Soil and carbon losses under rainfall simulation from two contrasting soils under maize-improved fallows rotation in Eastern Zambia

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Résumé

L'objet de cette étude est de déterminer l'effet de diverses jachères améliorées sur les pertes en nutriments par ruissellement et érosion durant la campagne de culture qui suit la jachère. Erosion et ruissellement ont été déterminés sous pluies simulées de 35 mm h^{-1} sur deux sols très contrastés à Kalunga avec 7% d'argile et Msekera avec 15% d'argile. Quatre traitements ont été comparés : *Sesbania sesban, Tephrosia vogelii,* jachère naturelle (NF) et Mais en continu.

A Kalunga, l'infiltration n'était pas stabilisée après 30 min, sauf pour le maïs après 7 min.Les pertes en terre atteignent 0.4 t ha^{-1} sous maïs continu, mais ne dépassent pas <0.2 t ha^{-1} après les autres jachères. Les pertes en carbone dans les sédiments étaient 4.5 kg C ha^{-1} sous mais continu et < 2.6 kg C ha^{-1} après les autres jachères en octobre 2001. Aucune différence significtive entre les jachères. A Msekera, le stade d'infiltration stabilisée n'a pas été atteint après 30 min sous NF, mais bien après 18, 8 et 4 min après Ss, Tv, et maïs continu. Cependant après une seule saison des pluies, , le niveau d'infiltration finale sous jachère naturelle est descendu au même niveau que sous maïs continu. Le maïs continu a perdu 0.43 t ha^{-1}alors que les autres jachères perdaient <0.26 t / ha , durant les averses sur sol sec. Pas de différence significative au niveau 0.05pour le C total érodé. Nous avons conclu que les jachères améliorées avaient amélioré l'infiltration et réduit le ruissellement et l'érosion ainsi que les pertes en nutriments , mais que ce bénéfice diminuait rapidement dès la première saison de culture.

Mots–clés : Zambie, simulation de pluies, jachères améliorées, sols, Infiltration, ruissellement, pertes en terre, pertes en C

Abstract

Fallows have been reported to improve soil organic carbon (OC), but information on how much OC is lost through erosion is not readily available. The aim of this study was to determine potential sediment OC losses during the cropping phase in a maize-improved fallow rotation. The investigation was carried out on two contrasting soils under improved fallow treatments using simulated rainfall at 35 mm h^{-1} on 1-m^2 microplots, at Kalunga, which had 7% clay, and Msekera with 15% clay (0-20 cm). The simulations involved dry runs and wet runs. Four treatments studied were, *Sesbania sesban, Tephrosia vogelii,* natural fallow (NF) and continuous maize (*Zea mays*). At Kalunga time to runoff and steady state infiltration rate generally decreased, whereas runoff, soil loss, sediment enrichment in OC, and OC loss generally increased from October 2000 to October 2001 (dry runs), and from dry to wet runs in October 2001. Runoff and erosion were significantly greater under continuous maize than in fallow treatments, but the differences decreased from 2000 to 2001 and from dry to wet runs. In 2001, loss of OC during dry runs was twice greater under continuous maize than in fallow treatments, but differences between treatments were smaller during wet runs. Differences between fallow treatments were small in general, thus as compared with natural fallow, improved fallow did not seem any better for soil and water conservation at Kalunga. At Msekera, similar overall tendencies were observed in the comparisons between 2000 and 2001,

between dry and wet runs, and between treatments. The main differences with Kalunga were the greater soil loss in natural than in improved fallow treatments and the tendency to greater OC loss in NF than in *S. sesban* treatment (in 2001), thus the greater interest of planted fallows. Additionally, sediment enrichment in OC was smaller in continuous maize than in fallow treatments at Msekera, but not at Kalunga. On the whole, soil susceptibility to runoff and OC losses was generally greater at Msekera (15% clay, 4% slope) than at Kalunga (7% clay, 2% slope), but differences between sites were less clear for soil loss, and sediment enrichment in OC was generally smaller at Msekera. We concluded that fallowing reduced soil and OC losses, and that improved fallows were not superior to natural fallow except for soil loss at Msekera site.

