Title: WATER-SMART AGRICULTURE: MANAGING RAINWATER *INSITU* FOR SUSTAINING ENVIRONMENT AND FOOD PRODUCTION IN TANZANIA

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ABSTRACT

Available soil water management is critical for food production. Increasing climate variability attests importance of integrated systems of managing rainwater in-situ for crop production. This work attempted to improve tradition tillage practice by integrating practices, scientific knowledge and ideas in mitigating and adapting to climate variability. Integration of scientific ideas and technologies enhanced effectiveness in management of available soil water and soil productivity. Integrated cross-raised seedbed tillage practice, resulted into increased conservation of soil and water, built up of soil fertility and crops tolerance to prolonged no-rainfall spells. Subsoil available moisture increased from 17-23 mm in traditional practice plot to 43-62 mm in cross-raised seedbed practice plot. The soil organic carbon content increased from 19.4 to 25.2 g/kg in 0.1-0.2m soil layer of the raised seedbed as compared to increase from 19.4 to 20.8 g/kg in the same layer, of the traditional practice plots with organic materials incorporated. Productivity of bean and maize were significantly ($p<0.01$) increased by 46% and 108%, respectively, in integrated cross-raised seedbed tillage practice, compared to the traditional tillage practice. Profitability of using integrated cross-raised seedbed tillage practice is 105 to 125% over traditional farmer practice. The proposed future development should address constraints of input access by organizing smallholder farmers, linking them with micro-finance institutions and labour by mechanizing the cross-seedbed tillage practice to significantly increase uptake and impact in food production and environmental conservation in the face of climate change and variability.

1.0 BACKGROUND, PROBLEM STATEMENT AND JUSTIFICATION

1.1 Background

Water is a precious resource in life, which constitute on average over 70% of living organisms. Healthy environment and survival of living things is heavily determined by water availability. Food and fiber production through irrigated agriculture accounts for 70% of all fresh water use around the world. Environmental degradation and climate change and variability are intertwined problems, stressing water availability in turn threatening agriculture and food production, leading to hunger and looming poverty. These are overarching challenge to Millennium Development Goals (MDGs) for sustainable development on eradication of extreme hunger and poverty.

The growth of the population increases food demand at the same time exerts pressure on water resources, which in turn, result into environmental change and hence increased climate changes and variability, such as, increased temperature and rainfall variability (Karl *et al*., 1995). Climate change and variability influence water resources in many ways. These include increased drought frequencies, temperature and decline soil productivity (Thornton, 2012; Pendall *et al*., 2004; Farauta, *et al*., 2012). Increase in temperature and drought directly affects Soil Organic Matter (SOM), natural plant nutrients' supply and available soil moisture (Simard and Austin, 2010). Increase in extremes of the temperatures and drought frequencies in tropical environments often causes decline in agricultural land's capacity to retain and supply balanced plant nutrition. This happens due to fast oxidation of SOM and reduced recharge of available soil water (Simard and Austin, 2010).

1.2 The problem

In Tanzania, currently climate pattern is changing and is negatively affecting food security at household levels as well as national socio-economic development (URT, 2007). Linkages of the impacts of climate change and variability on environment and rural livelihoods are increasingly becoming evident (Madulu, 2003; Malley *et al*., 2007; 2008; 2009). Madulu (2003) observed a strong link of poverty to change in the climate. Malley *et al*., (2007) analyses in the semi-arid Usangu plain, southwestern Tanzania, found the link of increasing climate variability to increasing water stress and notable decline in land quality and in agricultural productivity. Other effects of the climate variability found were increase in rural conflicts over water resources (Malley *et al*., 2008), decline in wildlife biodiversity and energy generation capacity (Malley *et al*., 2007) and health risks, due to increase in scarcity of water for domestic needs (Malley *et al*., 2009).

Water stressed farm soils is desiccated and its productivity lowered substantially, growing crops get wilted or completely fail. The consequence of decline in agricultural land's productivity is the general food insecurity, characterized by downward spiral of low crop yields-low farmers' incomes-food insecurity. Simulations show that maize yields are lowered because of increased temperatures and decreased rainfall (URT, 2007). The results of simulation at national level show average yield decrease of 33%, but there are decreases as high as 84% in the central regions of Dodoma and Tabora. Furthermore, results reveal that climate change could reduce maize yield by 10-15% in Southern Highlands of Tanzania. Climate change and variability are predicted to significantly reduce future maize yields in Tanzania, through reducing agronomic productivity in all agro-ecological zones. These reductions are mainly due to increase in temperatures that shorten the length of the growing season, decrease in rainfall amount and its effectiveness and due to reduction in eco efficiency or use efficiency of water, nutrients and energy.

