Andre Bationo
Boaz Waswa
Jeremiah M. Okeyo
Fredah Maina
Job Kihara
Editors

Innovations as Key to the Green Revolution in Africa – Vol.1

Exploring the Scientific Facts

Springer

Editors
Andre Bationo
Alliance for a Green Revolution in Africa (AGRA)
Soil Health Program
6 Agostino Neto Road
Airport Residential Area
PMB KIA 114, Airport-Accra
Ghana
abationo@agra-alliance.org

Boaz Waswa
Tropical Soil Biology and Fertility Institute of the International Centre for Tropical Agriculture (TSBF-CIAT)
Nairobi, Kenya
bswaswa@yahoo.com

Jeremiah M. Okeyo
Tropical Soil Biology & Fertility (TSBF)
African Network for Soil Biology and Fertility (AfNet)
c/o ICRAF, Off UN Avenue
P.O. Box 30677-00100
Nairobi, Kenya
jmosioma@gmail.com

Fredah Maina
Kenya Agricultural Research Institute
Socio-economics and Biometrics
P.O. Box 14733-00800
Nairobi, Kenya
fredah.maina@yahoo.com

Job Kihara
Tropical Soil Biology & Fertility (TSBF)
African Network for Soil Biology and Fertility (AfNet)
c/o ICRAF, Off UN Avenue
P.O. Box 30677-00100
Nairobi, Kenya
j.kihara@cgiar.org

Please note that some manuscripts have been previously published in the journal 'Nutrient Cycling in Agroecosystems' Special Issue "Innovations as Key to the Green Revolution in Africa: Exploring the Scientific Facts". (Chapters 13, 14, 19, 20, 23, 36, 42, 57, 59, 78, 80 and 113)

Printed in 2 volumes

ISBN 978-90-481-2541-8 e-ISBN 978-90-481-2543-2
DOI 10.1007/978-90-481-2543-2
Springer Dordrecht Heidelberg London New York

Library of Congress Control Number: 2011930869

Printed on acid-free paper

Springer is part of Springer Science+Business Media (www.springer.com)

Nutr Cycl Agroecosyst
DOI 10.1007/s10705-011-9423-7

ORIGINAL ARTICLE

Conservation tillage, local organic resources and nitrogen fertilizer combinations affect maize productivity, soil structure and nutrient balances in semi-arid Kenya

J. Kihara · A. Bationo · D. N. Mugendi · C. Martius · P. L. G. Vlek

Received: 25 April 2008 / Accepted: 13 January 2011

Abstract Smallholder land productivity in drylands can be increased by optimizing locally available resources, through nutrient enhancement and water conservation. In this study, we investigated the effect of tillage system, organic resource and chemical nitrogen fertilizer application on maize productivity in a sandy soil in eastern Kenya over four seasons. The objectives were to (1) determine effects of different tillage-organic resource combinations on soil structure and crop yield, (2) determine optimum organic–inorganic nutrient combinations for arid and semi-arid environments in Kenya and, (3) assess partial nutrient budgets of different soil, water and nutrient management practices using nutrient inflows and outflows. This experiment, initiated in the short rainy season of 2005, was a split plot design with 7 treatments involving combinations of tillage (tied-ridges, conventional tillage and no-till) and organic resource (1 t ha^{-1} manure + 1 t ha^{-1} crop residue and; 2 t ha^{-1} of manure (no crop residue) in the main plots. Chemical nitrogen fertilizer at 0 and 60 kg N ha^{-1} was used in sub-plots. Although average yield in no-till was by 30–65% lower than in conventional and tied-ridges during the initial two seasons, it achieved 7–40% higher yields than these tillage systems by season four. Combined application of 1 t ha^{-1} of crop residue and 1 t ha^{-1} of manure increased maize yield over sole application of manure at 2 t ha^{-1} by between 17 and 51% depending on the tillage system, for treatments without inorganic N fertilizer. Cumulative nutrients in harvested maize in the four seasons ranged from 77 to 196 kg N ha^{-1}, 12 to 27 kg P ha^{-1} and 102 to 191 kg K ha^{-1}, representing 23 and 62% of applied N in treatments with and without mineral fertilizer N respectively, 10% of applied P and 35% of applied K. Chemical nitrogen fertilizer application increased maize yields by 17–94%; the increases were significant in the first 3 seasons ($P < 0.05$). Tillage had significant effect on soil macro- (>2 mm) and micro-aggregates fractions (<250 µm >53 µm: $P < 0.05$), with aggregation indices following the order no-till > tied-ridges >

J. Kihara (✉) · A. Bationo
Tropical Soil Biology and Fertility Institute of CIAT, 30677-00100 Nairobi, Kenya
e-mail: jkiharam@yahoo.com

J. Kihara · C. Martius · P. L. G. Vlek
Zentrum für Entwicklungsforschung (ZEF), University of Bonn, Walter-Flex-Strasse 3, 53113 Bonn, Germany

A. Bationo
Alliance for Green Revolution in Africa (AGRA-Alliance), CSIR Office Complex, #6 Agostino Neto Road, Airport Residential Area, PMP KIA 114 Airport-Accra, Ghana

D. N. Mugendi
Kenyatta University, 43844-00100 Nairobi, Kenya

Present Address:
C. Martius
Inter-American Institute for Global Change Research (IAI), Avenida dos Astronautas 1758, São José dos Campos, SP 12227-010, Brazil

Published online: 29 January 2011

This article has been previously published in the journal "Nutrient Cycling in Agroecosystems" Volume 88 Issue 1.
A. Bationo et al. (eds.), Innovations as Key to the Green Revolution in Africa: Exploring the Scientific Facts. © 2010 Springer.

A. Bationo et al. (eds.), *Innovations as Key to the Green Revolution in Africa*,
DOI 10.1007/978-90-481-2543-2_14, © Springer Science+Business Media B.V. 2011

conventional tillage. Also, combining crop residue and manure increased large macro-aggregates by 1.4–4.0 g 100 g^{-1} soil above manure only treatments. We conclude that even with modest organic resource application, and depending on the number of seasons of use, conservation tillage systems such as tied-ridges and no-till can be effective in improving crop yield, nutrient uptake and soil structure and that farmers are better off applying 1 t ha^{-1} each of crop residue and manure rather than sole manure.

Keywords Crop residue · Manure · Soil aggregation · Nutrient balance · Tillage

Introduction

Farming in sub-Saharan Africa (SSA) traditionally depended upon natural fallows to restore soil fertility (Maroko et al. 1998). Due to factors such as increased population pressure and demand for food, natural fallows are not feasible hence the need for sustainable land management systems (Pascual and Barbier 2006). Maintenance and or improvement of soil organic matter (SOM) is one of the key components of sustainable management of agricultural lands due to the associated system productivity (Bationo and Vlek 1997; Martius et al. 2001; Bationo et al. 2007). One promising approach to manage SOM and promote activities of soil micro-organisms is the concomitant use of organic (such as crop residue and manure) and inorganic nutrient resources (Goyal et al. 1999). The extent of organic amendments on SOM, soil structure and soil micro-organisms vary according to the crop residue type and quantity (Scopel et al. 1998).