Key words
Runoff, soil erosion, soil carbon erosion, sediment enrichment, improved fallows, rainfall simulation, Zambia

Introduction

Soil loss through erosion has been associated with losses in soil organic carbon (SOC). Studies on watersheds have shown that SOC is easily lost because it is usually sediment bound. Nutrient enrichment ratios of eroded sediments of up to 5.7 have been reported (Coleman et al., 1990). The close association of organic matter with plant nutrients in the soil makes erosion of soil organic matter a strong indicator of the overall plant nutrient loss resulting from erosion (Follet et al., 1987).

Runoff losses have been determined using different methods (Sharpley et al., 1994; Zhang and Miller, 1996), but in spite of these there is no widely accepted procedure. Runoff experiments have often used the whole watershed (Lowrance, 1992; Goss et al., 1993), or use simulated rainfall on microplots. Simulated rainfall has the advantage that many parameters can be controlled compared to natural rainfall for watershed measurements (Barthès et al., 1999). However microplots used with simulated rainfall (mesocosm study) only give information on the soil detachability and erodibility and not on total erosion that takes place in the field as the complete hydrodynamic process of soil detachment, transport, deposition, and resuspension cannot be represented. Therefore the use of microplots in mesocosm studies has been retained in order to evaluate the potential of soil erosion and sediment transport.

Improved fallow systems increase soil organic matter (SOM) and improve soil physical and chemical properties (Jou and Lal, 1977). However there is little work that has looked at how long these benefits can last after fallowing and how SOC losses are affected by soil type in the Southern Africa region. Most work done to date on improved fallows has concentrated on effect of nutrient mineralisation and cycling (Hartemink et al., 1996; Mafongoya et al., 1997; Chikowo et al., 2003). The objective of this study was to determine the potential erodibility of two different soils and losses in SOC at fallow termination and after one maize cropping season using simulated rainfall in a maize-improved fallow rotation. We hypothesized that soil and SOC losses are lower under improved fallows and increase during the cropping phase.

Materials and methods

Site description

The study was conducted at Msekera Research Station and Kalunga Farmers Training Centre in Eastern province of Zambia from 1996-2001 seasons. Msekera Research Station is located 32°34'S and 13° 34'E at an altitude of 1032 m above sea level with a slope of about 4-5%, and has a mean annual rainfall of 1092 mm and a mean annual temperature of 25°C. The soil is classified as haplic Luvisol (FAO-ISSS-ISRIC, 1998). Kalunga Farmers Training Centre is located 32°33'S and 13°50'E at an altitude of 1015 m above sea level with a slope of about 2%, with a mean annual rainfall of 1000 mm and a mean annual temperature of 28°C. The soil is classified as ferric Luvisol (FAO-ISSS-ISRIC, 1998). Selected soil properties from the 0-20 cm depth, as at November 1996, are shown in Table 1. Both sites were established in the 1996/1997 seasons and had been under natural vegetation prior to trial establishment. The plots were under planted fallows in the 1996/97 seasons before they were put under maize in 1997/98 seasons. They were again under planted fallows for two years from 1998/99 to 1999/2000 seasons. Planted fallows were cut at the beginning of the 2000/2001 seasons after growing for 24 months, and maize was grown in the 2000/2001 season. The fallow treatments were planted *Sesbania sesban* and *Tephrosia vogelii* (two legumes), natural fallow (NF) and continuous maize (control). Grass in NF plots was burnt before tillage at fallow termination. The plots were tilled using an ox drawn plough and ridges were then made using hoes. The maize crop was planted on top of the ridges. The treatments were arranged in a complete randomised block design (RCBD), using slope as a blocking factor, with three replicates. The gross plot size was 10 m x 10 m, and a spacing of 1.0 m x 1.0 m and 1.0 m x 0.5 m was used for *S. sesban* and *T. vogelii* respectively.