1.3 Justifications

Demographic growth and the impacts of climate change are expected to stress water availability leading to fewer water supplies for recharging aquifers, ecosystems services, food production and domestic use. World wide, farmers have not been passive to food production stresses, they tend to actively develop their own local practices, which mitigate and/or help them to cop with the effects of climate change and variability on the land productive quality and food production (Critchley *et al.,* 1994). Lal, (1990), reported that, smallholder farmers throughout the world use ridge tillage systems, with many different modifications but with the same goal, to enhance the land productive quality. Other examples in of farmers' practices in Africa linked to the land's quality and climate deteriorations include planting pits practiced in the Dogon plateau, Nigeria (Kassogue *et al.,* 1990), the *deshek* basins in the Bay Region in Somalia and the *Kofyar* used in the Jos plateau, Nigeria (Critchley *et al.,* 1994). The *Chitemene* and *Fundikila* are reported in Zambia (Lungu, 1999) and *Ngoro* cultivation system in south-western Tanzania (Malley *et al*., 2004).

According to Hatfield *et al.,* (1998), smallholder farmers use ridge tillage systems for: saving the labor, enhancing the soil fertility, better management of water, controlling water and wind erosion, facilitating multiple cropping, enhancing the rooting depth and increased pest management. Work of Wiyo *et al*., (1999) in Malawi, show that ridge tillage plays important role in on-field water harvesting for crop use. Similarly, Malley *et al*., (2004) investigations into the effects of *Ngoro* cultivation system on water conservation and crop performance, used in steep slopes in south-western Tanzania revealed that, this traditional practice play multiple roles for sustainable management of the land productive quality. However, effectiveness is declining due to population growth, changes in social, economic and cultural settings of the rural people (Malley *et al*., 2006). Evidence show that there is a scope for improvement of farmers' practices through integrating scientific knowledge and modern technologies (Malley *et al*., 2009), which would deliver effective and farmers' acceptable integrated hybrid innovations for promotion in managing the water in food production.

2.0 CROSS-RAISED SEEDBED PRACTICE FOR MANAGING RAINWATER *INSITU*

Managing rainwater *insitu* encompasses use of simple soil surface roughness to enhance rainwater infiltration and conservation into the soil for crop use, managing soil, organic matter and nutrients on the farmlands. Mulching, trash lines, raised seedbed, ridging, tie-ridges, box ridging, basins and planting pits are some of such practices. However, integrated practice increases effectiveness in management of plant available water in the soil. Using the benefits and weaknesses of effectiveness of ridging, tie-ridges and planting basins alone, Agricultural Research Institute-Uyole conceptualized integrative cross-raised seedbed tillage and tested the practice (Figure 1). The integrated cross-raised seedbed tillage practice encompassed application of raised seedbed spaced at 0.8 m which are crossed by other raised seedbed at 2-4 m intervals making a field with a mosaic of rectangular basins surrounded by raised seedbeds. All raised seedbeds are surfaces for planting the crop and basins harvest rainwater, soil and nutrients *insitu*, which are conserved on-farmland (Figure1). Organic residues are covered in the raised seedbeds and others are placed on the basin during weeding or after crop harvest, legume cereal rotation and soil disturbances minimized through alternating soil tillage and no-till practices. The practice is climate-smart through sequestration of organic carbon and management of water within the fields.

Figure 1 Within the farm trapping of the rainwater, soil and nutrient by cross-raised seedbeds tillage practice.