In many cropping systems within poor smallholder farms, little or no agricultural residue is returned to the soil due to low productivity in these areas and competing uses such as fodder and fuelwood (Erenstein 2003). Also, and especially in Kenyan drylands, manure is limited due to free range system of livestock management practiced here that leaves large amounts of manure in the bushlands, and only small amounts dropped in the shed at night are available for use in crop production. The challenge is optimizing the limited resources available to the small-scale farmers for improved productivity of the systems. Quite often though, the needed or recommended levels of organic amendments used by scientists in experimental set-ups are too high for any practical use by majority of farmers. It is needed to investigate the effect of the small quantities of organic resources available to the farmers on both crop productivity and soil structure, and how these effects can be improved by a judicious choice of amendments of varying quality. In this study, we assess soil aggregation and crop yield under different tillage and organic resource systems. Village-level residue management study in West African agro-ecosystems showed that 21–39% of residue from previous crops is available on the farm at planting (Bationo et al. 2007). Thus, given the low productivity observed in the dryland agro-ecosystems (3–4 t ha^{-1} of maize stover Miriti et al. 2007), farmers can retain about 1 t ha^{-1} of maize stover residue in their fields and this quantity is tested in this study.

Conservation tillage practices such as reduced tillage have been observed to result in better soil structure (Six et al. 2000) and have higher soil organic carbon compared to conventional tillage practice, especially at the top soil depths (Madari et al. 2005; McCarty and Meisinger 1997). Combined with crop residue applied as mulch, reduced tillage also conserves available rainwater important for crop growth. Such rainwater is currently lost in the magnitude of 70–85% from cropping systems in sub-Sahara Africa through soil evaporation, deep percolation and surface runoff (Rockstrom et al. 2003). The additional mulch produced by the crops could play a key role in reducing runoff and direct evaporation from the soil (Erenstein 2003), and often reduces the emergence of weeds (Erenstein 2003). In low rainfall seasons, substantial increases in crop yields above conventional practices are expected where tied-ridges are used for in situ water harvesting (Gebrekidan 2003).

We hypothesized that combining conservation tillage with the limited quantities of organic and inorganic nutrient resources available and affordable by smallholder farmers would result in increased maize productivity and higher efficiency of resources through improvements in soil structure. The objectives were to (1) determine effects of different tillage systems and low quantities of organic resources on soil structure and crop yield, (2) determine optimum organic–inorganic nutrient combinations for arid and semi-arid environments in Kenya and, (3) assess partial nutrient budgets of different soil, water and nutrient management practices using nutrient inflows and outflows.

Materials and methods

Location

This study was conducted in a semi-arid zone at Machang'a in Mbeere, Eastern Kenya. The site is located at 0°45′S and 37°45′E, at an altitude of 1,050 m.a.s.l. The study was conducted for 2 years (from September 2005 to August 2007) which constituted four seasons of experimentation (two seasons per year). The two seasons in a year are the short rainy season from September to March and the long rainy season from April to July. Much of the seasonal rainfall often falls in a few storms distributed over the season. Figure 1 shows cumulative rainfall recorded in the study site during the four seasons of experimentation. Short rains 2005 (SR2005, season one) had lower rainfall (245 mm) compared to long rains 2006 (LR2006, season two) with 285 mm, although there was better distribution in the former. During short rains 2006 (SR2006, season 3) up to 825 mm rainfall was recorded, while 374 mm of rainfall, very poorly distributed, was recorded during long rains 2007 (LR2007, season 4). Average temperature was 23.4 (±1.53) as observed during the four seasons.

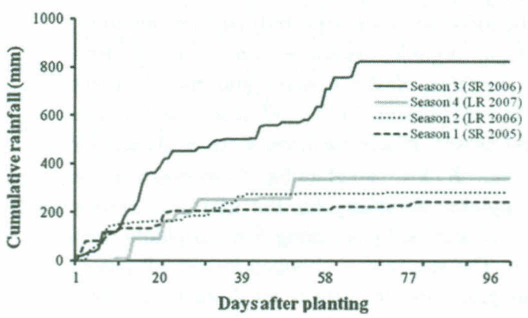

Fig. 1 Seasonal cumulative rainfall recorded at Machang'a in Mbeere, eastern Kenya during the four seasons of study (September 2005 to July 2007). SR = short rainy season, LR = long rainy season

Soils characteristics

The soils, classified as chromic cambisols (Warren et al. 1997), had 65% sand, 22% clay and 13% silt. Chemical analysis was done at the main plot level because the field was observed to exhibit some variability. The Analysis showed that SOC content was 0.61 (±0.07)%, total N 0.05 (±0.01)%, pH water 6.5 (±0.46), extractable phosphorus 6.3 (±7.74) mg P kg^{-1}, exchangeable potassium 0.56 (±0.14) me 100 g^{-1} of soil, exchangeable magnesium 0.78 (±0.077) me 100 g^{-1} of soil, and exchangeable calcium 2.29 (±1.04) me 100 g^{-1} of soil. The site was characterized by C/N ratio varying between 9.0 and 22.1. The data showed high nutrient variability (Fig. 2) that is common in farmers' fields due to local land use histories or biological activity (termite mounds that concentrate nutrients).

Treatments and crop management

The experiment, initiated in the short rainy season of 2005, was a split plot design with seven (7) tillage-organic resource treatments in main plots as follows:

(1) Conventional tillage without organic residue (control)
(2) Conventional tillage + crop residue (1 t ha^{-1}) + manure (1 t ha^{-1})
(3) Conventional tillage + manure (2 t ha^{-1})
(4) No-Tillage + crop residue (1 t ha^{-1}) + manure (1 t ha^{-1})
(5) No-Tillage + manure (2 t ha^{-1})
(6) Tied-Ridges + crop residue (1 t ha^{-1}) + manure (1 t ha^{-1})
(7) Tied-Ridges + manure (2 t ha^{-1})

Split plots comprised 0 and 60 kg N ha^{-1} as chemical nitrogen fertilizer. The experiment was replicated three times. Tillage in the conventional system was done to about 15 cm soil depth using hand hoes as commonly done by farmers. Tied-ridges were prepared by digging, using hand hoes, during trial initiation and they were maintained throughout the experiment, with tillage restricted to refreshment of the ridges. Ridge tops were not hoed but retained some fresh soils as a result of the ridge maintenance work. The main ridges on which maize was planted were 90 cm apart while the ties were made at distances of 2 m. In the no-tillage system, tillage

