield (kg/ha)

than the conventional tillage systems (Naudin *et al*., 2010). In the Mediterranean region of Turkey, Mert *et al*., (2006) observed ridge till systems to yield better and promote earliness in a year that was wetter than the normal. While in the drier years, the tillage systems were not significant. On the Vertisols of semi-arid central India, conservation tillage systems were found to be either better or as good as the conventional till systems (Blaise and Ravindran, 2003; Blaise, 2006). But on the silty clay loam soil of Pakistan (Usman *et al.,* 2013) and the sandy loam of north India (Chaudhary *et al*., 2016), tillage systems had no significant effect. From the findings of the researchers mentioned above, it is evident that the conservation till system was either better than or similar to the conventional till systems. It is important to note that the conservation till systems result in significant savings in terms of fuel and labour (Raunet and Naudin, 2006). Thus, it should not be judged on the basis of yield alone. Even if the yield levels are similar, the net gains should be an incentive good enough for the management practice to be taken up, unless there is a significant decline in yields such as the one reported by Baudron *et al*. (2012) in southern Zambia. It cannot be considered that the tillage system will work in a similar manner all across soil types and climates (Giller *et al*., 2009). Moreover, limitations in knowledge and availability of farm equipment could constrain the adoption of the conservation till systems (Grabowski *et al*., 2016). Therefore, it is important to learn and adapt to the local conditions through innovative technologies. Furthermore, it is also essential to understand that the conservation tillage systems tend to show benefits over a period of time.

Soil cover

Management of crop residues is a critical part of CA systems because conservation tillage systems alone cannot improve organic C (Corbeels *et al*., 2006). Cotton is considered a low residue crop that may not provide sufficient surface residue to reduce erosion and protect the soil. There are five possible avenues for producing adequate quantities of crop residue mulch.

- Residue from the previous crop can be used as mulch through minimum/no tillage or non-inversion tillage (Blaise and Ravindran, 2003; Jalota *et al*., 2008).

***Chrysanthemum* grown as intercrop**

Sunnhemp grown as an intercrop

Sunnhemp mulched offers very good protection against the weeds and also adds nitrogen to soil

- Specific crop can be grown to produce biomass that can form mulch for succeeding cotton e.g. maize/soybean/finger millet or rapid growing legumes followed by cotton.
- Producing the mulch locally and imported to the field from surrounding areas e.g. L*eucaenea loppings* (Tarhalkar and Venugopalan, 1995).
- Intercropping or co-cultivation of short duration legumes between cotton rows and turning down is an option (Blaise, 2011). Strips of legumes can be grown as an alley after few rows of cotton and pruned regularly to be used as mulch. Intercropping and sequential relay cropping in cotton based cropping systems provide the mulch (Naudin and Balarabe, 2009).

When the soil surface is provided a cover and the crop residues are mulched, in general, it offers the following benefits (Unger, 1990); (i) moderate soil temperatures, (ii) reduce evaporation, (iii) improve biological activity and (iv) provides favourable environment for root growth.

Cotton crop residues

After cotton harvest, approximately 1.5-2.0 t/ha of cotton crop residue is available in the form of stalks and leaves. This crop residue is considered as a waste material and disposed of by burning. The quantity though low, is a precious C source especially in situations where only a single crop of cotton is taken up in a year. However, on-farm experiences indicate that when crop residues such as cotton stalks are recycled, it improved productivity (Blaise and Ravindran, 2003). In north India, which is irrigated, cotton-wheat and cotton-gram are established cropping systems. The residue of the previous crop can be effectively utilised as a surface cover and cotton planted directly with minimum soil disturbance (Jalota *et al*., 2008). In cotton-cereal systems, the biomass produced prior to cotton planting is as great as 5 t/ha and offers considerable protection to the soil and improves soil quality. On the other hand, in the cotton-legume system, the amount of residue cover provided by legume crop is small.

Considering this, farmers need to be advised that retaining even small amount of crop residues, available at the farm, would result in increased SOC. Importantly, no potential harmful effects of retaining cotton crop residues on the field were observed. However, cotton stalks are of poor quality because of their high lignin content, high C/N ratio (Blaise and Bhaskar, 2003) and therefore, could cause problems of N immobilisation (Chen *et al*., 2014). Further, for phytosanitary reasons, cotton crop residues are not recycled in most of the countries. However, the crop residue can be composted and made safe for application. By enriching with minerals such as rock phosphate and other organic manures such as poultry manure, farmyard manure, the value of the cotton stalk compost can be further enhanced (Reddy *et al*., 2017).