2.1 Functioning of integrating crossing-seedbed for *in-situ* management of rainwater

The basins of the cross-seedbed tillage practice create surface roughness within the field, which traps rainwater, preventing run-off (Figure 1). This facilitates infiltration of rainwater into the soil and prevents losses of the soil, water and nutrients. These losses are the processes through which quality of the land is depleted. Infiltrated rainwater recharges underground reserve, which is available for crops use, during the water stress. This reduces the water stress in crops, in periods of the prolonged no-rainfall of the growing seasons. Important water management function inherent in the practice are: first, when there is excess water, due to rainfall variability the seedling root zone become free of excess water through draining it into the basins; second, when there is moisture stress, conserved water in the subsoil, supports the plant growth, through capillary movement to root zone; and third, the incorporated organic residues into the soil, increases the soil humus, which in turn improves water and nutrient holding capacity of the soil. Soil humus is essential for increasing capacity of the land to retain soil moisture and nutrients for a longer period, and for enhancing the buffering capacity of the soil to pH change. According to Brady (1990), on the weight basis, humus can hold 4-5 times more available water than mineral soils. The crop rotation and judicious use of fertilizers in the practice increases water use efficiency of the crops. This implies that, the cross-raised seed bed tillage practice is important in soil water management as well improving the production environment for food production.

2.2 Conservation in the integrated cross-raised seedbed tillage practice

Integrated cross-seedbed tillage system increased soil and moisture conservation. The soil water monitoring showed that in the top 0-0.1m of the surface soil profile on the ridges; consistently have low moisture content (17-32 mm) than traditional cultivated plots moisture contents (21-37mm). The soil profile of 0.2-0.3m, had more soil moisture content (43-62mm) in cross-raised seedbed plots, compared to the traditionally cultivated plots (29-47 mm). The boreholes near the farms applying the practice, farmers asserted increased water levels that were available for longer time during the dry seasons. The soil organic carbon content increased from 19.4 to 25.2 g/kg in 0.1-0.2m soil layer of the organic ridges as compared to increase from 19.4 to 20.8 g/kg in the same layer, of the traditional practice plots with organic materials incorporated. Monitoring of the built up of the nutrients on farmers fields show on average increased available soil phosphorus from 4.9 to 7.4 mg/kg and soil organic carbon content from 20 to 22.4g/kg.

2.3 Productivity in the integrated cross-raised seedbed tillage practice

There were significant increases in the crop growth vigour by integrated cross-seedbed tillage practices (Figure 2 & 3). Cross-raised seedbed in combination with mineral fertilizers has the highest maize yields. This implies that, available moisture in combination with soil fertility management increases efficiency in crop productivity.

Figure 2 Bean grown in fields with cross-raised seedbed tillage practice

Figure 3 Maize grown after beans in undisturbed field with cross-raised seedbed tillage practice

Bean and maize yields were significantly ($p<0.01$) increased by 46% and 108%, respectively, in integrated cross-raised seedbed tillage practice, compared to the traditional ridge tillage practices (Table 1). The additional planting surfaces due to cross-seedbed increased plant population by 18%

over the recommended 44,444 per hectare in conventional tillage practice. Assessment of 100 cob weights showed that, in traditional tillage practice, mean 100 cob weight was 12.3 kg, while in integrated cross-raised seedbed tillage practices was 15.9 kg (Table 1). This means cross-raised seedbed trapped moisture increased soil capacity to support high plant population and increased the crop productivity, apart from increasing the surface per unit area for planting. Application of the integrated cross-raised seedbed tillage practice at an acre farm scale, revealed that bean and maize yields have increased by over 60%, compared with the baseline data (Table 2).

Table 1 Means of on-farm bean and maize grain yields and 100-cob weights from traditional ridge tillage practices and improved- integrated ridge tillage practices in Mbozi plateau, SW Tanzania

Practices tested with farmers	**Bean yield (kg /ha) in 2000 (N = 8)**	**Maize yield (kg/ha) in 2001 (N = 8)**	**Maize 100 cob weight (kg) (N=8)**
Traditional tillage practices[1]	471	1730	12.34
Integrated cross-raised seedbed tillage practices[2]	686	3600	15.93
SE	49	530	0.87
t-value	4.37**	3.54**	4.12**

[1]bean crop grown on open ridges with organic incorporated **but without mineral fertilizers** and then maize was grown after beans harvest by **opening the ridges into flat land** with **fertilizers applied to maize** as recommended.

[2]bean crop grown on **integrated cross-raised seedbed tillage practice** with organics incorporated and then maize planted by **dibbling on the same ridges**. **Fertilizers applied to both crops** as recommended.

** Significant at $p \leq 0.01$

Table 2 Mean beans and maize yields from harvest measurement in the farm plots using the integrated cross-raised seedbed tillage practice and from the survey before and after intervention in Mbozi plateau, SW Tanzania.