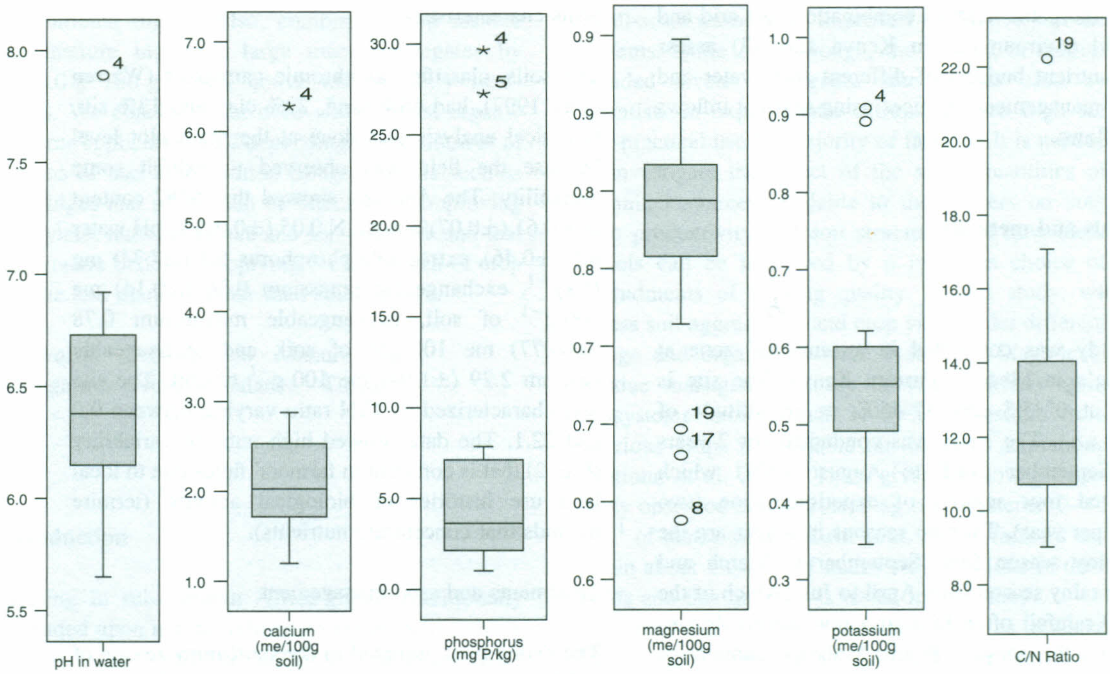

Fig. 2 *Box plots* describing initial characteristics for selected soil parameters ($n = 21$) at Machang'a in Mbeere, Eastern Kenya in 2005

for land preparation was done using hand hoes with no subsequent use of hand hoes in between the season. Weeding in no-till system was done by hand pulling.

Organic resources applied were goat manure (on average 2.67, 0.52 and 4.17% of N, P and K, respectively) broadcast at planting at 1 and 2 t ha^{-1} and maize stover (0.65, 0.08 and 1.78% of N, P and K, respectively) applied at 1 t ha^{-1}. The manure was imported from one farmer at all times while maize stover was from the harvested crop, except in the first season when it was sourced from an immediate farm. The stover was spread over the plots prior to land preparation. Each of the treatments was split into two subplots that received 0 and 60 kg N ha^{-1}, respectively. The chemical nitrogen fertilizer was split applied with $^1/_3$ at planting and $^2/_3$ at 4 weeks after planting.

Test crop was maize (*Zea mays*) Katumani composite variety that takes 72 days to mature. The seeds were planted at 90 and 60 cm inter and intra-row spacing, respectively and thinned to two plants per hole after germination. Harvesting was done leaving one border row and end plants making a harvest net plot area of 4.5 m by 1.8 m from the initial subplot plot of 6 m by 3 m.

Plant nutrient uptake

Nutrient inputs from fertilizer were calculated based on application amounts and fertilizer formulation. Inputs from organic resources were derived from nutrient contents of the manure and maize stover applied in each season. At the end of season 4, maize grain and stover at subplot level were analyzed for %N, P and K for calculations of seasonal plant nutrient uptake. Sampling for the grain and stover was done at harvest by selecting five (5) plants from each plot. The stover was chopped into small pieces and both grain and the stover air-dried to constant weight. A subsample was then ground, separately for grain and stover, before analysis. The results were used to calculate partial nutrient balances for N, P and K as:

Partial nutrient balance = input (fertilizers + organics) − uptake (removal in grain and stover)

The estimates excluded inputs in wet and dry deposition, sedimentation, and nutrient accessions by deep roots from subsoil layers, and outputs by leaching, erosion, run-off, and gaseous losses.

Separating aggregate fractions

Soil sampling for aggregation assessment was done at the end of the 4th season in all −N plots at 0–15 cm depth at five spots (along the two diagonals). A sampling core with 5 cm diameter was used and the soil was mixed before taking a total sample of 1 kg. Within tied-ridges, soil sampling was at sloping part of the ridge (mid-way between furrow and ridge-top). The samples were air dried for 2 days to constant weight before passing through an 8 mm sieve from where 80 g was weighed for wet sieving, and an additional 10 g for moisture content determination. The 80 g soil was submerged in water over a 2 mm sieve for 5 min to allow slaking, followed by sieving for 2 min. Soil that passed through the 2 mm sieve was sieved again for 2 min using a 250 μm sieve to obtain small macro-aggregates. The aggregates not captured by the 250 μm sieve were then sieved for 2 min using a 53 μm sieve to obtain micro aggregates. The filtrate obtained after sieving with a 53 μm sieve was shaken using a dispenser and 250 ml sampled into a beaker. The four different samples were dried at 60°C for 48 h before weighing. Sand correction was not done. Mean weight diameter (MWD) of the aggregate fractions was calculated as $MWD=\Sigma X_i W_i$, where X_i is the diameter of the ith sieve size and W_i is the proportion of the total aggregates in the ith fraction. Higher MWD indicate higher proportions of macro-aggregates. Geometric mean diameter (GMD) was calculated as, $GMD = \exp\left(\frac{\Sigma W_i \ln X_i}{\Sigma W_i}\right)$, where W$i$ is the weight of aggregates in size class i and Xi is the mean diameter of that size class. GMD estimates the size of the most frequent aggregate size class (Filho et al. 2002).

Chemical soil and plant analysis

Plant and soil analysis were conducted at ICRAF laboratories in Nairobi, Kenya, and all analysis were done according to the ICRAF laboratory procedures as detailed by (ICRAF 1995). Analysis for plant N, P and K was by wet oxidation based on Kjeldahl digestion with sulphuric acid (Parkinson and Allen 1975). Potassium was determined through flame photometry, and N and P were determined by colorimetric determination. Soil total N was also based on wet oxidation using Kjeldahl digestion while soil total carbon was extracted using acidified dichromate. Analysis for extractable inorganic phosphorus and exchangeable potassium were based on a modified Olsen extractant. Soil pH was determined in water while exchangeable Ca and Mg were extracted using 1 N KCl extractant and determined using a spectrophotometer.

Data analysis

Maize germination and yield data (grain and stover), were analyzed in Genstat Discovery edition 3, using split plot procedure with initial soil parameters values (available Phosphorus, exchangeable calcium, magnesium and potassium and C/N ratio) as covariates to take care of the variability observed in the experimental field. Soil aggregation data was obtained at main plot level and was analyzed using generalized linear model (GLM procedure) in Statistical Analysis System (SAS) version 9.1 and treatment least square means obtained by the LSmeans statement. Pearsons correlation coefficients were used to establish relationship between different soil parameters using SAS software but first, the outliers and extreme values, identified by box plots in SPSS version 14.0 for windows, were removed.

Results

Soils across the experimental field were heterogeneous. Excluding outliers and extreme values shown in Fig. 2, Pearson's correlations showed pH to be largely correlated to exchangeable calcium ($R^2 = 0.8$).

