



Extrapolating effects of conservation tillage on yield, soil moisture and dry spell mitigation using simulation modelling

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ABSTRACT

There is big effort to disseminate conservation tillage practices in Tanzania. Despite wide spread field demonstrations there has been some field experiments meant to assess and verify suitability of the tillage options in local areas. Much of the experiments are short lived and thus long term effects of the tillage options are unknown. Experiments to study long term effects of the tillage options are lacking because they are expensive and cannot be easily managed. Crop simulation models have the ability to use long term weather data and the local soil parameters to assess long term effects of the tillage practices. The Agricultural Production Systems Simulator (APSIM) crop simulation model; was used to simulate long term production series of soil moisture and grain yield based on the soil and weather conditions in Mkoji sub-catchment of the great Ruaha river basin in Tanzania. A 24 year simulated maize yield series based on conventional tillage with ox-plough, without surface crop residues (CT) treatment was compared with similar yield series based on conservation tillage (ox-ripping, with surface crop residues (RR)). Results showed that predicted yield averages were significantly higher in conservation tillage than in conventional tillage ($P < 0.001$). Long term analysis, using APSIM simulation model, showed that average soil moisture in the conservation tillage was significantly higher ($P < 0.05$) (about 0.29 mm/mm) than in conventional tillage (0.22 mm/mm) treatment during the seasons which received rainfall between 468 and 770 mm. Similarly the conservation tillage treatment recorded significantly higher yields (4.4 t/ha) ($P < 0.01$) than the conventional tillage (3.6 t/ha) treatment in the same range of seasonal rainfall. On the other hand there was no significant difference in soil moisture for the seasons which received rainfall above 770 mm. In these seasons grain yield in conservation tillage treatment was significantly lower (3.1 kg/ha) than in the conventional tillage treatment (4.8 kg/ha) ($P < 0.05$). Results also indicated a probability of 0.5 of getting higher yield in conservation than in conventional tillage practice. The conservation tillage treatment had the ability to even-out the acute and long intra-seasonal dry spells. For example a 36-days agricultural dry spell which occurred between 85th and 130th day after planting in the 1989/1990 season (in the CT treatment) was mitigated to zero days in the RR treatment by maintaining soil moisture above the critical point. Critical soil moisture for maize was measured at 0.55 of maximum soil moisture that can be depleted crop (0.55 D). It is concluded that conservation tillage practice where ripping and surface crop residues is used is much more effective in mitigating dry spells and increase productivity in a seasonal rainfall range of between 460 and 770 mm. It is recommended that farmers in the area adopt that type of conservation tillage because rainfall was in this range (460–770 mm) in 12 out of the past 24 years, indicating possibility of yield losses once in every 2 years.

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1. Introduction

There are efforts to disseminate conservation tillage practices among smallholder farmers in Tanzania (Shetto and Owenya, 2007). These efforts are accompanied by activities to validate some of conservation tillage technologies such as ripping, soil surface

cover with organic crop residues, cover crops and crop rotations (Mkomwa et al., 2007; Ringo et al., 2007; Enfors, 2009). There were some experiments also to validate ability of ripping with crop residue mulch in enhancing water productivity and moderating irrigation scheduling in Mkoji sub-catchment (Mlengeru, 2008). A considerable knowledge exists on the advantages of conservation tillage practices as dry spell mitigation and productivity enhancement measures (Barron et al., 2003). However, most research in Africa quantified soil water storage (e.g. Makurira et al., 2007)

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and runoff yield (Rwehumbiza et al., 2000; Bwana, 2008) in various types of conservation tillage practices. Most such studies correlated moisture conservation and grain productivity in trying to demonstrate good effects of the tillage practices. Some studies linked soil moisture storage and runoff to ability of conservation tillage in mitigating effects of intra-seasonal dry spells. A study by Baron et al. (2003) in Machakos Kenya demonstrated a detailed analysis of on-farm water balance in semi-arid environment. However the study was based on supplementary irrigation and in situ rainwater harvesting using terraces and, not other conservation tillage practices such as ripping. Rockström et al. (2009) presented results from most recent participatory on-farm experiments on conservation farming systems for smallholder farmers carried out over 3–4 years (1999–2003) in Ethiopia, Kenya, Tanzania and Zambia. There was a thorough analysis of in situ rainwater harvesting effect of conservation tillage treatments such as ripping, tie ridging and mulch producing cover crops and the resulting relationship between yield and rainfall productivity. However conclusions were based on yield-rainfall relationships lacking insight into dry spells dynamics and how mitigation by conservation tillage is effected.

Actually most of the studies in Tanzania and in Africa South of the Sahara, at large, were meant to assess and verify suitability of the tillage options in local areas with very little flexibility and transferability of results (Mkomwa et al., 2007; Rockström et al., 2009; Enfors, 2009). Further more some of the experiments were short lived while long term effects of the tillage options are not well understood. There is therefore an incomplete picture of the interactions among biophysical factors related to conservation tillage practices in the short and long term perspective. A combination of field experiments and computer simulation model can be an appropriate option to capture important biophysical factors and their interactions so to have a comprehensive elucidation of the effects of conservation tillage practices on yield and productivity.