Legume cover crops

Various cover crops (legume and forage crops) have been tried in the cotton growing countries in Africa. It is ideal to incorporate leguminous residues because they mineralise at faster rate and release N rapidly due to its low C/N ratio. Conservation tillage practices when combined with surface managed crop residues sets in the processes whereby slow decomposition of residues results in (i) soil structural improvement and (ii) better recycling and availability of plant nutrients (Unger, 1990). Popular cover crops for Africa are Mucuna and lablab. In general, in Africa, cover crop is not grown as an inter-row crop since it affects the cotton lint quality.

Crop rotation

Apart from enhancing nutrient-use-efficiency, crop rotations offer the benefit of providing adequate residue cover and also to break cycles of the pest and disease (Giller *et al*., 2009). Nutrient use efficiency of N, P and K was higher with the cotton-soybean rotation (C-S) compared to the cotton-cotton (C-C) monoculture on the Vertisols of central India. Therefore, crop rotations that best fit the region and the cropping system, its economic viability etc. should be considered while designing the crop rotations. In Cameroon, the two-year rotation of cereal-cotton was designed (Naudin *et al*., 2010). The two year rotation of 'sorghum + cowpea – cotton' was found to be an ideal system that not only provides sufficient crop residues, but also ensures food security. In these systems, cotton is preferentially treated with fertilisers that benefit the subsequent cereal crops which do not receive any fertiliser inputs.

Conclusions

Producing more from less land will be the major challenge in the coming decades. Using the Best Management Practices such as the Conservation Agriculture (CA) can help address this challenge. Performance of CA in cotton based systems depends on three critical elements – minimising tillage, residue generation and its retention, and crop rotation. From the above, we can see how CA practices differ from region to region. Non-availability of adequate amount of crop residues, poor efficacy of popular herbicides to manage a wide spectrum of grassy and broad leaved weeds and lack of appropriate farm implements for practicing conservation agriculture are the impediments in adopting CA in cotton based systems. Therefore, it needs to be tailormade to suit the situation by considering the local conditions. Further information is needed, specifically for the various regions of Africa, on

1) Identification of tillage requirements
2) Identification of suitable cover crops that provide adequate plant biomass
3) Identification of an appropriate crop rotation system to avoid pests and disease outbreaks
4) Change in the farmers mindset for technology adoption

References

Baudron, F. 2007. Production ou Conservation? Le dilemme du coton en peripherie du Parc Transfrontie `re du W du Niger. Cre´ation-diffusion de syste `mesagroe ´cologiques plus durables et plus respectueux de l'environnement. Ouagadougou, Burkina Faso. ECOPAS.

Baudron, E., Tittonell, P., Corbeels, M., Letourmy, P., and Giller, K. E. 2012. Comparative performance of conservation agriculture and current small holder farming practices in semi-arid Zimbabwe. Field Crops Res. 132, 117–128. doi: 10.1016/j.fcr.2011.09.008.

Blaise, D. 2006. Effect of tillage systems on weed control, yield and fibre quality of upland (*Gossypium hirsutum* L.) and Asiatic tree cotton (*G. arboreum* L.). Soil and Tillage Research 91: 207-216.

Blaise, D. 2011. Tillage and green manure effects on Bt transgenic cotton (*Gossypium hirsutum* l.) hybrid grown on rainfed Vertisols of central India. Soil and Tillage Research 114: 86-96.

Blaise, D. and Bhaskar, K.S. 2003. Carbon mineralisation patterns of cotton leaves and stems in Vertisols and Inceptisols. *Archives of Agronomy and Soil Science* 49: 171-177.

Blaise, D. and Ravindran, C.D. 2003. Influence of tillage and residue management on growth and yield of cotton grown on a Vertisol over 5 years in a semi-arid region of India. Soil and Tillage Research 70: 163-173.