Effect of treatment on germination

Germination was significantly affected by tillage-organic resource system ($P < 0.01$) during the last two seasons with treatments under tied-ridge systems having lower germination than no-till and conventional tillage systems (Table 1). Germination was highest in the 2nd season but declined in the subsequent seasons. The decline was highest in tied-ridges where 88, 62 and 29% germination was observed in the 2nd, 3rd and 4th seasons respectively compared to 91, 81 and 77% in the other systems, during the same period. Chemical nitrogen fertilizer application did not affect germination in any of the seasons.

Effect of treatment on maize yield

Tillage-organic resource system had no significant effect on maize grain yield in any of the season. However, important trends were observed when comparing the different tillage and organic residue treatments. For example, treatments under no-till system had the lowest yields during the first two seasons but improved to achieve the highest yield by the fourth season (Table 2). During the fourth season, and without N application, no-till + manure achieved significantly higher maize grain yields than control ($P < 0.05$). These data show continual progression of crop yield improvement under no-till system over the 4 seasons. Regardless of tillage-organic resource system, the highest seasonal yield was observed in season 3 (SR2006).

Combining CR and manure resulted in additive maize yields over manure only treatments in all the seasons of study. Over the four seasons for example, combining 1 t ha^{-1} of crop residue and 1 t ha^{-1} of manure, in plots not applied with chemical N, increased average maize grain yield above manure only treatments by 52, 17 and 27% in conventional, no-till and tied-ridge treatments, respectively (Table 2). During the same period, average maize stover yield in CR + manure treatments was more than manure only treatments by 22–36%, for treatments not applied with chemical nitrogen fertilizer. We observed that under tied-ridges, conventional and no-till systems, there were $^6/_8$, $^6/_8$ and $^4/_8$ cases respectively in which organic resource combination (1 t ha^{-1} each of crop residue and manure) had additive maize grain yields over manure only (applied at 2 t ha^{-1}).

Chemical nitrogen fertilizer application had a positive and significant effect on maize yield in the first three seasons while its interaction with tillage-organic resource system was significant during the fourth season. On average, application of chemical nitrogen fertilizer increased yield by 39, 59, 91 and 13% over plots not applied with the nitrogen fertilizer in season 1, 2, 3 and 4 respectively. Averaged over the four seasons, maize grain increases due to N application in CR + manure and manure only treatments were 23 and 34% in conventional tillage, 18 and 59% in no-till and, 17 and 35% in tied-ridges, respectively. Greater response to fertilizer N in manure only treatments over manure + CR was also observed with maize stover.

Table 1 Effects of tillage and organic resource on percent germination of maize at Machang'a in Mbeere, Kenya during the September 2005 to July 2007 period

Tillage system	SR2005		LR2006		SR2006		LR2007	
	−N	+N	−N	+N	−N	+N	−N	+N
Conventional (control)	83.3^{b}	85.8^{bc}	93.0^{bc}	89.0^{ab}	81.7^{b}	81.7^{b}	66.7^{b}	78.3^{bc}
Conventional + CR + manure	83.3^{b}	75.3^{a}	91.7^{abc}	93.0^{b}	83.3^{b}	83.3^{b}	80.0^{c}	71.7^{b}
Conventional + manure	91.7^{c}	81.7^{ab}	95.0^{c}	91.3^{ab}	78.3^{b}	85.0^{b}	78.3^{c}	71.7^{b}
No-till + CR + manure	80.0^{ab}	86.7^{bc}	89.7^{ab}	92.3^{ab}	73.0^{b}	85.3^{b}	76.7^{c}	76.7^{bc}
No-till + manure	80.3^{ab}	91.7^{c}	87.0^{a}	89.7^{ab}	80.0^{b}	80.0^{b}	81.7^{c}	80.0^{c}
Tied-ridges + CR + manure	75.0^{a}	85.0^{bc}	89.0^{ab}	88.3^{ab}	73.0^{b}	56.7^{a}	33.3^{a}	28.3^{a}
Tied-ridges + manure	83.3^{ab}	88.3^{c}	88.3^{ab}	87.3^{a}	57.7^{a}	60.0^{a}	28.3^{a}	26.7^{a}
SED	3.2	(4.1)	2.3	(2.8)	6.3	(7.7)	3.4	(6.3)

CR = crop residue, SR2005 = short rainy season of 2005, LR2006 = long rainy season of 2006, SR2006 = short rainy season of 2006, LR2007 = long rainy season of 2007, Values in the same column followed by the same letter are not significantly different ($P = 0.05$), SED = standard error of the differences of means. The values in bracket are SED to compare across different tillage treatments and nitrogen levels

Table 2 Effect of tillage, manure, crop residue and chemical nitrogen fertilizer on maize grain and stover yield at Machang'a in Mbeere, eastern Kenya during the September 2005 to July 2007 period

Tillage system	SR2005		LR2006		SR2006		LR2007	
	−N	+N	−N	+N	−N	+N	−N	+N
Maize grain yield (t ha^{-1})								
Conventional (control)	1.14^{ab}	1.62^{ab}	1.03^{ab}	1.52^{ab}	1.22^{ab}	3.10^{a}	1.00^{a}	2.29^{a}
Conventional + CR + manure	2.05^{b}	2.62^{b}	1.07^{ab}	1.57^{ab}	3.91^{b}	4.89^{a}	2.83^{ab}	3.09^{a}
Conventional + manure	1.30^{ab}	1.87^{ab}	1.36^{ab}	1.68^{ab}	2.12^{ab}	3.40^{a}	1.73^{ab}	1.74^{a}
No-till + CR + manure	0.55^{a}	0.75^{a}	0.61^{ab}	0.92^{ab}	1.73^{ab}	3.10^{a}	2.77^{ab}	1.91^{a}
No-till + manure	0.76^{ab}	1.73^{ab}	0.24^{a}	0.65^{a}	0.76^{a}	2.02^{a}	3.09^{b}	3.29^{a}
Tied-ridges + CR + manure	2.13^{b}	1.92^{ab}	1.53^{b}	2.20^{b}	2.35^{ab}	3.56^{a}	1.81^{ab}	1.48^{a}
Tied-ridges + manure	1.53^{ab}	1.64^{ab}	1.15^{ab}	1.43^{ab}	1.84^{ab}	3.65^{a}	1.65^{ab}	1.59^{a}
SED	0.60	(0.65)	0.52	(0.52)	1.24	(1.21)	0.80	(0.77)
Maize stover yield (t ha^{-1})								
Conventional (control)	1.23^{a}	2.09^{a}	1.59^{a}	2.30^{a}	1.43^{a}	2.68^{b}	1.07^{a}	1.72^{a}
Conventional + CR + manure	2.95^{ab}	3.63^{a}	1.26^{a}	1.69^{a}	2.20^{a}	2.83^{b}	2.43^{a}	1.66^{a}
Conventional + manure	2.55^{ab}	2.81^{a}	1.80^{a}	2.55^{a}	1.20^{a}	2.32^{ab}	1.64^{a}	1.18^{a}
No-till + CR + manure	2.11^{ab}	2.33^{a}	1.34^{a}	1.82^{a}	1.52^{a}	3.12^{b}	1.24^{a}	1.34^{a}
No-till + manure	1.53^{a}	2.56^{a}	0.68^{a}	1.27^{a}	0.90^{a}	1.23^{a}	2.00^{a}	2.12^{a}
Tied-ridges + CR + manure	4.15^{b}	2.33^{a}	1.84^{a}	2.80^{a}	2.06^{a}	2.36^{ab}	1.66^{a}	1.06^{a}
Tied-ridges + manure	2.84^{ab}	3.51^{a}	1.37^{a}	1.35^{a}	1.54^{a}	2.61^{b}	1.39^{a}	1.13^{a}
SED	0.81	(0.90)	0.70	(0.72)	0.58	(0.68)	0.70	(0.68)