Crop simulation models (CSMs) have been used successfully as powerful tools for irrigation and agricultural decision-making (Hoogenboom, 2000). There are practical applications of decision support systems (based on crop simulation models) for pests and diseases (Kropff et al., 1995), breeding (Yin et al., 2000) and in assessing and optimizing irrigation water management scheduling (e.g., Li et al., 2005) to mention but a few examples. They are also being used in evaluating crop management practices; yield gap analyses, strategic and tactical decision-making, as educational tools and study development processes which are either too complex or time-demanding to study in the field (e.g., Ruiz-Nogueira et al., 2001; Graves et al., 2002; Kato et al., 2004; Shang et al., 2004).

APSIM model is one of the efficient tools in agro-ecosystem analysis. The model has been widely tested in a variety of conditions in Australia and Europe (Asseng et al., 2004). APSIM modelers have widely studied African farming systems and have improvised modules to simulate low yields due to genetically low seed quality and the low available soil phosphorus (Probert et al., 2004) prevalent in African farming systems. In this regard Probert et al. (2005) developed a module to enable simulation of release of nitrogen and phosphorus from manure and organic residues which are major sources of *P* in the cited farming systems. APSIM can of late simulate intercropping (Carberry et al., 1996), relay cropping and green manuring (Robertson et al., 2005), legume crops such as pigeon pea (Robertson et al., 2001) and other cereals such as millet (van Oosterom et al., 2001). This has enhanced capabilities of APSIM to carry out credible simulations for the diversity of management systems, soil conditions, cereal types and legumes as dictated by the situation in southern African farming systems (Ncube et al., 2009).

Whitbread et al. (2010) presents an extensive experience in the use of APSIM from work conducted in Kenya, Malawi, South Africa

and Zimbabwe between 1985 and 2008, primarily in maize-based farming systems. These researchers have demonstrated ability of APSIM model in “adding value to field experimentation; facilitate direct engagement with farmers to develop better understanding of key drivers of crop growth; explore constraints and opportunities with researchers and change agents; and generate understanding of key system drivers and seasonal variation for institutions and service providers”. The use of APSIM in smallholder systems in Africa outside this group of scientists is still young, where a few instances of use in Kenya (Rao and Okwach, 2005) can be sighted. While APSIM has a lot of capabilities shown to assist in exploring various management options under African conditions (Carberry et al., 2002), there has been limited use of APSIM to simulate observed crop response to conservation tillage in crop production. This study therefore used field experiments data to parameterize and validate the APSIM model. The model was then used to enhance rigorous analysis of the potentials of conservation tillage in improving water productivity through mitigating dry spells by simulating predictions based on measured climate variables from the last 24 seasons of the same site. Therefore, the main objective was to study the long term trends of the effects of conservation tillage on soil moisture, yield and dry spell mitigation. This was done by validating the APSIM model followed by simulating the effects of conservation tillage practice on soil moisture and yield for the last 24 years in Mkoji sub-catchment.

2. Materials and methods

2.1. Study site, experimental design and crop management

A field experiment was conducted at the Ministry of Agriculture Training Institute Igurusi farm located within ‘Igurusi ya Zamani’ Traditional Irrigation Scheme (IZTIS), representing the semi-arid low lands in the Mkoji sub-catchment and run for three rainy seasons of 2005/2006, 2006/2007 and 2007/2008. IZTIS lies on latitude 8.33°S and longitude 33.53°E, at an altitude ranging from 1100 to 1200 m above mean sea level. The location was strategically selected to make use of the long term climatic data at Igurusi agromet station and to represent typical soils under maize production in the semi-arid part of the sub-catchment. Six tillage treatments were tested in the experiment as follows:

- (1) Conventional tillage with ox-plough, without surface crop residues (CT).
- (2) Conventional tillage with ox-plough, with surface crop residues (CTR).
- (3) Conventional tillage with ox-plough, with surface crop residues and lablab dolicos cover crop (CTRCv).
- (4) Tie ridging (TR).
- (5) Ox-ripping, with surface crop residues (RR).
- (6) Ox-ripping, with surface crop residues and lablab dolicos cover crop (RRCv).
- (7) The experiment was randomized complete block design (RCBD) with six tillage treatments replicated three times. This resulted in 18 experimental plots of 4.5 m wide and 15 m long (67.5 m²) with length running down 2% slope. Supplementary irrigation.

Tanzania Maize Variety 1 – Streak Resistant (TMV1–ST) (*Zea mays* L.) composite maize cultivar one of the maize varieties commonly grown in the study area was used as a test crop. The crop was planted at an inter-row spacing of 0.75 m and intra-row spacing of 0.30 m in all the plots, which resulted in 300 plants per plot (extrapolated plant population of 44,444 plants per hectare). Planting was done on January 6th, 21st December, and 15th January for

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