Bolliger,, A., Magid,, J., Amado, J.C.T., Skora Neto, F., Ribeiro, F., Calegari, A., Ralish, R., de Neegaard, A. and Donald, L.S. 2006. Taking stock of the Brazilian ''zero-till revolution'': a review of landmark research and farmers' practice. Adv. Agron. 91, 47–111.

Boquet, D.J., Hutchinson, R.L. and Breitenbeck, G.A. 2004. Long-term tillage, cover crop, and nitrogen rate effects on cotton: plant growth and yield components. Agron. J. 96, 1443–1452.

Casao, Jr. R., de Araujo, A.G. and Llanillo, R.F. 2012. No-till agriculture in southern Brazil. FAO and IAPAR, FAO, Rome, Italy.

Chaudhory *et al*., 2016. Evaluation of tillage and crop establishment methods integrated with relay seeding of wheat and mungbean for sustainable intensification of cotton-wheat system in South Asia. Field Crops Res. 199: 31-41.

Chen, B., Liu, E., Tian, Q., Yan, C. and Zhang, Y. 2014. Soil nitrogen dynamics and crop residues. A review. Agronomy for Sustainable Development, 34 (2), pp.429-442.

Corbeels, M., Scopel, E.,Cardoso, A.,Bernoux, M., Douzet, J.M. and Siqueira Neto, M., 2006. Soil carbon storage potential of direct seeding mulch-based cropping systems in the Cerrados of Brazil. Glob. Change Biol. 12: 1–15.

Dumanski, J., and R. Peiretti. 2013. Modern concepts of soil conservation. International Soil and Water Conservation Research 1(1):19-23.

Elwell, H. A., and M. Stocking. 1988. Loss of soil nutrients by sheet erosion is a major hidden farming cost. Zimbabwe Science News. 22[7]:79-82.

FAOSTAT. 2017. Available at http://www.fao.org/faostat/en/#data

Giller KE, Witter E, Corbeels M and Tittonell P. 2009. Conservation agriculture and smallholder farming in Africa: the heretics'view. Field Crops Res 114: 23-34.

Grabowski, P.P., J.M. Kerr, S. Haggblade, and S. Kabwe. 2016. Determinants of adoption and disadoption of minimum tillage by cotton farmers in Eastern Zambia. Agriculture, Ecosystems and Environment 231: 54–67.

Haggblade, S. and C. Plerhoples. 2010. Productivity impact of conservation farming on smallholder cotton farmers in Zambia. Food Security Research Project. MSU. Working paper No. 47.

Haggblade, S. and Tembo, G. 2003. Conservation farming in Zambia. International Food Policy Research Institute, Washington DC.

Heathcote, A.J. Filstrup, C.T. and Downing, J.A. 2013. Watershed sediment losses to lakes accelerating despite agricultural soil conservation efforts. PlosOne 8(1): e53554. doi: 10.1371/journal.pone.0053554

Hulugalle, N.R., de Bruyn, L.A.L. and Entwistle, P. 1997. Residual effects of tillage and crop rotation on soil properties, soil invertebrate numbers and nutrient uptake in an irrigated Vertisol sown to cotton. Appl. Soil Ecol. 7: 11-30.

IPCC (Intergovernmental Panel on Climate Change). 2013. Climate change 2013: The physical science basis. Working Group I contribution to the IPCC Fifth Assessment Report. Cambridge, United Kingdom: Cambridge University Press.

Jalota, S.K., Buttar, G.S., Sood, A., Chahal, G.B.S., Ray, S.S. and Panigrahy, S. 2008. Effects of sowing date, tillage and residue management on productivity of cotton (*Gossypium hirsutum* L.) – wheat (*Triticum aestivum* L.) system in northwest India. Soil and Tillage Research 99: 76-83.

Kassam, A.H., Mkowma, S. and Friedrich, T. 2016. Conservation Agriculture for Africa: Building resilient farming systems in a changing climate. CABI, Croydon, UK, 318 p.

Lal, R. 1976. No-tillage effects on soil properties under different crops in western Nigeria. Soil Sci. Soc. Am. J. 40, 762–768. doi: 10.2136/sssaj1976. 03615995004000050039x

Lal, R. 1985. Soil erosion and sediment transport research in tropical Africa. Hydrological Sci. J. 30: 2239-2256.

Mando, A. 1997. Effect of termites and mulch on the physical rehabilitation of the structurally crusted soils in the sahel, Land Degradation and Development 8, pp. 269–278.