Cropping season /survey	**Number of farms/ households**	**Mean yield (kg/ha)**	
		Beans	**Maize**
2004/2005	8	297.80	3,023.00
2005/2006	9	421.00	3,622.20
2006/2007	9	858.12	3,886.70
After-intervention survey of 50 households	32*	960.43	4,565.00

Pre-intervention HH survey (baseline)	80	325.05	1,998.76

* Number of the HH, who harvested at least one bean-maize cycle under integrated cross-raised seedbed tillage practice

2.4 Profitability of the integrated cross-raised seedbed tillage practice

Assessment of economic profitability of cross-raised seedbed tillage system is 105 to 125% over traditional farmer practice (Figure 4). The profitability of the bean-maize rotation cycles, under–integrated cross-seedbed tillage practices was more than two-fold of the traditional tillage practices. The profitability is a result of high productivity of the crops planted on the integrated cross-raised seedbed tillage practice and reduced cultivation costs by not destroying the seedbeds, replaced by the minimum tillage idea for maize planting. This means that, use of additional inputs for improving the traditional practice into cross-raised seedbed tillage practice is a worth investment by farming households for increasing their income through increased crop productivity and saving in following season.

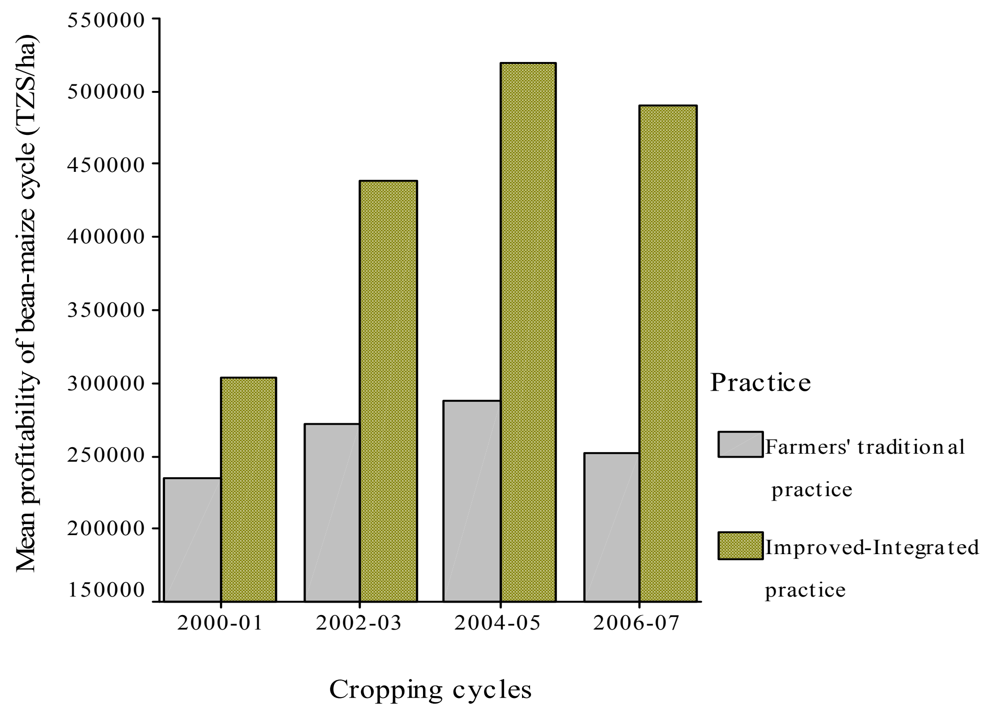

Figure 4 Profitability trend of using traditional practice and integrated cross-raised seedbed tillage practices in Mbozi plateau, SW Tanzania.

2.5 Farmer perceptions of cross-raised seedbed tillage practice

In a household survey conducted in 2007, 94% of the respondents showed that, use of the integrated cross-raised seedbed tillage practices is beneficial (Table 3). The benefits indicated in using the practices are: soil and water conservation (100%), soil fertility built up on the farms (96%), increased yield of crops (96%) and saving labour or its costs for land preparation (68%) in the following season for growing of maize (Table 3). About 58% and 60% of the respondent, respectively, reported increase in effectiveness of soil and water conservation and enhancement of the soil fertility, to the extent of 75-100% on the farms (Table 3).

Table 3 Observed benefits of the integrated cross-raised seedbed tillage practice and opinions of those who have been exposed to the practices on the farms in Mbozi plateau, SW Tanzania.