CR = crop residue, SR2005 = short rainy season of 2005, LR2006 = long rainy season of 2006, SR2006 = short rainy season of 2006, LR2007 = long rainy season of 2007, Values in the same column followed by the same letter are not significantly different ($P = 0.05$), SED = standard error of the differences of means. The values in bracket are SED to compare across different tillage treatments and nitrogen levels. Minus N (−N) refers only to chemical fertilizer N and not N contained in the organic resources used. As such, the −N treatments contain some N from these organic resources

Partial nutrient balances

Summed up over the four seasons of this study, nutrient inputs of up to 455 kg N ha^{-1}, 200 kg P ha^{-1} and 560 kg K ha^{-1} were applied as fertilizer, manure and crop residue (Table 3). Highest total nutrient uptake contained in the above ground plant parts was 196 kg N ha^{-1}, 27 kg P ha^{-1} and 191 kg K ha^{-1}. Of the total uptake, uptake by stover ranged from 21.6 kg N ha^{-1} in control to 47.2 kg N ha^{-1} in tied ridge, 3.0 kg P ha^{-1} in no-till to 6.6 kg P ha^{-1} in tied ridge and 87 kg K ha^{-1} in no-till to 165 kg K ha^{-1} in conventional tillage (data not shown). This represented 25–35, 20–33 and 86–92% of total N, P and K uptake respectively. Generally, total N uptake, in treatments not applied with chemical N fertilizer for example, was in the order conventional tillage + CR + manure > tied-ridges + CR + manure > tied-ridge + manure > conventional tillage + manure > no-till + CR + manure > no-till + manure > control (Table 3). As with harvested yield, combination of crop residue and manure resulted in an additional uptake of 79, 16 and 9 kg N ha^{-1} in conventional tillage, no-till and tied ridge systems, respectively, for plots not applied with chemical N fertilizer. Also, plots applied with inorganic fertilizer N had more K and N taken up than non-N plots. Grain/stover nutrient ratio varied from 1.5 to 4.0 for N, 2.0 to 6.1 for P and 0.15 to 0.25 for K. Highest ratios for N and P were observed in no-till treatment.

Nitrogen partial nutrient balances were positive (+6 to +350 kg N ha^{-1}) except for the control (−57 kg N ha^{-1}) and conventional tillage + CR + manure (−48 kg N ha^{-1}; Table 3). Negative balances indicate nutrient mining. Phosphorus and potassium not used by crops ranged between 141 to 193 kg P ha^{-1} and 75 to 462 kg K ha^{-1}. Although apparent P and K recoveries (uptake/input) were similar between N and non chemical N fertilizer plots, apparent

Table 3 Effects of tillage and organic resource on total N, P and K uptake by maize and partial balances observed over four seasons (September 2005 to July 2007) at Machang'a in Mbeere, eastern Kenya

Tillage system	Organic resource	Chemical N Fertilizer	Input± (kg nutrient ha^{-1})			Uptake (kg nutrient ha^{-1})			Partial balance (kg nutrient ha^{-1})		
			N	P	K	N	P	K	N	P	K
Control	None	−N	0	160	240	67	14	120	−67	146	120
Conventional	CR + manure	−N	133	186	470	183	22	185	−50	164	285
Conventional	Manure	−N	214	206	557	104	18	143	110	188	414
No-till	CR + manure	−N	133	186	470	97	12	122	36	174	348
No-till	Manure	−N	214	206	557	81	15	102	133	191	455
Tied-ridges	CR + manure	−N	133	186	470	127	17	164	6	169	306
Tied-ridges	Manure	−N	214	206	557	118	21	159	96	185	398
Control	None	+N	240	160	240	137	20	168	103	140	72
Conventional	CR + manure	+N	373	186	470	196	27	181	177	159	289
Conventional	Manure	+N	454	206	557	137	18	191	317	188	366
No-till	CR + manure	+N	373	186	470	111	18	182	262	168	288
No-till	Manure	+N	454	206	557	109	18	153	345	188	404
Tied-ridges	CR + manure	+N	373	186	470	160	20	178	213	166	292
Tied-ridges	Manure	+N	454	206	557	144	20	172	310	186	385

CR = crop residue, ± applied to maize through manure, crop residue and fertilizer over four season

recoveries of N were 0.76 for non-N treatments and 0.38 for treatments applied with N respectively. In all cases, lower uptake and higher nutrient balances were observed in 'manure only' treatments than treatments involving combination of manure and CR.

In most cases, partial N, P and K balances were significantly and negatively correlated with maize yield (Table 4), indicating that increased crop productivity led to lower partial nutrient budgets. Taking partial P balance as an example, treatments combining both CR and manure had more significant correlations with grain and stover compared to treatments with manure as the only organic resource applied. For the different organic resources and N fertilizer application combinations, there was positive influence of initial soil total N and exchangeable P and K on total N, P and K uptake by maize (data not shown).

Soil aggregation

Soil aggregation was assessed at the main plot level, allowing to determine the separate effects of tillage and organic resources. Tillage had significant effect on large macro-aggregate fraction (>2 mm) and micro-aggregates fraction (<250 μm >53 μm), with the highest macro-aggregates and aggregation indices in no-till followed by tied-ridges and least in conventional tillage (Table 5). In treatments combining CR and manure, large macro-aggregates were up to 2 times higher in conservation systems (no-till and tied ridges) compared to conventional tillage system, with resultant reductions in micro-aggregates. Also, combining crop residue and manure increased large macro-aggregates by 1.4–4.0 g 100 g^{-1} soil above manure only treatments and simultaneously decreased micro-aggregates by 6.2 g 100 g^{-1} soil in tied-ridges and 4.0 g 100 g^{-1} soil in no-till below manure only treatments. Aggregate mean weight diameter (MWD) was significantly affected by tillage ($P > 0.05$) being greatest in no-till followed by tied-ridges and least in conventional tillage. As with large macro-aggregates, MWD was higher (not significant) in treatments combining CR and manure compared to those with only manure as the organic resource. Particulate organic matter (POM > 2 mm), small macro-aggregates (<2 mm >53 μm), silt and clay (<53 μm) and geometric mean diameter (GMD) were not affected either by tillage or organic resource.

