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Effects of selected soil and water conservation techniques on runoff, sediment yield and maize productivity under sub-humid and semi-arid conditions in Kenya

K.F. Ngetich [a,*], J. Diels [b], C.A. Shisanya [a], J.N. Mugwe [a], M. Mucheru-muna [a], D.N. Mugendi [c]

[a] Kenyatta University, P.O. Box 43844-00100, Nairobi, Kenya
[b] K.U. Leuven, Department of Earth and Environmental Sciences, Celestijnenlaan 200E, Box 2411, B-3001 Leuven, Belgium
[c] Embu University College, P.O. Box Embu 6-60100, Embu, Kenya

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ABSTRACT

The aim of this work is to investigate the consequences of selected soil and water conservation techniques and tillage practices on runoff amounts, sediment yield and maize yields under semi-arid and sub-humid environments. Field trials were set in Kigogo primary school in Meru South Sub-County, Tharaka Nithi County, representing the sub-humid conditions, and Machang'a secondary in Mbeere South Sub-County, Embu County (semi-arid) in the central highlands of Kenya. The experiment layout was a randomized complete block design and the treatments were implemented in runoff plots. Tied ridging (TR) was the most efficient technique in reducing runoff and sediment yield and at the same time boosting crop yields in the semi-arid region. It significantly ($p < 0.05$) reduced sediment yields by 94% compared to the conventional tillage (CT) during the study period. The effects were particularly strong in periods of below average rainfall (dry seasons). During the drier season of short rains 2010 (SR10), grain yield under TR was 7 times higher compared to CT ($p < 0.01$). In the sub-humid region, minimum tillage (MT) generated high runoff but relatively low sediment yield compared to CT. During periods of enough rainfall (over 450 mm per season) in the drier site, intercropping suppressed maize yields significantly ($p < 0.01$) by 42% compared to conventional tillage in the drier site. The results on the magnitude of runoff and sediment under the different soil and farm management practices are crucial in selection and promotion of valid farm management practices and tillage alternatives that not only abate soil erosion but also boost agricultural productivity in both sub-humid and semi-arid agro-ecological zones.

1. Introduction

Erosion by water is a primary agent of soil degradation at the global scale, affecting 1094 million ha, or roughly 56% of the land experiencing human induced degradation (Oldeman et al., 1991). Most regions of the humid tropics of Africa suffer from severe land degradation because of water erosion with its detrimental impact on food and agricultural productivity and production (Defersha and Melesse, 2012a).

In Kenya, soil erosion is mainly due to surface-water runoff. According to El Swaify et al. (1982), erosion rates of up to 200 ton/ha/yr have been noted in Kenya. Based on the Revised Universal Soil Loss Equation, Angima et al. (2003) predicted that total annual soil loss variation from one overland flow segment to the next ranged from 134 Mg ha^{-1} per year for slopes with average slope length and steepness (LS) factors of 0–10 to 549 Mg ha^{-1} per year for slopes with average LS-factors of 20–30 in the central Kenyan highland conditions. Soil degradation by accelerated erosion implies long-term decline in the soil's productivity and in the moderating capacity of its environment and is therefore a serious problem (Lal, 2001). The problem is more pronounced in the marginal lands, such as most semi-arid parts of Kenya, due to erratic and highly variable rainfall both spatially and temporally. The rainfall often occurs as high intensity, short duration giving rise to severe soil erosion especially early in the cropping season when the ground is still bare (Chikozho, 2010; Trabucco et al., 2008). Besides the undesirable effect of soil erosion, soil moisture is generally limited and crop growth is almost always stressed by drought during the growing season, resulting in decreased and unsustainable crop yields especially in the marginal lands.

The quantification of the forms/type, rate, and extent of erosion has been the primary goal of soil erosion-related research worldwide. As a result, much more is known about the erosion process than the consequences of erosion (Pierce and Lal, 1994). There is a lack of information on the effect of erosion on crop yields and efficiency of management practices.

The main limitation in stabilizing and increasing grain yields in rainfed farming systems of dry-spell prone areas is crop water stress

* Corresponding author at: Department of Agricultural Resource Management, Kenyatta University, P.O. Box 43844-00100, Nairobi, Kenya. Tel.: +254 721 289 269.
E-mail address: felixngetich@gmail.com (K.F. Ngetich).

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caused by inefficient use of total available seasonal rainwater (McHugh et al., 2007). Even during periods of high seasonal rainfall, if the interval between consecutive rain events is too long it can cause total pasture and crop failure (Tilahun, 2006). The risk of drought in sub-Saharan Africa is also linked to lack of available water as a result of deteriorated soil physical characteristics (Stroosnijder and Slegers, 2008) accelerated by physical processes such as soil erosion due to runoff. Runoff is a major force that initiates soil movement, transports sediments and accounts for the redistribution of rainfall water (Malam Issa et al., 2011). Runoff can be caused by low infiltration rates as a result of soil physical properties such as crusting, compaction, expanding clay minerals or due to saturation, slope surface management as well as rainfall properties. Infiltration capacity is the most important factor controlling runoff. Soil infiltration capacity is related to spatial variability of soil properties such as structure, organic matter content, soil texture and antecedent soil moisture (Vaezi et al., 2010). Soil structure is strongly influenced by processes such as tillage, cropping system and climate.