Rainfall simulations

Rainfall simulations were conducted at a rainfall intensity of 35 mm h^{-1} on 1-m^2 plots surrounded by a 50-cm buffer zone. Simulations were carried out soon after cutting the fallows, before land preparation in October 2000, and just before land preparation for the second maize crop in October 2001. At fallow termination the twigs and litter were not removed from the plots. In October 2001, the maize stover was removed from the plots before simulations as these are normally fed to livestock. At fallow termination rainfall simulations in the natural fallow plots were carried out without removing the grasses and weeds and their litter and these were burnt just before land preparation for the first maize crop. During the simulation events the microtopography of the soil was not tempered with. A portable rainfall simulator based on a single full cone nozzle principle, calibrated after Panini et al. (1993), was used. The plots, which had an average slope of 2% at Kalunga and 4% at Msekera, were demarcated and hydrologically confined using aluminium sheets installed on all sides leaving about 7 cm of the sheets above the ground. A metal flume was anchored at the outlet, leading into a small trench to collect runoff. Borehole water with a pH of 6.9 and an electrical conductivity of 190 mS cm^{-1} (Standard error Se = 3.2) was used for simulations. Rainfall simulations involved dry and wet runs. Dry runs were conducted on a dry soil and wet runs were carried out at the same spot used for dry runs the following day. In October 2000, rainfall simulations continued for 3 hours or until steady state runoff was attained. The antecedent soil moisture content (weight basis) at 0-10 cm for dry and wet runs at Kalunga site were 6% (Se = 0.6) and 10% (Se = 0.2), respectively, for both October 2000 and 2001. At Msekera the mean initial soil moisture content at 0-10 cm was 9% (Se = 0.2) at fallow termination and 6% (Se = 0.9) in October 2001 dry runs, and 12% (Se = 1.2) for wet runs for both October 2000 and 2001. In 2000, runoff intensity (mm h^{-1}) was periodically measured by sampling water flowing from each plot. The sediments in the collected runoff were dried and bulked for analysis. In October 2000, total runoff losses were estimated by plotting runoff against time and the area under the curve was calculated and expressed as a percentage of the total rainfall discharged from the plots. In 2001, a container was anchored at the base of the outlet to collect all the runoff and sediments. Runoff was then estimated by summing up runoff collected from the container and that collected during periodic sampling. The sediment collected in the container was weighed before being mixed with the solids separated from runoff collected during the simulations. Solids were separated from water through centrifugation, dried at 60°C for 12 hours, weighed and analysed for carbon. SOC was determined using the modified Walkley–Black procedure (Nelson and Sommers, 1982) and a correction factor of 1.3 was used in the calculations.

Table 1: Selected properties of the soils under study from the 0-20 cm depth, November 1996.

	Msekera	Kalunga
Clay (g kg^{-1})	150	70
Sand (g kg^{-1})	660	770
Silt (g kg^{-1})	190	160
pH (0.01 M $CaCl_2$)	4.3	4.5
Organic carbon (g kg^{-1})	10	4
Total nitrogen (g kg^{-1})	1.0	0.4
Phosphorus (ppm)	36	7
Exchangeable K (mmol kg^{-1})	2	1

Table 2. Runoff and steady state infiltration rates under rainfall simulations at Kalunga in October 2000 (00) and October 2001 (01).

Treatment	Time to runoff (min)			Steady state infiltration rate (mm hr^{-1})			Runoff coefficient (%)		
	00 dry	01 dry	01 wet	00 dry	01 dry	01 wet	00 dry	01 dry	01 wet
C. maize	10.0^{a}	9.0^{a}	5.5^{a}	7.0	7.0^{a}	7.0^{a}	36.0	71.0^{c}	75.0^{c}
S. sesban	60.0^{b}	21.0^{b}	7.8^{b}	nd	21.0^{b}	12.0^{b}	0.0	12.0^{a}	51.0^{a}
T. vogelii	104.0^{c}	14.0^{ab}	7.0^{b}	nd	16.0^{ab}	12.0^{b}	0.0	27.0^{b}	66.0^{b}
Natural F.	116.0^{c}	14.0^{ab}	10.0^{c}	nd	20.0^{b}	14.0^{b}	0.0	11.0^{a}	65.0^{b}
Lsd	30.6	11.4	1.1	-	12.3	2.1	-	4.6	7.5