Table 4 Pearson correlation coefficients between maize yield and partial N, P and K balances after four seasons of cropping (September 2005 to July 2007) at Machang'a in Mbeere, eastern Kenya

Fertilization	Partial N balance		Partial P balance		Partial K balance	
	Grain	Stover	Grain	Stover	Grain	Stover
CR + manure −N	−0.95***	−0.67*	−0.92***	−0.81**	−0.85**	−0.72*
Manure −N	−0.78*	−0.63	−0.75*	−0.49	−0.81**	−0.73*
CR + manure +N	−0.89**	−0.50	−0.82**	−0.69*	−0.56	−0.73*
Manure +N	−0.90***	−0.45	−0.66	−0.54	−0.66	−0.85**

CR = crop residue, * significant at $P = 0.05$, ** significant at $P = 0.01$, *** significant at $P = 0.001$

Table 5 Soil aggregation as affected by tillage and organic resources at 0–15 cm at Machang'a in Mbeere, eastern Kenya in 2007

Tillage system	Organic resource	POM (>2 mm) g 100 g−¹ soil	Large macro (>2 mm) g 100 g−¹ soil	Small macro (<2 mm >250 μm) g 100 g−¹ soil	Micro (<250 >53 μm) g 100 g−¹ soil	Silt + clay (<53 μm) g 100 g−¹ soil	MWD	GMD
Conventional	Zero	0.05[a]	2.6[a]	27.4[a]	59.9[bc]	8.8[a]	0.60[a]	0.25[a]
Conventional	CR + manure	0.09[a]	3.7[a]	24.7[a]	62.3[c]	8.0[a]	0.62[a]	0.24[a]
Conventional	Manure	0.05[a]	2.4[a]	27.1[a]	60.7[c]	8.3[a]	0.59[a]	0.24[a]
No-till	CR + manure	0.11[a]	8.3[b]	27.9[a]	53.7[a]	7.9[a]	0.88[b]	0.30[a]
No-till	Manure	0.09[a]	4.3[ab]	29.6[a]	57.7[abc]	7.9[a]	0.71[ab]	0.29[a]
Tied-ridges	CR + manure	0.08[a]	6.4[ab]	29.1[a]	54.0[ab]	8.4[a]	0.80[ab]	0.28[a]
Tied-ridges	Manure	0.07[a]	4.4[ab]	26.9[a]	60.2[c]	7.4[a]	0.68[ab]	0.27[a]
SE		0.032	1.344	1.631	2.024	0.854	0.073	0.026

CR = crop residue, SE = standard error, POM = particulate organic matter, MWD = mean weight diameter of aggregates, GMD = geometric mean diameter of aggregates, Values in the same column followed by the same letter are not significantly different ($P = 0.05$)

Discussion

No-till and reduced tillage systems have been reported to perform better (Mrabet 2002), similar and sometimes poorer than conventional tillage systems in terms of agronomic yields (Blaise and Ravindran 2003; Diaz-Zorita 2000). In our case, agronomic performance in no-till system improved throughout the four seasons. Reduced yield under no-till compared to conventional system, especially during initial seasons, has been reported elsewhere in Africa (Hoogmoed 1999; Rawitz et al. 1986) and attributed to crusting, surface sealing off the pores for water percolation and runoff (Osunbitan et al. 2005; Rosolem et al. 2002). We observed leaf closing (wilting) and drying off plants indicating low water availability in the rooting zone of no-till during the first seasons. The amount of applied crop residue in our case was lower than the amount used in many conservation tillage trials and this could have contributed to the low yields under no-till during the initial seasons. The absence of residue during the fallow periods (between seasons as in our case) likely decreased agronomic performance in the no-till system, and future no-till trials should maintain residue cover throughout the year. High performance in no-till by the 4th season could be attributed to improvements of soil structure and therefore rooting and soil water relations, or simply response to the rainfall regime. Residue retention is necessary in no-till systems and Govaerts et al. (2009) and Verhulst et al. (2009) have shown that similar improvements in soil quality (increased direct infiltration in the soil) and crop yields can be achieved with partial or with full residue retention. Recently, in order to improve water relations and crop performance in no-till systems, modifications have emerged including ripping and sub-soiling and the results are promising (Busscher et al. 1995; Diaz-Zorita 2000; Motavalli et al. 2003), especially where soil compaction is

Fig. 3 Soil and water sinks formed by Tied ridges in Mbeere, Eastern Kenya. Picture taken on 12th April 2007 after 77 mm of rainfall 15 h earlier. *Rings* around the basins represent silt and SOM retained rather than washing away in runoff

evident (Evans et al. 1996) but also depending on the rainfall regime (Gameda et al. 1994). The next challenge in no-till farming is weed management in systems where chemical control is not viable.

Similar yield between conventional tillage and tied-ridges as observed during the first three seasons, even though tillage under tied-ridge was restricted to ridge maintenance, is attributed to soil moisture improvement since the basins of tied-ridges harvest rainwater and allow it to percolate rather than runoff (Fig. 3). Rainfall was often stormy and in season two for example, 75% of the seasonal rainfall was received only in 7 days. Tied-ridge systems have been observed to increase yield over conventional tillage by up to 85% (Nyakatawa et al. 1996) but the increase depends on soil type, ridge flow (closed or open) and planting position (in furrow or ridge top—as in our case Belay et al. 1998). Negative yields under tied ridges have also been reported and were attributed to high rainfall (>700 mm Jensen et al. 2003) and water logging (Olufayo et al. 1994). Sandy soils in eastern Kenya allow quick percolation of water into subsurface horizons and no water-logging has been observed. Decreased yield in tied-ridges compared to conventional tillage and no-till systems especially during the last season is attributed to lower germination. As also reported by Twomlow and Bruneau (2000), poor crop germination in tied ridges, especially for season four that had lowest rainfall during the first weeks, is attributed to incomplete wetting up of the tied-ridges at beginning of season. In Zimbabwe, the current practice to counter low germination on ridges is to use post emergence tied-ridges (Nyagumbo, personal communication), but this requires rebuilding the ridges every season rather than maintaining old ones across seasons.

System performance under different organic resources shows clearly that farmers are better off combining different organic resources (manure and crop residue) for better yields. The benefits maybe derived from a synchrony mechanism where manure releases nutrients more readily meeting plant demand at early stages, while crop residues release nutrients slowly meeting requirements at later stages when plant demand is also lower. Also, in manure-only treatments, greater amounts of N could be released and get leached out of the system while presence of crop residue in CR + manure treatment could lead to immobilization of such readily mineralizable manure N by micro-organisms during decomposition of the low quality crop residue. In northern France, for example, low quality straw retained in treatments reduced average mineralization over 4 months from 45 to 21 kg N ha^{-1} through immobilization (Beaudoin et al. 2005). Such immobilized N could be released at later crop stages thereby enhancing crop performance. Greater losses of N in manure only than in CR + manure treatments could explain the greater maize response to chemical N fertilizer application observed in manure only treatments, compared to CR + manure treatments. Sandy environments, as is the case in our study site, are reported to experience excess drainage below the rooting zone accompanied by nitrogen leaching (Cameira et al. 2003) and up to 154 kg N ha^{-1} could be leached annually (Beaudoin et al. 2005). Higher yields with than without crop residue within conservation tillage systems (Dam et al. 2005) could be attributed to reduction in surface runoff. In Nigeria, Erenstein (2003) observed that runoff was reduced from 75.4 to 43.4% using 2 t ha^{-1} of surface mulch. Combining crop residue and manure could be a good strategy for semi-arid environments such as Mbeere, eastern Kenya, where poor rainfall distribution could lead to occasional flushing of plant available nutrients down the soil profile. It is such technologies that enhance synchrony between nutrient release and uptake by crops, and that consider farmers' organic resource access that could increase farm productivity and profitability.

