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Effects of soil conservation technologies in improving soil productivity in northern Ghana

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A four year study was carried out to ascertain the usefulness of conservation agriculture (CA) technologies in improving biomass cover as well as the physical and chemical properties of the soil across 6 communities in northern Ghana. The conservation agriculture introduced include: Zero tillage, cover cropping, crop rotation and intercropping. Bunding was also introduced as a means of moisture retention. After four years of successful introduction and adoption of CA, soil and water evaluation study was conducted and compared with non CA fields. Parameters studied include: water infiltration, particle size distribution, bulk density, cation exchange capacity, exchangeable bases, exchangeable acidity, soil pH, total nitrogen, available phosphorus and soil organic matter. The results reveal an enhanced biomass accumulation and productivity of the soils with adequate N and P fertilization and moisture retention in CA fields compared to non CA fields. Conservation agriculture thus helps to temporally increase the productivity of soils toward a more sustainable crop production.

Key words: Conservation agriculture, crop production, soil moisture, tillage.

INTRODUCTION

Poor soil productivity is a major contributory factor to low yields in northern Ghana (Kugbe et al., in press; Abekoe and Tiessen, 1998). The productivity of soils have been observed to decline steadily over time and the causes are numerously discussed (Kugbe et al., 2012). In Ghana, majority of farmers still use shifting cultivation and fire for clearing land. Crop production in Ghana is limited by low and declining soil fertility, especially available nitrogen (N) and phosphorus (P). Increasing pressure on land due to increasing population and competing uses of land have shortened fallow periods leading to continuous cropping and consequently undesirable effects on soil structure and nutrient status. The declining soil fertility problem is also aggravated by indiscriminate bush burning, continuous cropping and low nutrient application rates, over grazing among others. The slash-and-burn system is no longer appropriate and reduced fallow periods due to increased pressure on agricultural lands lead to gradual soil degradation and declining soil fertility. Thus dependency increases the consumption of external inputs such as mineral fertilizers. The tedious field work and low returns to labour make agriculture unattractive for the youth, resulting in rural-urban migration in search of non-existing jobs.

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In order to obtain appreciable yield under continuous cropping and the inherently low plant available N and P, external nutrient additions in the form of fertilizers have become inevitable. Ensuring that the options for increasing productivity are available to the smallholder farmer is a task for scientists concerned with agricultural production and land management. About two-thirds of the N applied to cereals is accumulated in the grain and is exported during harvest. Much of the remaining N and a greater proportion of K are located in the stover and will not necessarily be cycled back to the soil because farmers remove almost the entire crop residues for uses with higher economic value, such as animal feed, fuel for cooking, building materials or raw material for handicrafts and often burn what is left. Baanante et al. (1992) in a farm survey in the forest zone of Ghana reported that 70% of crop residues served no useful agricultural purpose.

Adoption of conservation agriculture (CA) technology to halt and reverse degradation, as well as boost agricultural productivity have gained increasing interest in Africa and the world at large. Conservation agriculture is viewed as an attractive potential solution to reversing soil degradation and increasing land productivity in sub-Saharan Africa (Fowler and Rockstrom, 2001; Hobbs, 2007). In general, CA was introduced by the FAO (2008) as a concept for resource-efficient agricultural crop production, based on an integrated management of soil, water and biological resources combined with external inputs. In practice, CA relies on simultaneous application of three basic principles that are believed to enhance biological processes above and below the ground. These are (i) Minimum soil disturbance or if possible, no tillage; (ii) Permanent soil cover; and (iii) Crop rotation and/or associations (Braundron et al., 2005; Erenstein, 2003).

Unlike conventional tillage that causes the loss of topsoil due to erosion, CA specifically aims to address the problems of soil degradation that results from agricultural practices and which deplete the organic matter and nutrient content of the soil. Besides, it addresses the problem of intensive labour that is required in smallholder agriculture (African Conservation Tillage Network, 2008). Soil organic matter plays a central role in enhancing and sustaining soil productivity while contributing to improved soil structure and water retention, thus allowing effective use of water and nutrients by plants, and maintaining water quality through its filtering effects. It also contributes to carbon sequestration while the build up of soil organic matter provides the food for soil biological activity, especially soil macro-fauna (such as earthworms) which maintain soil structure, texture, physical properties and wide range of soil microbial populations. It has long been proposed that Conservation agriculture (CA) increases the productivity of soils in the long run. However, limited knowledge exists on specific geographic studies that can verify this assumption.

CARE international, an international NGO introduced And implemented a Conservation Agriculture Project (CAP) that introduced a set of soil and water management options to farmers with the view of improving soil productivity among the implementing communities. The project was aimed at increasing crop yield and income of subsistence farmers in 6selected communities of three Districts (Bawku Municipality, East Mamprusi district and Lawra district) in the three northern regions of Ghana. A key objective of the project was to increase crop yield through long-term sustainable management and conservation of soils. Data collected during the study offers a base to verify the assumption that CA improves long term soil productivity.