C. maize: continuous maize
Natural F.: natural fallow
Lsd at $P < 0.05$
nd: not determined

Data analyses

For estimating infiltration rate, the empirical Horton-type model was used. The balance of rain minus runoff estimated infiltration, Infiltration (I) = precipitation (P) – runoff (Q). A modified version of the Horton-type equation proposed by Morin and Benjamin (1977) was fitted to the infiltration data: $i = i_f + (i_o - i_f)\, e^{-R/K}$

where: i is estimated instantaneous infiltration rate (mm h^{-1}); i_f is final infiltration rate (mm h^{-1}); i_o is initial infiltration rate (mm h^{-1}); R is cumulative rainfall (i.e. intensity x time, in mm); K is the infiltration rate decay coefficient, which expresses infiltration dynamics as affected by soil properties (mm) and was calculated when infiltration data was fitted to the equation. Data on time to ponding, time to runoff, amount of runoff and quantity of soil losses, nutrient losses and steady state infiltration rates were subjected to analysis of variance using Genstat Statistical package.

Results

Kalunga site

At fallow termination (October 2000), SOC content in the topsoil (0-10 cm) was 30% to 70% greater under fallow treatments than under continuous maize, and among fallow treatments, was 14 to 25% greater under natural than under improved fallow treatments ($P < 0.05$; Table 3). Time to runoff and steady state infiltration rate decreased while runoff, soil loss, sediment OC content and OC loss generally increased from October 2000 to October 2001 (dry runs), and from dry to wet runs in October 2001 (Tables 2 and 3). However, under continuous maize, steady state infiltration rate and sediment OC content were constant over the two seasons (sediment OC content was also constant over 2001 runs for *S. sesban* and *T. vogelii* treatments). When compared to fallow treatments, plots under continuous maize generally showed large differences: smaller time to runoff and steady state infiltration rate, and greater runoff. Soil loss was twice greater under continuous maize than in fallow treatments for both 2001 runs ($P < 0.05$). Loss of OC under continuous maize was also twice greater than in fallow treatments during dry runs (October 2001; $P < 0.05$), but was only 10 to 30% greater during wet runs. When compared to topsoil (0-10 cm), sediments had 2.6 to 4.5 times more OC, but the effect of treatments was unclear (enrichment ratio was higher for *S. sesban* treatment). In short, susceptibility to runoff, erosion and OC loss increased after fallow termination and from dry to wet initial conditions, and was greater under continuous maize than in fallow treatments. Differences between fallow treatments were small in general. Additionally, the effect of treatments on sediment OC enrichment was unclear.

Msekera site

At fallow termination (October 2000), topsoil OC content (0-10 cm) was 20 to 50% greater in fallow treatments than for continuous maize ($P < 0.05$; Table 5). From October 2000 to October 2001 (dry runs), time to runoff generally increased, but it decreased sharply in NF treatment (Table 4). In October 2001 time to runoff generally decreased by ca. 50% from dry to wet runs. Steady state infiltration rate decreased from October 2000 to October 2001 and from dry to wet runs, except under continuous maize where it was constant. Runoff rate increased markedly from October 2000 to October 2001, then slightly from dry to wet runs in October 2001. Susceptibility to runoff was generally higher (i.e., smaller time to runoff and steady state infiltration rate, and greater runoff loss) under continuous maize than under fallow treatments in 2000 (dry runs) and 2001 (both runs). However, in October 2001, steady state infiltration rate in *T. vogelii* and NF treatments did not differ significantly from that under continuous maize. Among the fallow treatments, NF had a smaller susceptibility to runoff than improved fallow treatments in 2000 (dry runs) but not in 2001. In October 2001, soil loss was 1.4 to 2.3 times greater in wet than in dry runs. When compared to fallow treatments, plots under continuous maize lost 1.7 to 3.1 times more sediments during dry runs, and 2.5 to 4.3 times more during wet runs (October 2001). Among the fallow treatments, soil loss was 1.5 to 1.9 times greater under NF than in improved fallow treatments, but the difference

Table 4. Runoff and steady state infiltration rates under rainfall simulations at Msekera in October 2000 (00) and October 2001 (01).