Reported benefits/opinions	Respondents	Frequency (%)
Overall views on benefits		
Improved-integrated practices are beneficial (N=50)	47	94.0
Improved-integrated practices are not beneficial (N=50)	1	2.0
Net certain whether beneficial or not (N=50)	2	4.0
Type of benefits reported[1]		
Increased crop yield (N= 47)	45	95.7
Soil and water conservation (N= 47)	47	100.0
Soil fertility build up on farm (N = 47)	45	95.7
Saving of labour in maize cropping season (N = 47)	32	68.1
Perceived extent of benefits in management of the soil and water		
Soil and water conservation (N = 47)		
• Increased in the range of 25-49%	1	2.1
• Increase in the range of 50-74%	19	40.4
• Increase in the range of 75-100%	27	57.5
Soil fertility build up (N = 45)		
• Increased in the range of 25-49%	2	4.4
• Increase in the range of 50-74%	16	35.6
• Increase in the range of 75-100%	27	60.0
Adoption setbacks of the improved-integrated practices (N= 50)		
No setbacks in using the practices	40	80.0
Some setbacks for using the practices	10	20.0
Setbacks of using the practices (N= 10)		
Cash outlay for external inputs required	7	70.0
Increased labour in preparation improved-integrated ridges in first year	3	30.0

[1]more than one response per respondent were recorded.

2.6 Limitation to adoption of cross-raised seedbed tillage practice

About 20% reported setback of in cross-raised seedbed tillage practice as cash-outlay required for external inputs (fertilizers, roundup herbicide and improved seeds), and initial labour in establishing integrated cross-raised seedbed tillage practice. The increased inputs prices aggravated the cash-outlay limitation, which hinders farmers from using the complementary technologies in harnessing practices for efficient use of available water in food production. The practice is currently used by over 300 households in Mbozi plateau.

3.0 CONCLUSION AND FUTURE DEVELOPMENT

3.1 Conclusion

The cross-raised seedbed tillage practice is a hybrid practice that proved to be effective in managing rainwater *in-situ*, significantly increased productivity and profitability in beans and maize production at farm scale. In addition, it conserves the environment through soil and water conservation in the farmlands, without losses. Farmers' perception showed the practice is acceptable to significant proportion. However, problem of accessing inputs for good farm practices would seemingly reduce accruing benefits of water conservation and through less productivity and profitability.

3.2 Proposed future development

Wider uptake of integrated cross-raised seedbed practice by smallholder farmers for increased resilience to climate change and variability impacts, the limitations should be minimized, such capital to access associated inputs. Support to organizing smallholder farmers and linking them with microfinance institutions, such as Savings and Credit Cooperative Societies (SACCOS) and Agricultural Marketing Cooperatives Societies (AMCOS) is crucial. The labour demand based on hand hoe alone should be addressed through partial mechanization of the operation. An innovative attempt to use a combination of animal drawn mouldboard plough and hand hoe, showed possible to reduce labour and get same results. However, the extent of labour saving benefits of using combination of hand hoe and the animal drawn mouldboard plough has not clearly been established during this work. In addition, it has not been clear if the benefits of cross-seedbed tillage will increase or decrease, when draft animal or power tillers are applied in tillage in combination hand hoe to complete cross-seedbed. Therefore, it is logical, to undertake additional development to harness the benefits, using farmer participatory approach through testing and subsequent promotion to more farmers for reduced drudgery, while sustaining technical and economic effectiveness of cross-seedbed tillage practice. This would then, result into increased use of the cross-seedbed by more farmers in the area and elsewhere for effective rainwater management for food production and environmental conservation in the face of climate change and variability.

The proposal aims to increase the use of the cross-raised seedbed tillage practice for increased food production and environmental conservation. This proposed work objectives specifically are:

- To organize smallholder farmers and link to microfinance institutions for soft input loans
- To develop partially mechanized cross-raised seedbed tillage practice using animal drawn moldboard plough and/or power tillers with bed former attachment in combination with hand hoe.
- To determine extent of labor saving benefits of partial mechanization of cross-raised seedbed practice.
- To asses if the use of mechanized tillage would not affect environmental and agronomic benefits of the cross-raised seedbed tillage.
- To promote partially mechanized cross-raised seedbed tillage with reduced labor inputs for adoption by more farmers.

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