Significant response to chemical N fertilizer indicates the importance of application of fertilizer in the cropping systems. Cropping system management should thus entail combinations of an appropriate tillage system, application/retention of organic resources, even though in small quantities, and the use of chemical nutrient sources. Nevertheless, the additional benefits following fertilizer application vary with seasonal rainfall. Lowest response to fertilizer in season 4 (LR 2007) is attributed to lack of adequate rainfall during the first 2 weeks after planting. This was likely through negative effects on root development for the already germinated crop (there was no effect of chemical N fertilizer on germination percentage). On the contrary, highest response to fertilizer was observed during the season with highest, well-distributed rainfall (SR 2006). In general, highest yields achieved when chemical N fertilizer was combined with CR and manure demonstrate the importance of integrated soil fertility management (ISFM). This is well demonstrated by Vanlauwe et al. (2010) through a meta-analysis involving 90 ISFM-based per-reviewed publications that revealed greater agronomic performance when fertilizer was combined with manure or compost.

For the apparent nutrient recovery, the values observed in this study are similar to those reported by Saidou et al. (2003). Leaching is a prevalent problem in sandy soils and 25–33% of applied N could be leached as observed in a sandy soil in England (Salazar et al. 2005), and values could even be higher. The large partial balance observed in manure only treatments compared to those combining CR and manure could constitute more of nutrients lost by leaching or runoff. The correlations of NPK balances with maize yield further show that there were some manure only treatments where partial balance was not related with yield and this could be due to such leaching losses. Low nutrient uptake in no-till system compared to conventional and tied-ridge systems is attributed to the lower yields observed during the initial seasons. Our observation of higher N uptake following application of fertilizer N agrees with the observation of reduced aboveground N uptake in N-stress treatments in West Africa (Oikeh et al. 2003).

Greater soil macro-aggregation in no-till systems due to reduced disturbance normally caused by plowing has been reported by several authors (Filho et al. 2002; Pinheiro et al. 2004). The presence of crop residue within no-till improved soil aggregation, agreeing with Lal (1984) who observed that crop residue and reduced tillage drastically reduced soil detachment and its transport through runoff. Similarly, Ogunremi et al. (1986) reported increased proportion of aggregates exceeding 2 mm diameter in no-till compared to ploughed plots, and the differences were more pronounced when no-till was combined with crop residue application. In another study, Ley et al. (1989) found soil passing through 125-μm sieves at Samaru to be 10 times less in no-till compared to tilled treatment. Aggregation indices also showed that soil structure was improved under tied-ridges compared to conventional tillage plots, again due to less disruptions by tillage and enhanced soil moisture. But aggregation in tied-ridges was lower than in no-till because the restricted tillage for ridge maintenance contributed to aggregate disruptions.

Conclusions

Since combining 1 t ha^{-1} manure and 1 t ha^{-1}crop residue result in improvement of maize yield and soil aggregation compared to sole application of manure at 2 t ha^{-1}, we conclude that application of high quality manure combined with low quality crop residue is a good practice that could reduce N leakage and increase nutrient use efficiency within dryland maize cropping systems. No-till system can achieve better yield than conventional tillage but this is achieved after some cropping seasons. The best practice for farmers will be to use combination of conservation tillage (no-till or tied-ridges) and manure plus crop residue. Also, the application of chemical N fertilizer in the system is appropriate for further increases in yield. These results are applicable in farmers' fields and can be implemented immediately since the rates of organic resources used are within the access of majority of small-holder farmers in the dryland environments.

Acknowledgments This work was made possible by the funding from the International Foundation for Science (IFS) to which I am greatly indebted. Thanks also to Ivan Adolwa (TSBF-CIAT) and Samuel Njoroge (Kenyatta University) for assisting with literature searches and soil fractionation.

References

Bationo A, Vlek PLG (1997) The role of nitrogen fertilisers applied to food crop in the Sudano-Sahelian zone of West

Africa. In: Renard G et al. (ed) Soil fertility management in West African land use systems. Proc. regional workshop Univ. Hohenheim, ICRISAT Sahelian Centre and INRAN 4–8 March 1997, Niamey, Niger. Margraf Verlag, Germany

Bationo A, Kihara J, Vanlauwe B, Waswa B, Kimetu J (2007) Soil organic carbon dynamics, functions and management in West African agro-ecosystems. Agric Syst 94:12–25

Beaudoin N, Saad JK, Van Laethem C, Machet JM, Maucorps J, Mary B (2005) Nitrate leaching in intensive agriculture in Northern France: effect of farming practices, soils and crop rotations. Agric Ecosyst Environ 111:292–310

Belay A, Gebrekidan H, Uloro Y (1998) Effect of tied ridges on grain yield response of maize (Zea mays L.) to application of crop residue and residual N and P on two soil types at Alemaya, Ethiopia. S Afr J Plant Soil 15:123–129

Blaise D, Ravindran CD (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 Tillage Res 70:163–173

Busscher WJ, Edwards JH, Vepraskas MJ, Karlen DL (1995) Residual effects of slit tillage and subsoiling in a hardpan soil. Soil Tillage Res 35:115–123

Cameira MR, Fernando RM, Pereira LS (2003) Monitoring water and NO_3-N in irrigated maize fields in the Sorraia Watershed, Portugal. Agric Water Manag 60:199–216

Dam RF, Mehdi BB, Burgess MSE, Madramootoo CA, Mehuys GR, Callum IR (2005) Soil bulk density and crop yield under eleven consecutive years of corn with different tillage and residue practices in a sandy loam soil in central Canada. Soil Tillage Res 84:41–53

Diaz-Zorita M (2000) Effect of deep-tillage and nitrogen fertilization interactions on dryland corn (Zea mays L.) productivity. Soil Tillage Res 54:11–19

Erenstein O (2003) Smallholder conservation farming in the tropics and sub-tropics: a guide to the development and dissemination of mulching with crop residues and cover crops. Agric Ecosyst Environ 100:17–37

Evans SD, Lindstrom MJ, Voorhees WB, Monscrief JF, Nelson GA (1996) Effect of subsoiling and subsequent tillage on soil bulk density, soil moisture, and con yield. Soil Tillage Res 38:35–46

Filho CC, Lourenco A, Guimaraes FM, Fonseca ICB (2002) Aggregate stability under different soil management systems in a red latosol in the state of Parana, Brazil. Soil Tillage Res 65:45–51

Gameda S, Raghavan GSV, McKyes E, Watson AK, Mehuys G (1994) Response of grain corn to subsoiling and chemical wetting of a compacted clay soil. Soil Tillage Res 29:179–187

Gebrekidan H (2003) Grain yield response of sorghum (Sorghum bicolor) to tied ridges and planting methods on entisols and vertisols of Alemaya Area, Eastern Ethiopian Highlands. J Agric Rural Dev Trop Subtrop 104:113–128