Treatment	Time to runoff (min)			Steady state infiltration rate (mm hr^{-1})			Runoff coefficient (%)		
	00 dry	01 dry	01 wet	00 dry	01 dry	01 wet	00 dry	01 dry	01 wet
C. maize	3.0^{a}	5.0^{a}	2.9^{a}	5.0^{a}	5.0^{a}	4.8^{a}	55.0^{c}	70.0^{b}	82.0^{b}
S. sesban	7.0^{a}	8.0^{a}	4.0^{b}	18.0^{b}	8.0^{b}	5.0^{a}	37.0^{b}	58.0^{a}	69.0^{a}
T. vogelii	7.0^{a}	9.0^{a}	3.5^{ab}	8.0^{a}	7.1^{ab}	4.8^{a}	24.0^{b}	61.0^{ab}	68.0^{a}
Natural F.	27.0^{b}	5.8^{a}	3.5^{ab}	nd	6.1^{ab}	4.8^{a}	2.0^{a}	68.0^{ab}	71.0^{a}
Lsd	17.8	4.8	0.9	7.2	2.8	1.2	12.0	11.1	3.2

C. maize: continuous maize
Natural F.: natural fallow
Lsd at $P < 0.05$
nd: not determined

was significant in wet runs only ($P < 0.05$). Sediment OC content as well as sediment enrichment in OC did not vary much between years and between runs. Sediment OC content was 40 to 70% smaller under continuous maize than in fallow treatments ($P < 0.05$ in general), and among the fallow treatments, was 20 to 40% smaller under NF than for improved fallow treatments. Sediment enrichment in OC was the smallest under continuous maize (1.3-1.6) and the greatest under *T. vogelii* treatment (3.6-4.1). From dry to wet runs (October 2001), total OC loss increased by 40 to 70% under fallow treatments, but by 180% under continuous maize. Total OC loss was 50 to 80% greater under continuous maize than under fallow treatments during wet runs ($P < 0.05$), whereas differences between treatments were unclear during dry runs (nevertheless OC loss was 50% greater under NF than under *S. sesban*, $P < 0.05$). In short, runoff and soil losses were greater in wet than in dry runs, and higher under continuous maize than in fallow treatments. Sediment OC enrichment tended to be greater in fallow treatments than in continuous maize, and OC loss was greater under continuous maize than in fallow treatments during wet runs only. Differences between fallow treatments were small in general.

Comparison between Kalunga and Msekera sites

There was a significant site and treatment interaction on time to runoff ($P < 0.05$) except for continuous maize. There was a significant site and treatment interaction on soil loss for *S. sesban* and on OC loss for *T. vogelii* only ($P < 0.05$). If we compare the two sites, time to runoff and steady state infiltration rate were smaller and runoff losses generally higher at Msekera than at Kalunga (15 vs. 7% clay at 0-20 cm, and 7-11 vs. 3-5 mg C g^{-1} at 0-10 cm in October 2000, respectively, cf. Tables 1, 3 and 5). Differences in soil loss between sites were less clear. Sediment OC content and OC loss were generally greater at Msekera than at Kalunga due to greater topsoil OC content at Msekera. In contrast, sediment enrichment in OC was generally smaller at Msekera than at Kalunga. However at both sites continuous maize had the lowest time to runoff, steady state infiltration rates and the highest runoff and soil losses relative to fallow treatments. Susceptibility to runoff and OC losses was thus greater at Msekera than at Kalunga.

Discussion

The decrease in time to runoff and steady state infiltration rate from fallow termination (October 2000) to the beginning of the second cropping season (October 2001) in fallow treatments at both sites could be attributed to introduction of tillage and lack of leaf/grass litter on the surface. The leaf/grass litter protected the soil surface resulting in higher infiltration rates at fallow termination and this had disappeared through burning (natural fallow) and soil incorporation (improved fallows) as a result of tillage after the first cropping. Reduced steady state infiltration rates then resulted in increased runoff and soil losses (Nyamadzawo et al., 2003). High rates of soil loss have been attributed to tillage (Havelin et al., 1990), as conventional tillage using an ox drawn plough destroyed soil structure. Total soil losses increased in fallow treatments after one cropping season showing that the benefits of fallowing decreased with the introduction of cropping and tillage.