MATERIALS AND METHODS

Location of study and land preparation

The study was carried out in 6 communities across northern Ghana: Yaroyiri and Boayini in the East Mamprusi district; the Bawku Municipality; Nabugang, Betaglo and Babile Tanchara in the Lawra district. The area falls within the Sudan and Guinea savannah zones (Bonsu, 1996). Rainfall is among the lowest in the country, ranging between 645 and 1240 mm per annum. The uni-modal rainy season occurs between May and October but is irregular with dry spells during the rainy season. Peak rainfall occurs in August and September. The rains are followed by a long period of dry weather from November to April. Temperatures are generally high throughout the year, ranging from a minimum 20°C to maximum 45°C. The hottest part of the year is from March to May just prior to the start of the rainy season. Relative humidity is high during the rainy season but falls extremely low during the early part of the dry season as a result of desiccating winds off the Sahara Desert referred to as the harmattan season. The vegetation is predominantly savannah grass species with scattered trees. The region is subject to extreme bushfire outbreaks during the dry season. The landscape is characterized by gentle sloping areas with rocks outcrops and stony areas. The soils range from sandy to laterite and are generally of poor nutrient status. They are typically extremely low in organic matter (generally less than 1% compared to well-structured soil levels of 3.5%). They are particularly noted for their low levels of available nitrogen and phosphorous. Poor soil fertility is a common concern to farmers in the area as a fundamental cause, combined with erratic rainfall, of low crop yields. The savannah soils are less leached. As many soils are shallow with underlying iron pans, temporary waterlogging as well as lack of moisture in the following long dry season are common. Soils are highly susceptible to erosion as they break down over the years as a result of human activities including mechanized land preparation, continuous cropping, bush burning, lack of bunds or terraces on sloping land, felling of trees for building poles and fuel wood.

During land preparation, permanent parallel plots of 20 m by 20 m were established to compare no-tillage land preparation methods with farmers' current land preparation practice of conventional tillage at the 6 communities. In each location CA (zero tillage, crop rotation and cover cropping) was compared with farmer practices (conventional tillage). The experiments were initiated in 2008 to 2010. Data on soils, soil vegetative cover build up and yield analysis of crops cultivated were consistently taken over the study period. Before the introduction of Conservation Agriculture (CA) technologies, soils were initially sampled from each community. Composite soil samples were collected from each field at a depth of 0 to 25 cm. The samples were air dried, sieved and subjected to laboratory analysis (section 2.2, 2.3). Soil vegetation cover, before and after CA was also determined as plant biomass produced per meter square. After four years of successful introduction and adoption of the technologies, soil evaluation study was conducted in all six (6) communities to assess the efficacy of the CA interventions.

Determination of soil physical properties

Water infiltration

Infiltration measurements were done on three spots per community on minimum tillage plots before and after the minimum tillage adoption. A double-ring infiltrometer with an inner ring diameter of 28 cm and outer ring diameter of 54 cm was used to conduct the infiltration test *in situ*. For the same surface area, the rate of infiltration was determined as the amount of water which penetrated the soil per unit time. The measurements exclusively took place in the inner ring through which the water runs vertically.

The analysis of the infiltration test was based on Kostiakov (1932), which shows a decreasing infiltration rate with time. The equation by Kostiakov (1932) was used to compare the measured parameters with published literature values. The Kostiakov's equation has been found to fit field measured infiltration data especially over relatively short periods; that is, in the range of a few hours. The Kostiakov equation is described as follows:

$$i = c(t)^{a} \qquad (1)$$

Where, i = depth of infiltration, (cm), t = time of infiltration, (min), c and a = empirical constants.

This equation assumes that the rainfall intensity is greater than the infiltration capacity at all times and that the infiltration rate decreases with time (Bedient and Huber, 1992). From the measured data on the field, the infiltration rate (mm/h) versus time (hour) was plotted, from which the Kostiakov's equation was determined for all the curves.

Particle size distribution

The particle size distribution of the soil was determined by the modified bouyoucos hydrometer method as described by Day (1965). A forty gram soil was weighed into a beaker after which one hundred milliliters of 5% calgon (sodium hexametaphosphate) solution was added. The suspension was allowed to stand for about 10 min and then stirred with a mechanical stirrer for 30 min. The samples were not digested with hydrogen peroxide because of very low levels of organic matter in the soils.