Govaerts B, Verhulst N, Sayre KD, Kienle F, Flores D, Limon-Ortega A (2009) Implementing conservation agriculture concepts for irrigated wheat based systems in Northwest Mexico: a dynamic process towards sustainable production. In: Innovations for improving efficiency, equity and environment. Lead papers for the 4th world congress on conservation agriculture held 4–7th February 2009 in New Delhi, India. 4th world congress on conservation agriculture, New Delhi, India

Goyal S, Chander K, Mundra MC, Kapoor KK (1999) Influence of inorganic fertilizers and organic amendments on soil organic matter and soil microbial properties under tropical conditions. Biol Fertil Soils 29:196–200

Hoogmoed WB (1999) Tillage for soil and water conservation in the semi-arid tropics. Doctoral Thesis, Wageningen University, Wageningen, the Netherlands

ICRAF (1995) International Centre for Research in Agroforestry: Laboratory methods of soil and plant analysis, Nairobi, Kenya

Jensen JR, Bernhard RH, Hanse S, McDonagh J, Moberg JP, Nielsen NE, Nordbo E (2003) Productivity in maize based cropping systems under various soil-water-nutrient management strategies in a semi-arid, alfisol environment in East Africa. Agric Water Manag 56:217–237

Lal R (1984) Mechanized tillage systems effects on soil erosion from an alfisol in watersheds cropped to maize. Soil Tillage Res 4:349–360

Ley GJ, Mullins CE, Lal R (1989) Hard-setting behavior of some structurally weak tropical soils. Soil Tillage Res 13:365–381

Madari B, Machado PLOA, Torres E, de Andrade AG, Valencia LIO (2005) No tillage and crop rotation effects on soil aggregation and organic carbon in a rhodic ferralsol from southern Brazil. Soil Tillage Res 80:185–200

Maroko JB, Buresh RJ, Smithson PC (1998) Soil nitrogen availability as affected by fallow-maize systems on two soils in Kenya. Biol Fertil Soils 26:229–234

Martius C, Tiessen H, Vlek PLG (2001) The management of organic matter in tropical soils: what are the priorities? Nutr Cycl Agroecosyst 61:1–6

McCarty GW, Meisinger JJ (1997) Effects of N fertilizer treatments on biologically active N pools in soils under plow and no tillage. Biol Fertil Soils 24:406–412

Miriti JM, Esilaba AO, Bationo A, Cheruiyot H, Kihumba J, Thuranira EG (2007) Tied-ridging and intergrated nutrient management options for sustainable crop production in semi-arid eastern Kenya. In: Bationo A et al (eds) Advances in integrated soil fertility management in sub-Saharan Africa: challenges and opportunities. Springer, Dordrecht

Motavalli PP, Stevens WE, Hartwig G (2003) Remediation of subsoil compaction and compaction effects on corn N availability by deep tillage and application of poultry manure in a sandy-textured soil. Soil Tillage Res 71:121–131

Mrabet R (2002) Stratification of soil aggregation and organic matter under conservation tillage systems in Africa. Soil Tillage Res 66:119–128

Nyakatawa EZ, Brown M, Maringa D (1996) Maize and sorghum yields under tied-ridges of fertilized sandy soils in semi-arid south-east lowveld of Zimbabwe. Afr Crop Sci J 4:197–206

Ogunremi LT, Lal R, Babalola O (1986) Effects of tillage and seeding methods on soil physical properties and yield of upland rice for an ultisol in southeast Nigeria. Soil Tillage Res 6:305–324

Oikeh SO, Carsky RJ, Kling JG, Chude VO, Horst WJ (2003) Differential N uptake by maize cultivars and soil nitrate

dynamics under N fertilization in West Africa. Agric Ecosyst Environ 100:181–191
Olufayo A, Baldy C, Some L, Traore I (1994) Tillage effects on grain sorghum (Sorghum bicolor (L) Moench) development and plant water status in Burkina Faso. Soil Tillage Res 32:105–116
Osunbitan JA, Oyedele DJ, Adekalu KO (2005) Tillage effects on bulk density, hydraulic conductivity and strength of a loamy sand soil in southwestern Nigeria. Soil Tillage Res 82:57–64
Parkinson JA, Allen SE (1975) A wet oxidation procedure suitable for the determination of nitrogen and mineral nutrients in biological materials. Commun Soil Sci Plant Anal 6:1–11
Pascual U, Barbier EB (2006) Deprived land-use intensification in shifting cultivation: the population pressure hypothesis revisited. Agric Econ 34:155–165
Pinheiro EFM, Pereira MG, Anjos LHC (2004) Aggregate distribution and soil organic matter under different tillage systems for vegetable crops in a red latosol from Brazil. Soil Tillage Res 77:79–84
Rawitz E, Hoogmoed WB, Morin J (1986) The effect of tillage practices on crust properties, infiltration, and crop response under semi-arid conditions. In: Proceedings of international symposium on assessment of soil surface sealing and crusting, ISSS Ghent, Belgium, pp 278–284
Rockstrom J, Barron J, Fox P (2003) Water productivity in rainfed agriculture: challenges and opportunities for small holder farmers in drought prone tropical agro-ecosystems. CABI; IWMI, Wallingford, UK; Colombo, Sri Lanka
Rosolem CA, Foloni JSS, Tiritan CS (2002) Root growth and nutrient accumulation in cover crops as affected by soil compaction. Soil Tillage Res 65:109–115
Saidou A, Janssen BH, Temminghoff EJM (2003) Effects of soil properties, mulch and NPK fertilizer on maize yields and nutrient budgets on ferralitic soils in southern Benin. Agric Ecosyst Environ 100:265–273
Salazar FJ, Chadwick D, Pain BF, Hatch D, Owen E (2005) Nitrogen budgets for three cropping systems fertilised with cattle manure. Bioresour Technol 96:235–245
Scopel E, Muller B, Tostado JMA, Guerra EC, Maraux F (1998) Quantifying and modelling the effects of a light crop residue on the water balance: an application to rainfed maize in Western Mexico XVI world congress of soil science—Montpellier, France, August 1998
Six J, Elliott ET, Paustian K (2000) Soil macroaggregate turnover and microaggregate formation: a mechanism for C sequestration under no-tillage agriculture. Soil Biol Biochem 32:2099–2103
Twomlow SJ, Bruneau PMC (2000) The influence of tillage on semi-arid soil-water regimes in Zimbabwe. Geoderma 95:33–51
Vanlauwe B, Kihara J, Chivenge P, Pypers P, Coe R, Six J (2010) Agronomic use efficiency of N fertilizer in maize-based systems in sub-Saharan Africa within the context of integrated soil fertility management. Plant Soil 339:35–50
Verhulst N, Govaerts B, Verachtert E, Kienle F, Limon-Ortega A, Deckers J, Raes D, Sayre KD (2009) The importance of crop residue management in maintaining soil quality in zero tillage systems; a comparison between long-term trials in rainfed and irrigated wheat systems. In: Innovations for improving efficiency, equity and environment. Lead papers for the 4th world congress on conservation agriculture held 4–7th February 2009 in New Delhi, India. 4th world congress on conservation agriculture, New Delhi, India
Warren GP, Atwal SS, Irungu JW (1997) Soil nitrate variations under grass, sorghum and bare fallow in semi-arid Kenya. Exp Agric 33:321–333