Although soil loss increased after fallow termination, runoff and soil loss in fallow treatments generally remained lower relative to continuous maize at both sites, due to the destruction of structure resulting from continuous cultivation. At Msekera, after one cropping season, steady state infiltration rates in *T. vogelii* and NF treatments had decreased and did not differ from that under continuous maize. This shows that at Msekera the benefits of fallowing using these species were short lived and there was need to return to fallowing earlier. May be two years of cropping before fallowing again could be optimal as suggested by Mafongoya and Dzowela (1999) although they were looking at length of cropping phase from a soil fertility perspective. This rapid decline in steady state infiltration rates after the first crop seems to be accompanied by a decline in soil fertility as fertile topsoil gets eroded (Mafongoya and Dzowela, 1999).

Table 3. Soil and OC losses at Kalunga site in October 2000 (00) and 2001 (01).

Treatment	Total soil loss ($g\ m^{-2}$)			Sediment OC content ($mg\ C\ g^{-1}$)			Topsoil OC* ($mg\ C\ g^{-1}$)	OC enrichment ratio**			OC loss ($g\ C\ m^{-2}$)		
	00 dry	01 dry	01 wet	00 dry	01 dry	01 wet	00	00 dry	01 dry	01 wet	00 dry	01 dry	01 wet
C. maize	nd	41.0^{b}	71.0^{b}	10.0	11.0^{a}	10.0^{a}	3.0^{a}	3.3	3.7	3.3	nd	0.45^{b}	0.71^{c}
S. sesban	0.0	15.0^{a}	36.0^{a}	-	17.0^{c}	18.0^{bc}	4.0^{b}	-	4.3	4.5	0.00	0.26^{a}	0.65^{bc}
T. vogelii	0.0	16.0^{a}	40.0^{ab}	-	15.0^{bc}	16.0^{b}	4.4^{c}	-	3.4	3.6	0.00	0.24^{a}	0.64^{b}
Natural F.	0.0	20.0^{a}	26.0^{a}	-	13.0^{ab}	21.0^{c}	5.0^{d}	-	2.6	4.2	0.00	0.26^{a}	0.55^{a}
Lsd	-	15.0	34.0	-	3.4	4.0	0.2	-	-	-	-	0.11	0.06

*Soil OC content at 0-10 cm in October 2000
**Sediment OC content / topsoil OC content (0-10 cm) in October 2000
C. maize: continuous maize
Natural F.: natural fallow
Lsd at $P < 0.05$

Table 5. Soil and OC losses at Msekera site in October 2000 (00) and 2001 (01).

Treatment	Total soil loss ($g\ m^{-2}$)			Sediment OC content ($mg\ C\ g^{-1}$)			Topsoil OC* ($mg\ C\ g^{-1}$)	OC enrichment ratio**			OC loss ($g\ C\ m^{-2}$)		
	00 dry	01 dry	01 wet	00 dry	01 dry	01 wet	00	00 dry	01 dry	01 wet	00 dry	01 dry to check	01 wet to check
C. maize	nd	43.0^{b}	99.0^{c}	12.0^{a}	10.0^{a}	12.0^{a}	7.2^{a}	1.7	1.4	1.7	nd	0.43^{a}	1.19^{b}
S. sesban	nd	14.0^{a}	24.0^{a}	29.0^{b}	28.0^{ab}	27.0^{c}	11.0^{c}	2.6	2.5	2.5	nd	0.39^{a}	0.65^{a}
T. vogelii	nd	17.0^{a}	23.0^{a}	31.0^{b}	34.0^{b}	35.0^{d}	8.5^{b}	3.6	4.0	4.1	nd	0.58^{b}	0.81^{a}
Natural F.	0.0	26.0^{ab}	40.0^{b}	-	22.0^{ab}	21.0^{b}	11.0^{c}	-	2.0	1.9	0	0.57^{b}	0.84^{a}
Lsd	-	22.0	23.0	13.0	22.0	5.5	0.5	-	-	-	-	0.13	0.21

*Soil OC content at 0-10 cm in October 2000
**Sediment OC content / topsoil OC content (0-10 cm) in October 2000
C. maize: continuous maize
Natural F.: natural fallow
Lsd at $P < 0.05$

Sediment bound OC was highest in fallow treatments relative to continuous maize, in relation with greater topsoil OC content. However, due to much greater soil losses under continuous maize than in fallow treatments at both sites, OC loss was generally greater under continuous maize. The OC enrichment ratio of sediments was higher in fallow treatments than in continuous maize at Msekera, indicating selective detachment and transport of fine particles (including small aggregates), which include more OC. This is also because fallow treatments had more SOC than continuous maize in the topsoil. This observation is supported by findings of Wan and El-Swaify (1997). Palis et al. (1997) also found out that carbon enrichment ratios were greater for aggregated soils with high clay contents. Soil OC losses can be used as indicators of plant nutrient losses because most nutrients are associated with OC, which is washed away with the soil (Follet et al., 1987).