Mavunganidze *et al*., 2014. The impact of tillage system and herbicides on weed density, diversity and yield of cotton (*Gossypium hirsutum* L.) and maize (*Zea mays* L.) under the smallholder sector. Crop Protection 58: 25-32.

Mert *et al*., 2006. Response of cotton (*Gossypium hirsutum* L.) to different tillage systems and intra-row spacing. Soil and Tillage Research 85: 221-228.

Montgomery, D.R. 2007. Soil erosion and agricultural sustainability. PNAS 104: 13268-13277.

Naudin, K. and Balarabe, O. 2009. Use of cover crops by north Cameroonian farmers in a cereal//cotton cropping system. In: Latos, T.H. (Ed.), Cover Crops and Crop Yields. Nova publisher, New York.

Naudin, K., E. Gozé, O. Balarabe, K.E. Giller, and E. Scopel. 2010. Impact of no tillage and mulching practices on cotton production in North Cameroon: A multilocational on-farm assessment. Soil and Tillage Research 108 (1-2):68-76.

Nyakatawa, E.Z., Reddy, K.C. and Lemunyon, J.L., 2001. Predicting soil erosion in conservation tillage cotton production systems using the revised universal soil loss equation (RUSLE). Soil Tillage Res. 57, 213–224.

Raunet, M. and Naudin, K. 2006. Lutte contre la désertification: l'apport d'une agriculture en semis direct sur couverture végètale permanente (SCV). Les dossiers thématiques du CSFD. No 4. Septembre 2006. CSFD/Agropolis, Montpellier, France, 40 p.

Reddy, D. D., Blaise, D., Kumrawat, B. and Singh, A.K. 2017. Evaluation of Integrated Nutrient Management Interventions for Cotton (*Gossypium hirsutum*) on a Vertisol in Central India. *Communications in Soil Science and Plant Analysis* 48:4,469-4,475

Reed, J.N., E.M. Barnes and K.D. Hake. 2009. US Cotton Growers Respond to Natural Resource Survey. Technical Information Section. International Cotton Advisory Committee, THE ICAC RECORDER, Vol. XXVII. No. 2, June 2009. http://cottontoday.cottoninc.com/2008-Cotton-Grower-Survey-Results/2008-Cotton-Grower-Survey-Results.pdf

Reeves, D.W., Price, A.J. and Patterson, M.J. 2005. Evaluation of three winter cereals for weed control in conservation-tillage non-transgenic cotton. Weed Technol. 19: 731-736.

Schwab *et al*., 2002. Conservation tillage systems for cotton in the Tennessee valley. Soil Sci. Soc. Am. J. 66:569–577.

Tarhalkar, P.P. and Venugopalan, M.V.., 1995. Effect of organic recycling of fodder legumes in stabilising productivity of rainfed cotton on marginal lands. Tropical Agriculture 72 : 73-75.

Thierfelder, C. and Wall, P. C., 2009. Effects of conservation agriculture techniques on infiltration and soil water content in Zambia and Zimbabwe. Soil Tillage Res.105, 217–227.

Thierfelder,C. and Wall, P.C. 2010. Rotation in conservation agriculture systems of Zambia: effects on soil quality and water relations. Exp. Agric. 46, 309–325. doi:10.1017/S001447971000030X.

Tripp, R. 2009. Biotechnology and agricultural development. Transgenic cotton, rural institutions and resource poor farmers. By Tripp R. (ed.) London and New York: Routledge

Unger, P. W. 1990. Conservation tillage systems. Adv. Soil Sci. 13, 27–67.

Usman, K., Khan, N., Khan, M.U., Rehman, A.U. and Ghulam, S. 2013. Impact of tillage and herbicides on weed density, yield and quality of cotton in wheat based cropping systems. J. Integrative Agri. 12: 1568-1579.

Wall,P.C. 2008.Tailoring conservation agriculture to the needs of small farmers in developing countries. J. Crop Improv. 19, 137–155. doi: 10.1300/J411v19 n01_07

Watts, D.B. *et al*., 2017. Nitrogen fertiliser sources and tillage effects on cotton growth, yield, and fiber quality in a coastal plain soil. Field Crops Res. 201: 184-191.