The suspension was then transferred into a graduated sedimentation cylinder with the help of distilled water from a wash bottle and made up to the 1 L mark with distilled water. The content of the cylinder was mixed thoroughly using a plunger and hydrometer readings taken 5 min and 5 h thereafter. The suspension was then poured directly onto a 47 µm sieve and the particles retained on the sieve washed thoroughly with water and dried in an oven at 105°C for 24 h. The dried samples were then weighed to represent the sand fraction. The particle size distribution was then determined using the following formulae:

$$(Clay + Silt)\% = \frac{5\,minute\ \ hydrometer\ \ reading}{Sample\ \ mass} x\, 100 \qquad (2)$$

$$Clay(\%) = \frac{5\,hour\ \ hydrometer\ \ reading}{Sample\ \ mass} x\, 100 \qquad (3)$$

$$Sand\ (\%) = \frac{Oven\ drymass\ (g)\ of\ particle\ \ retainedon\ \ 47\ \mu m\ sieve}{Sample\ \ mass\ (g)} x\ 100 \qquad (4)$$

Silt = (1) – (2)

The textural class of the soil was then determined using the USDA textural triangle (http://www.pedosphere.ca/resources/sg_usa)

Determination of soil chemical properties

Cation exchange capacity (CEC)

The effective cation exchange capacity was determined by sum of cations. That is the sum of the basic cations (Ca, K, Mg and Na) and exchangeable acidity (Al + H).

Exchangeable bases, exchangeable acidity and effective cation exchange capacity

The basic cations on the soil colloids was extracted with NH_4OAc (pH 7.0) solution. Na^+ and K^+ ions were measured by flame photometry while Ca^{++} and Mg^{++} was determined by EDTA titration. For the determination of exchange acidity (H^+ Al^{+++}) the BaCl – TEA, buffered at pH 8.2, method was used. For exchangeable Al, the soil was leached with unbuffered 1 N KCl solution and Al in the leachate measured by titration. The ECEC was computed as the sum of the basic and acidic cations

Soil pH

Soil pH was determined in the laboratory using pH meters. The pH was determined in distilled water at a soil: water ratio of 1:1. For each sample collected, pH was determined in water by weighing 20 g of soil (air-dried, < 2 mm) into a 100 ml beaker after which 20 ml water was added and stirred vigorously. The suspension was made to stand for about 30 min, stirred again and the pH of the suspension measured.

Available nitrogen

Available nitrogen was determined by the Kjeldahl method (IITA, 1979).

Available phosphorous

The Available P was determined according to the method by Bray and Kurtz (1945) where 10 g of soil sample was weighed into an extraction bottle and 50 ml of extractant (Bray 1; made up of 0.03 N NH_4F in 0.025 N HCl) was added.

Organic matter

Organic carbon was determined using the Walkle Black (1934) procedure involving wet combustion of organic matter with a mixture of 10 ml of 1M potassium dichromate and 20 ml concentrated sulphuric acid at about 125°C. The residual dichromate was titrated against 1 M ferrous sulphate. Organic carbon content was converted to organic matter content by multiplying the organic carbon values with 1.824 (Van Bemmelen factor).

Table 1. Impact of conservation agriculture (CA) on the infiltration of soils in three districts of northern Ghana.

Location	Average initial infiltration rate F_o (mm/h)		Infiltration capacity F_c (mm/h)		Permeability indication ratio (F_o/F_c)	
	Before	After	Before	After	Before	After
			East Mamprusi District			
Yaroyili	48	610	23	109	2.3	5.6
Boayini	70	398	36	172	2.1	2.3
Bowku	61	546	48	166	1.5	3.3
			Lawra District			
Nabugang	185	631	61	124	3.6	5.1
Batanglo	100	633	38	159	2.5	4
Tanchara	149	617	65	101	2.4	6.1
			Bawku East District			
Binduri	637	588	176	87	3.5	6.7
Tansia	784	682	348	212	2.3	3.2
Azumsapeliga	508	722	346	217	1.5	3.3

Table 2. Permeability indication ratio as predicted by Mc Queen (1998).

Ratio (f_o/f_c)	Permeability capacity
Greater than five (> 5)	High permeability
Three to five (3-5)	Moderate permeability
Less than three (< 3)	Low permeability

RESULTS AND DISCUSSION

Infiltration test

The results of the initial infiltration tests (Table 1), indicates that the soils for the communities of the three Districts (Lawra, East Mamprusi and Bawku Municipality) have low permeability except Nabugang in the Lawra district and Binduri in the Bawku Municipality, which were moderately permeable with the permeability index of 3.6 (Table 2).

However, there was an observed decrease in infiltration from the soil surface to 100 mm depth, indicating the effects of compaction layers and lack of good soil porosity. This could be attributed to surface seals resulting from weakened structure and clogged or discontinuous pores. Observations during the conduct of infiltration test in the communities revealed that most of the plots have shallow top soil with stone outcrops and hard pans with the soil depth not up to 10 cm deep, making movement of water into the soil very difficult. This meant that the steady state infiltration rate (infiltration capacity) of the soil was reached in less than one hour as can be seen in the infiltration rate curves (Figure 1).

Lateral flow of water from the ring infiltrometer was high due to the shallow depth of the soils. The infiltration capacities of all sites were within the range for sandy soils (sand to very coarse sand) as the results of the various communities were above 30 mm/h. Agronomic problems on these fields include perched water tables in the wet season, water logging, low rainfall infiltration for moisture storage, increased surface runoff and poor traffic ability under wet conditions.