Greater runoff at Msekera than at Kalunga was perhaps related to greater topsoil content in fine particles (15 vs. 7% clay, and 34 vs. 23% clay + silt, respectively), resulting in a greater amount of particles available for dispersion and surface clogging. The relatively low time to runoff obtained at fallow termination at Msekera was due to relatively higher initial topsoil moisture content during simulations in October 2000 (9% compared to 6% in October 2001).

Fallow treatments were less susceptible to runoff and erosion than continuous maize, but improved fallows were largely comparable to natural fallow. Thus planting leguminous fallows did not result in clear benefit, at Kalunga especially (at Msekera, soil loss was smaller under NF than under improved fallow treatments). Therefore improved fallows could mainly be promoted for soil fertility benefits through N fixation, as they do not enhance soil hydraulic properties nor reduce erodibility when compared with natural fallow. The increase in susceptibility to runoff, soil and OC loss from dry to wet runs was due to reduced time to runoff and therefore more runoff as the rainfall simulations were contacted for a fixed duration (30 minutes).

The results from this work gave an indication of the potential OC erosion and erodibility under improved fallow systems. Although estimates of erodibility made from small plots cannot be readily extrapolated to the field or landscape scale (Stomph et al., 2002; van de Giesen et al., 2000), they are indicative of the differences between treatments and management. Extrapolations are difficult using this kind of data, plots are often too small and may not be representative of soil variability and some of the processes taking place in larger fields, for example sediment deposition (De Boer and Campbell, 1989; Govers, 1991; Mathier and Roy, 1996).

Conclusion

This study showed that fallowing increased topsoil OC content and steady state infiltration rates, and reduced runoff, erosion and loss of OC relative to continuous maize. However this benefits decreased from fallow termination to the beginning of the second cropping season. At Kalunga there were no differences in runoff and soil loss between improved fallow and NF treatments, thus the interest of fallow planting was not clear as regarded soil and water conservation. At Msekera improved fallow treatments had less soil eroded from the plots relative to NF, but similar runoff and OC losses. Runoff, soil and OC losses were higher at Msekera relative to Kalunga because of differences in initial soil moisture content, slope and soil type (texture especially).

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References

Barthès, B., A. Albrecht, J. Asseline, G. De Noni, and E. Roose. 1999. Relationship between soil erodibility and topsoil aggregate stability or carbon content in a cultivated Mediterranean highland (Aveyron, France). *Communications in Soil Science and Plant Analysis* 30: 1929-1938.

Coleman, T.L, A.U. Eke, U.R. Bishnoi, and C. Sabota. 1990. Nutrient losses in eroded sediments from limited resource farm. *Field Crop Research* 24: 105-117.

Chikowo, R., P. Mapfumo, P. Nyamugafata, G. Nyamadzawo, and K. E., Giller. 2003. Nitrate-N dynamics following improved fallows and maize root development in a Zimbabwean sandy clay loam. *Agroforestry Systems* 59: 1897-195.

De Boer, D.H, and I.A. Campbell. 1989. Spatial scale dependence of sediment dynamics in a semi arid badland drainage basin. *Catena* 16: 277-290.

FAO-ISSS-ISRIC. 1998. *World Reference Base for Soil Resources*. World Soil Resources Report 84, FAO, Rome.

Follet, R.F, S.C. Gupta, and P.G. Hunt. 1987. Conservation practices: Relations to the management of plant nutrients for crop production. p. 19-52. In: R.F. Follet (ed.), *Soil Fertility and Organic Matter as Critical Components of Production Systems*. SSSA Special Publication 19, Soil Science Society of America, Madison, WI.