Management of soil through conventional tillage changes soil water storage, evaporation losses and soil susceptibility to runoff generation. Most small scale farmers practice it. The advantages are clear: weeds are well controlled and the sowing and planting operation can be done effectively (Jin et al., 2007). However, the conventional tillage practices are very far from being sustainable and environmentally compatible from a soil and water conservation perspective because of the uncovered soil surface (Jin et al., 2007). In addition to the obvious effects on erosion rates and water losses through runoff, soil disturbance during regular tillage enhances direct evaporation of water from the soil surface. Increased evaporation of water with tillage has also been attributed to enhanced vapor flow near the surface and greater absorption of radiation by a tilled surface (Schwartz et al., 2010). Knowledge on the merits and demerits of conventional tillage notwithstanding, there is a gap in the quantification of runoff generation, sediment yields and impact on crop yields under rainfed farming systems and different soil types in the tropics.

Minimum tillage has the potential to reduce structural degradation of soil, or may reverse it, compared to conventional tillage systems (Karunatilake and van Es, 2002). Soil physical properties that are influenced by minimum tillage include bulk density, infiltration and water retention (Osunbitan et al., 2004). Improved infiltration of rainwater into the soil potentially increases water availability to plants, reduces surface runoff and improves groundwater recharge (Lipic et al., 2005). Depending on the exact technique, minimum tillage can substantially reduce soil erosion. For instance, in a study by Towery (1998) minimum tillage reduced soil erosion by 68%. Albeit the beneficial effect of minimum tillage especially on soil erosion reduction being known, there is paucity of quantitative data on its effect on runoff reduction and crop yield performance.

Mulch cover reduces surface runoff and holds rainwater on the soil surface thereby giving it more time to infiltrate into the soil (Mupangwa et al., 2007). It also shades the soil, serves as a water vapor barrier against evaporation losses and increases infiltration (Mulumba and Lal, 2008). Deng et al. (2006) reports an improved water-use efficiency by 10–20% as a result of reduced soil evaporation and increased plant transpiration attributed to mulching while Bezborodov et al. (2010) reports that, straw mulching has been shown to increase water-use efficiency from 1.55 to 1.84 kg m^{-3} maize. Mulching is a promising soil management practice that can increase soil water storage especially in semi-arid regions (Deng et al., 2006; Wang et al., 2009; Zhang et al., 2009). Despite the high potential of mulch, its effect for increasing yield would depend on the amount of precipitation during the crop growth season (Wang et al., 2009). Besides the runoff reduction, mulching affects hydro-thermal regime of soils by moderating soil temperature and reducing soil water evaporation component of evapotranspiration and controls weeds by their smothering action (Arora et al., 2011). Soil biota increase in a mulched soil environment thereby improving nutrient cycling and organic matter build up over a period of several years (Holland, 2004). Although the highlighted potential benefits can lead to improvements in crop yields, there is a lack of quantitative data on the effect of mulch on runoff reduction, sediment yield reduction and ultimately their effect on crop yields under sub-humid, arid and semi-arid environments of tropical regions.

Legume-cereal intercropping is common throughout East and Southern Africa (Giller, 2001). Farmers commonly intercrop to secure food production by averting risk and to maximize utilization of land and labor. When crops are complimentary in terms of growth pattern, aboveground canopy, rooting system, and their water and nutrient demand, intercropping effectively enables a more efficient utilization of available resources (sunlight, moisture and soil nutrients) and can result in relatively higher yields than when crops are grown separately, as pure stands (Mucheru-muna et al., 2010). Besides fertility related benefits, intercropping ensures good ground cover which can reduce runoff and increase infiltration (Olasantan, 1988). Increased infiltration rate in an intercrop may also be caused by increased soil biota activity as a result of lower soil temperature (Hulugalle and Ezumah, 1991). A special feature of intercrops is that, for some time during growth the component crops compete with each other for available resources (Fukai and Trenbath, 1993) leading to overall lower benefits when one of the resources is highly limiting. In order to overcome this limitation, studies have been done on the best arrangement of the intercropped crops and the best intercropping system recommended for Kenya is an innovative, improved intercropping system, named Mbili (kiswahili for "two", and an acronym for "Managing Beneficial Interactions in Legume Intercrops"); two maize rows are alternated by two legume rows, also known as a two-by-two staggered arrangement (Mucheru-muna et al., 2010; Tungani et al., 2002; Woomer, 2007). Mbili system superiority has been tested in the Central Highlands of Kenya by Mucheru-muna et al. (2010) and recommended based on its effect on the fertility status of the soil, but limited information is available on its impact on runoff generation and sediment yields under rainfed conditions.

Tied ridging can decrease runoff, increase water infiltration and consequently greater water storage than with either flat planting or open ridging. Planting on tied ridges has been found to result in striking yield increases on the Alfisols of the West African semi-arid tropics (Hulugalle, 1987). Apart from tied ridging reducing runoff, it increases profile water content and hence root growth and development. If poorly implemented, ridging can act as waterways and may cause erosion and this is the main reason of tied ridging; connecting the ridges every 2–3 m so that small basins are formed (Nuti et al., 2009; Temesgen et al., 2009). The exact impact of tied ridging effect on runoff and sediment yield reduction in the tropics under rainfed conditions is lacking.

Adoption of appropriate on-farm crop management strategies and tillage practices can be the key in reducing runoff generation and soil erosion. These appropriate management practices can increase available water content, enhance soil fertility and reduce sediment loss compared to the conventional practices. Therefore, understanding runoff, soil erosion, sediment yield and how they affect maize yield and agricultural productivity is essential for developing practices and policies for decision making, planning and reduction of soil erosion.

Based on this assumption, runoff plots were installed at two sites with varying agro-ecological conditions. The objective of the study was to evaluate the effects of minimum tillage, mulching, conventional tillage, tied ridging and Mbili intercropping on runoff amounts, sediment yield and maize yields under semi-arid and sub-humid environments in the Central Highlands of Kenya.

2. Materials and methods

2.1. Study area

The field research was carried at two contrasting sites in Central Kenya (Fig. 1): Kigogo (0°23′S and 37°37′E) in Meru South Sub-