Four years after introduction of CA technologies, the results of the infiltration tests and permeability indices indicate that the soils for the zero-tillage plots of the various communities have moderate to high permeability except in Boayini, which recorded a low permeability index of 2.3 (Table 1). Permeability after CA show an improvement over the initial infiltration test, which recorded low permeability in all the sites except Nabugang, and Binduri in the Lawra and Bawku municipalities respectively. These findings indicate that CA innovations have beneficial impacts on infiltration and permeability. Besides, there is an improvement in the soil structure (Table 3), as the organic matter residues decompose on the soil, resulting in increased water infiltration rate and reduction in runoff. The findings are consistent with those of others. For instance, the relatively small amounts of crop residues reduce soil erosion significantly (Damascus, 2011). Wagger and Denton (1992) reported that discouraging burning among farmers help to obtain the full benefit of stubble mulch as this would result in improved infiltration of moisture,

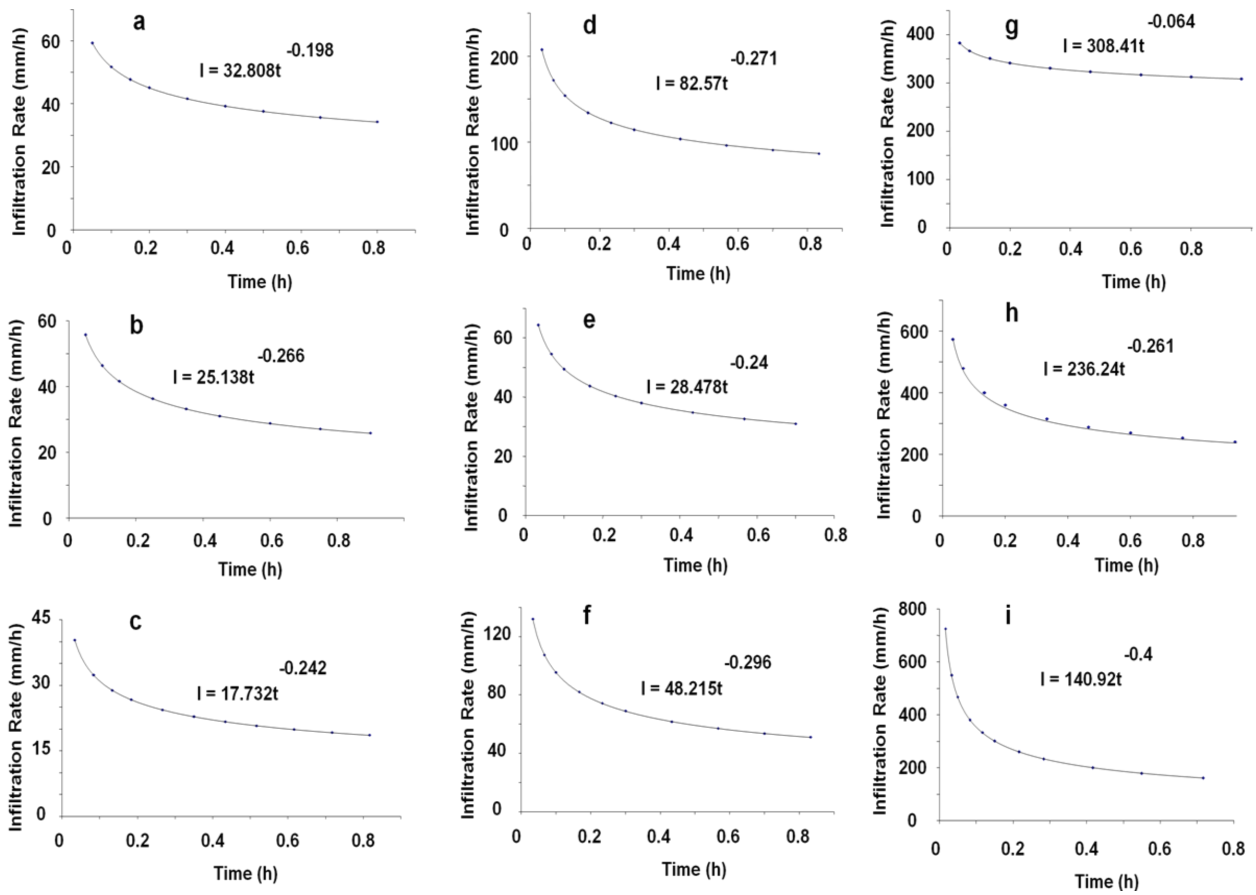

Figure 1. Temporal rate of water infiltration in 9 sites across the northern region of Ghana. a = Yaroyili, b = Boayini, c = Bowku, d = Nabogang, e = Batanglo, f = Tanchara, g = Azumsapeliga, h = Tansia, I = Binduri.

reduce or minimize erosion and increase crop yields. Similar reports have been observed by Biamah et al. (1993); Alabi and Akintunde (2004); Abdalla and Mohamed (2007) and Theodor and Kassam (2009). Giller et al. (2009), reports that the increased soil water availability for plants is due to reduced soil evaporation; reduced water run-off; increased water infiltration and reduced soil temperature oscillations. The findings indicate that where ever CA has been adopted it has proven the benefits usually claimed in its favour.