Goss, M.J., K.R. Howse, P.W. Lane, D.G. Christian, and G.L. Harris. 1993. Loss of nitrate-nitrogen in water draining from autumn sawn crops established by direct drilling and mouldboard ploughing. *Soil Science* 44: 35-48.

Govers, G. 1991. A field study on topographical and topsoil effects on runoff generation. *Catena* 18: 91-111.

Hartemink, A.E, R.J. Buresh, B. Jama, and B.H. Janssen. 1996. Soil nitrate and water dynamics in *Sesbania sesban* fallows, weed fallows and maize. *Soil Science Society of America Journal* 60: 568–574.

Havelin, J.L, D.E. Kissel, L.D. Maddaux, M.M. Cleassen, and J.H. Long. 1990. Crop rotation and tillage effects on soil organic carbon and nitrogen. *Soil Science Society of America Journal* 34: 448-452.

Jou, A.S, and R. Lal. 1977. The effects of fallow and continuous cultivation on the chemical and physical properties of an Alfisol in Western Nigeria. *Plant and Soil* 47: 567-584.

Lowrance, R. 1992. Nitrogen outputs from a field-size agricultural watershed. *Journal of Environmental Quality* 21: 602-607.

Mafongoya, P.L, P.K.R. Nair, and B.H. Dzowela. 1997. Multipurpose tree prunings as a source of nitrogen to maize under semi arid conditions in Zimbabwe: Part 3. Interactions of pruning quality and time and method of application on nitrogen recovery by maize in two soil types. *Agroforestry Systems* 35: 57–70.

Mafongoya, P.L, and B.H. Dzowela. 1999. Biomass production of tree fallow and their residual effects on maize in Zimbabwe. *Agroforestry Systems* 47: 139–151.

Mathier, L, and A.G. Roy. 1996. A study of the effects of spartial scale on parameters of sediment transport equation for sheet wash. *Catena* 26: 161-169.

Morin, J., and Y. Benjamin. 1977. Rainfall infiltration into bare soils. *Water Resources Research* 13: 813-817.

Nelson, D.W, and L.E. Sommers. 1982. Total carbon, organic carbon and organic matter. p. 539–579. In: A.L. Page, D.R. Keeney, D.E. Baker, R.H. Miller, E. Roscoe (jr.), and J.D. Rhoades (eds.), *Methods of Soil Analysis 2.* American Society of Agronomy, Madison, WI.

Nyamadzawo, G., P. Nyamugafata, R. Chikowo, and K.E. Giller. 2003. Partitioning of simulated rainfall under maize-improved fallow rotations in Kaolinitic Soils. *Agroforestry Systems*. 59: 207-214.

Palis, R.G., H. Ghandiri, C.W. Rose, and P.G. Saffigna. 1997. Soil erosion and nutrient loss: 3. Changes in the enrichment ratio of total nitrogen and organic carbon under rainfall detachment and entrainment. *Australian Journal of Soil Research* 35: 891–905.

Panini, T, M.P. Salvador Sanchis, and D. Torri. 1993. A portable rain simulator for rough and smooth morphologies. *Quaderni di Scienza del Suolo* 5: 47-58.

Sharpley, A.N, S.C. Chapa, R. Wedephahl, J.T. Sims, T.C. Daniel, and K.R Reddy. 1994. Managing agricultural P for protection of surface water. Issues and Options. *Journal of Environmental Quality* 23: 437-451.

Stomph, T.J, N. de Ridder, T.S. Steenhuis, and C. van de Giesen. 2002. Scale effects on Hortonian overland flow and rainfall-runoff dynamics: Laboratory validation of a process-based model. *Earth Surface Processes and Landforms* 27: 847–855.

Van de Giesen, N.C, T.J. Stomph, and N. de Ridder. 2000. Scale effects of Hortonian overland flow and rainfall-runoff dynamics in West African catena landscape. *Hydrological Processes* 14: 165–175.

Wan, Y., and S.A. El-Swaify. 1997. Flow-induced transport and enrichment of erosional sediment from a well-aggregated and uniformly-textured oxisol. *Geoderma* 75: 251–265.

Zhang, X.C, and W.P. Miller. 1996. Physical and chemical crusting processes after runoff and erosion in furrows. *Soil Science Society of America Journal* 60: 860-865.