Particle size distribution and texture

Before the start of the project, the soils of East Mamprusi were low in clay content (< 6.2%) and high in sand content (> 70%) (Table 3). The soils of Yaroyiri were mostly loamy sands and had low water holding capacity. The texture of the soils at Boayini and Bawku were similar to that of Yaroyiri. The soils were low in clay content and high in sand content. In the Lawra district, the soils of Babile Tanchara had similar particle size distribution as those described for the East Mamprusi district.

The pedon was high in sand content and very low in clay content. In contrast to the soils of Babile Tanchara, the percentage silt content of the soils at Nabugang and Zedong was high (Tables 3). This high silt content is indicative of their formation from alluvium. The particle size distribution of the soils in the Bawku municipality was similar to that observed in the East Mamprusi district. The sand content of the soils of Bawku was greater than 65% and the clay content greater than 3.2% (Table 3). The sandy loam and loamy sand texture, coupled with the low organic matter contents of these soils (Table 3), reflected in their poor water holding capacity (Figure 1).

After introduction of CA and subsequent evaluation after four years (Table 3), the soils of East Mamprusi could be described as sandy because the sand separates make up more than 70% and the clay separate less than 15% of the soil by weight. The observed results are very similar to the initial particle size distribution results obtained from the baseline survey (Table 3). The persistence of similar soil textural classes after the

Table 3. Selected initial and final physico-chemical properties of soils at locations where conservation agriculture were carried out across the three northern regions of Ghana.

Community	Depth (cm)	CA	pH (1:1)	% O.M	% N	P (mg/kg)	Extractable Bases (cmol/kg)					E.A.	E.C.E.C	% BS	Particle size distribution %			
							Ca	Mg	K	Na	T.E.B				Sand	Silt	Clay	Texture
Yaroyiri/Langbinsi	0-35	B	5.88	0.6			1.3	0.9	0.2	0	2.46	0.1	2.56	96.1	79.5	16	4.1	LS
		A	6.4	0.35	0.03	14.4	2.1	0.7	0.4	0.1	3.3	0.2	3.45	95.7	80.2	16	4	LS
	35-80	B	5.75	0.5			2.9	1.7	0.2	0.1	4.91	0.2	5.09	96.5	47.3	23	30.2	SCL
		A	5.5	0.54	0.05	8.82	2.4	0.5	0.2	0.1	3.23	0.5	3.68	87.8	76.1	20	4	LS
	80-125	B	5.48	0.28			1.9	1.3	0.1	0	3.37	0.3	3.67	91.8	49.6	26	24.1	SCL
		A	4.6	0.86	0.03	8.93	1.9	0.7	0.2	0.1	2.77	0.9	3.67	75.5	87.7	8.3	4	S
	125-175	B	5.31	0.14			1.3	0.8	0.1	0.1	2.34	1.3	3.64	64.3	47.8	26	26.1	SCL
		A	5.5	0.73	0.03	5.66	2.9	0.5	0.2	0.1	3.77	0.5	4.22	89.3	83.4	13	4	LS
Boayini	0-30	B	4.63	0.31			2.4	0.3	0.2	0.1	2.98	0.1	3.11	95.8	76.5	19	4.1	LS
		A	4.7	0.41	0.04	19.2	1.3	0.5	0.2	0.1	2.13	0.8	2.93	72.7	88	8	4	S
	30-50	B	5.44	0.34			1.1	0.5	0.1	0	1.71	0.3	1.99	85.9	68.6	23	8.1	SL
		A	5.1	0.66	0.04	9.01	1.9	0.3	0.2	0.1	2.36	0.6	2.96	79.7	81.4	15	4	LS
	50-135	B	5.58	0.36			1.3	0.5	0.1	0	2	1.9	3.85	51.9	39.5	28	32.2	CL
		A	5.4	0.6	0.04	7.1	2.1	0.5	0.2	0.1	2.93	0.5	3.43	85.4	90.1	7.9	2	S
	135-175	B	5.33	0.28			1.2	1.1	0.1	0.1	2.5	1	3.53	70.8	53.1	29	18.1	SL
		A	7	0.48	0.03	18.3	2.9	0.8	0.3	0.1	4.11	0.1	4.21	97.6	84.2	12	4	LS
Bawku	0-25	B	5.79	1.07			2.4	0.5	0.2	0.1	3.14	0.3	3.42	91.8	73.3	25	2.1	LS
		A	4.3	1.75	0.09	8.06	1.6	0.5	0.2	0.1	2.46	1.1	3.56	69.1	83	13	4	LS
	25-45	B	5.93	0.59			1.3	1.1	0.1	0	2.57	0.3	2.85	90.2	71.5	24	4.1	SL
		A	4.3	1.81	0.11	10.4	1.9	0.3	0.3	0.1	2.52	1.2	3.72	67.7	86.4	9.6	4	LS
	45-135	B	5.83	0.55			1.9	1.3	0.1	0.1	3.37	0.1	3.5	96.3	60.3	28	12.2	SL
		A	5.2	0.86	0.06	3.99	5.1	1.9	0.5	0.2	7.67	0.6	8.22	93.3	86	8	6	LS
Nabugang	0-24	B	10.1	0.91			2.1	0.8	0.3	1.2	4.42	0.1	4.47	98.9	52.8	45	2.1	SL
		A	5.5	0.92	0.06	6.44	5.3	3.5	0.5	0.1	9.38	0.5	9.83	95.4	83.9	10	6	LS
	24-38	B	10.2	0.31			4.5	0.4	0.5	5.8	11.22	0.1	11.27	99.6	44.8	39	16	L
		A	4.7	1.56	0.09	4.95	3.7	0.5	0.2	0.1	4.54	0.8	5.34	85	77.3	15	8	LS
	38-60	B	10.2	0.21			3.5	1.7	1.1	5.5	11.75	0.1	11.8	99.6	30.3	44	26.2	L
		A	4.8	1.75	0.08	19.2	3.7	0.5	0.2	0.1	4.52	0.8	5.27	85.8	85.7	8.3	6	LS
	60-120	B	10.1	0.17			3.2	1.9	0.5	4.6	10.14	0.1	10.19	99.5	27.1	57	16	Si L
		A	6.2	1.37	0.08	9.81	6.7	2.7	0.4	0.2	9.88	0.2	10	98.7	62.2	16	22	SCL
	120-195	B	9.52	0.07			2.7	1.9	0.4	4.5	9.41	0.1	9.46	99.5	33.6	58	8.1	Si L
		A	6.7	0.79	0.05	13.1	3.2	1.6	0.2	0.4	5.48	0.1	5.58	98.2	78.4	12	10	LS
BabileTanchara	0-20	B	6.98	2.55			4.3	1.9	0.3	0.1	6.6	0.1	6.65	99.2	37	59	4.2	Si L
		A	5.1	0.66	0.04	9.81	2.1	0.8	0.2	0.4	3.5	0.6	4.1	85.4	59.2	31	10	SL
	20-60	B	5.66	0.84			1.6	1.3	0.2	0.1	3.24	0.2	3.39	95.6	35.6	56	8.1	Si L

Table 3. Contd.

Community	Depth (cm)	CA	pH (1:1)	% O.M	% N	P (mg/kg)	Extractable Bases (cmol/kg)					E.A.	E.C.E.C	% BS	Particle size distribution %			
							Ca	Mg	K	Na	T.E.B				Sand	Silt	Clay	Texture
		A	4.9	1.68	0.07	9.57	3.5	2.1	0.3	0.5	6.36	0.8	7.11	89.5	71.5	19	10	SL
Betaglu	0-10	B	6.31	2.48			5.3	2.4	0.4	0.1	8.2	0.1	8.3	98.8	30.3	48	22.1	L
		A	5.8	1.24	0.08	3.35	3.2	2.1	0.2	0.5	6.11	0.4	6.46	94.6	82.5	9.5	8	LS
	0-35	B	6.12	1.1			4	1.3	0.2	0.1	5.61	0.1	5.71	98.2	45.1	45	10.2	L
		A	4.8	1.75	0.09	7.5	4.8	2.1	0.4	0.5	7.82	0.8	8.57	91.3	68.8	19	12	SL
	35-140	B	6.34	1.02			6.1	2.9	0.3	0.1	9.44	0.2	9.64	97.9	20.1	50	30.1	CL
		A	5.3	2.07	0.13	6.94	6.1	2.4	0.5	0.7	9.7	0.5	10.2	95.1	59.8	26	14	SL

% O.M. = Percentage organic matter, T.E.B = Total extractable base, E.A. = Exchangeable acidity, E.C.E.C = Effective cation exchange capacity, % B.S. = percentage base saturation, LS = Loamy sand, SCL = sandy clay loam, SL = Sandy loam, CL = Clayey loam, L = Loam, SiL = Silty loam.

introduction of the CA is attributed to the general difficulty in modification of soil textural classes in the field.

Soil reaction/pH

Values for pH in water ranged from 4.74 to 7.96. This is an indication of very strongly acidic to moderately alkaline soils. The acidic pH values suggest that appreciable amounts of extractable bases are leached from the surface layers of the soils and the exchange complex is dominated by acidic cations. Soil pH of 4.5 to 5.8 in mineral soils indicates the presence of sufficient exchangeable Al that can affect plant growth. The two plots in Tangbini which recorded pH values of 7.12 and 7.96 suggest the presence of basic cations on the exchange sites. The plot in Bowku, which recorded a pH value of 4.74 might require liming to increase the pH. According to Brady and Weil (1999), pH range of 5.5 to 6.5 or perhaps 7.0 may provide the most satisfactory plant nutrient levels overall. The pH values for most of the CAP plots in East Mamprusi fall within the recommended range. In the Lawra district, the pH values for surface soils ranged from 5.21 to 6.68, that is from strongly acidic to neutral (Table 3). These values are consistent with values recorded for these soils in previous studies (Bagamsah, 2005). The pH of the soils within the Lawra district is within the desirable range for cultivation.

After four years of adopting CA technologies, Soils of the East Mamprusi district had pH range of 4.6 to 7.4. That is, very strongly acidic to slightly alkaline. The pH values obtained suggest that appreciable amounts of extractable bases have been leached from the surface layers of the soils and the exchange complex is dominated by acidic cations. Soil pH of 4.5 to 5.8 in mineral soils indicates the presence of sufficient exchangeable Al that can affect plant growth significantly. Although the pH values obtained in the evaluation studies are comparable to those obtained in the baseline survey, there appear to be a trend towards acidity. Whereas only one plot in Bowku recorded pH below 5 in the baseline survey, five plots across the four communities recorded pH values lower than 5. Similar trends were observed for the Lawra district and the East Mamprusi district. The trend towards acidity may be due to the improved soil permeability, which resulted in the leaching of basic cations from the exchange site.

Organic matter

The soils across the study area generally had low organic matter before CA (Table 3). These low levels of organic matter were due to the low biomass produced on these soils as a result of the sparse and predominantly low grass vegetation (Kugbe et al., 2012). Even when biomass production is good, there is the problem of poor drainage because of the hardpan layers. This poor internal drainage results in lateral seepage of water, inhibiting *in situ* decomposition of organic matter (Nartey, 1994).

Evaluation of the soil fertility levels after CA show that the organic matter contents of the soils ranged from 0.35 to 2.7% (Table 3) as compared to 0.21 to 1.26% obtained in the baseline survey. The increasing levels of organic matter might have been due to the higher plant biomass now produced on these soils as a result of the CA interventions. Usually CA relies on reduced or zero tillage systems which maintains a cover of surface residues and cover crops; avoiding the rapid organic matter decomposition that are induced by tillage. According to African Conservation Tillage Network (2008), soil organic matter plays a central role in enhancing and sustaining soil productivity while contributing to improved soil structure and water retention, thus allowing effective use of water and nutrients by plants, and maintaining water quality through its filtering effects. The productive benefits of CA accumulate over time as mulching arrests soil degradation and gradually improves the soil in biological, chemical and physical terms (Erenstein, 2002). In general, availability of organic matter inputs is critical for productivity on farms in sub humid and semi-arid Africa; and fields that receive large inputs of organic matter in the form of crop residues, manure or compost as observed for fields that are generally close to the homestead, are generally rich in C, while fields that receive no or little organic matter- the outfields further away from the homestead- have small soil C contents (Tittonell et al., 2005; Samake et al., 2005; Zingore et al., 2007). In the drier areas of the northern savannah zone, manure is often broadcast and ploughed into the soil using animal drawn plough or hand held hoe before planting. Survey discussions with farmers and informal assessments indicate that farmers apply less than 2t/ha annually.

Kombiok et al. (1995) found that the best management option to maximize the benefits of the cover crop residue for high maize yield in northern savannah zone of Ghana was to plant the crop in no-till condition but making sure the cover crop residue was protected from bush fires. In general, continuous crop production on savannah soils with low levels of soil organic matter and N will be limited in the absence of organic and mineral fertilizers. Without fertilizers, crop yields will rapidly decline to the point that the farmer must abandon the field to a long-term fallow. Fertilizer N management practices on the fields of farmers should be improved if losses of soil organic N and organic matter are to be curtailed and stabilized in the short term.

Total nitrogen, available phosphorous and exchangeable potassium

Before the introduction of CA, all the soil samples showed very low levels of N (Table 3). The nitrogen content of surface mineral soils ranges from 0.02 to 0.5 g/kg, a value of 0.15 being representative of cultivated soils (Brady and Weil, 1999). The low N content of the soils is consistent with the low organic matter content of the soil, and similar to values reported for these soils by previous authors (Bagamsah, 2005). Available P was more variable than N, ranging from trace amounts to 22.69 mg/kg. The low levels of P might be the result of P fixation due to the high sesequioxide contents of the soils (Abekoe and Tiessen, 1998; Bationo et al., 2003). Due to the low levels of this nutrient in the soils, application of chemical fertilizer is recommended. The levels of potassium ranged from 60.26 to 164.04 mg/kg. Unlike nitrogen and phosphorous, potassium does not appear to be limiting in these soils. The CA innovations introduced did not appear to have increased the nitrogen levels in the soil. As the levels of 0.04 to 0.13 g/kg prior to the introduction of CA was comparable to 0.03 to 0.08 g/kg four years after CA. However, the levels of available P appear to have appreciated considerably (Table 3). Unlike the P values recorded in the baseline survey, no site recorded trace amounts of P.

Extractable bases, base saturation and effective cation exchange capacity

Before the introduction of CA, the extractable Ca content of the soils of East Mamprusi ranged from high to very low (Table 3). Two of the CA sites in Tangbini recorded extractable Ca content of 8.81 and 6.94 cmol/kg. These values are consistent with the alkaline pH values recorded for the same soils. The levels of extractable Mg ranged from very low to low. The soils of East Mamprusi contained very low amounts of K and Na.

The relative abundance of extractable bases in the soils of Lawra and Bawku was in the following order: Ca > Mg > K > Na (Table 3). The levels of these bases in the soils were similar to the levels recorded for the soils in East Mamprusi. The low levels of bases could be an indication of the advanced weathering state of the soils (Abekoe, and Tiessen, 1998). The base saturation values for all the soils are generally above 90% despite the advanced weathering state of the soils (Table 3). The results corroborate the findings of Tiessen et al. (1991), who noted that base saturation values of top soils in Northern Ghana are generally above 80%. They further stated that the annual deposition of dust from the Sahara, carried by the Harmattan weather system may be responsible for the high base saturation. The effective cation exchange capacity (ECEC) was generally low. Low ECEC is typical for soils with low levels of exchangeable bases. Similarly, Tiessen et al. (1991) described the soils in Northern Ghana as having low ECEC and mineralogy dominated by low activity clay and quartz. After the CA, the extractable Ca content of the soils of East Mamprusi ranged from high to very low (Table 3). The levels of extractable Mg also ranged from very low to low. The soils of East Mamprusi contained very low amounts of extractable K and Na in the top soil. The relative abundance of extractable bases in the soils was in the following order: Ca > Mg > K > Na, except for a few locations especially in Lawra, where extractable Na levels were slightly higher than K (Table 3).

Table 4. Average maize yield (t/ha) from tillage demonstrations in East Mamprusi and Lawra districts, 2009.

Tillage system	East Mamprusi district			Lawra district	
	Boayini	Tangbini	Yaroyiri	Zedung	Tanchara
Farmers practice	1.86	1.2	1.05	0.33	0.76
No-tillage with herbicide application	1.44	1.33	1	0.21	0.8
Direct planting without herbicide application	1.05	0.85	0.84	N/A	N/A
Lsd (0.05)	0.15	0.23	0.12	NS	NS

Plant biomass

One of the tenets of CA as introduced to participating farmers is 'Permanent Soil Cover'. The soils of the selected communities which were bare at the inception of the project, had biomass load of 250 ± 90 g m^{-2} in the dry season. Soils of East Mamprusi produced the highest plant biomass, followed by those in Lawra and Bawku respectively.

The plant biomass increased primarily through avoidance of burning of the residue and tillage. Leaving the root structure undisturbed is vitally important. Recent research indicates that most of the increases in soil carbon is as a result of undisturbed root biomass. The left organic residues on the surface increases the nutrient input in the system and stimulates the increase in soil organic matter (Damascus, 2011).

The production and maintenance of biomass to cover the soil is however a challenge as it is in the economic interest of farmers to use residues as feed for livestock rather than leave them to cover the soil surface. This challenge is resolved, in part, through the use of long duration grain legumes such as pigeon pea which inputs N through a substantial amount of biomass in the form of roots and leaves that fall before harvest.

In the first year of the no-till treatment, grain yields of sorghum obtained in the Lawra district (Table 4) were similar to yields obtained from traditional hoe weeding as practiced by farmers. Moreover highest maize yields were obtained from ploughed plots compared with no-till treatment at three sites in the East Mamprusi district.

The soils of the northern savannah zone, being bare, fire prone and with substantial iron-pan, however, restricts the smooth drilling and operation of the soil under no-tillage and may not result in higher yields as the soil might be hard and compact resisting free flow of water and air for crop utilization. Removal of all vegetation or crop residue from the soil surface reduces the penetration of moisture and its retention, resulting in fast dehydration and deterioration of the soil. The foregoing, and as noted by Kombiok et al. (1995) indicate that the best management option to maximize the benefits of cover crop residues for high maize yield in northern Ghana is to plant the crop in no-till condition but making sure that the cover crop residue is protected from bush fires.

CONCLUSION AND RECOMMENDATIONS

The agricultural productivity of the soils from the three CA districts has been enhanced with adequate fertilization and moisture retention through the adoption of conservation agricultural techniques. Moisture retention techniques like earth, vegetative (Vetiva grass) or stone bundings, together with zero tillage, cover cropping, crop rotation and intercropping of the fields at Bawku municipality, East Mamprusi district, and the Lawra district have helped improve the soil conditions. After four years of CA adoption, appreciable amounts of N and P have been added to the soil, while soil physical and chemical properties are enhanced for agricultural productivity.

Conflict of Interest

The authors have not declared any conflict of interest.

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