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Impact of land management system on crop yields and soil fertility in Cameroon

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Abstract

The impact of direct-seeding mulch-based cropping systems (DMC), direct seeding (DS) and tillage seeding (TS) on *Sorghum* yields, soil fertility and the rehabilitation of degraded soils was evaluated in northern Cameroon. Field work consisted of visual examination, soil sampling, yield and rainfall data collection. Three fertilization rates (F1: 100 kg ha^{-1} NPK + 25 kg ha^{-1} of urea in DMC, F2: 200 kg ha^{-1} NPK + 50 kg ha^{-1} of urea in DMC and F3: 300 kg ha^{-1} NPK + 100 kg ha^{-1} of urea in DMC) were applied to each cropping system (DS, TS and DMC), resulting in nine experimental plots. Two types of chemical fertilizer were used (NPK 22.10.15 and urea) and applied each year from 2002 to 2012. Average *Sorghum* yields were 1239, 863 and 960 kg ha^{-1} respectively in DMC, DS and TS at F1, 1658, 1139 and 1192 kg ha^{-1} respectively in DMC, DS and TS at F2, and 2270, 2138 and 1780 kg ha^{-1} respectively in DMC, DS and TS at F3. pH values were 5.2 to 5.7 under DMC, 4.9 to 5.3 under DS and TS, and 5.6 in the control sample. High values of cation exchange capacity were recorded in the control sample, TS system and F1 of DMC. Base saturation rates, total nitrogen and organic matter contents were high in the control sample and the DMC than in the others systems. All studied soils were permanently not suitable for *Sorghum* due to the high percentage of nodules. F1 and F2 of the DS were currently not suitable, while F1 and F3 of DMC, F3 of DS and F1, F2 and F3 of TS were marginally suitable for *Sorghum* due to low soil pH values.

1 Introduction

Drought, desertification and other types of land degradation currently affect more than 2 billion people in the world. The situation might worsen due to unsustainable use of soil and water under present scenarios of climate change (Gabathuler et al., 2009). Soil loss is a worldwide risk and adversely affects the productivity of all natural ecosystems as well as agricultural, forest, and rangeland ecosystems (Pimentel et al., 1995;

Pimentel, 2006; Perkins et al., 2013; Lemenih et al., 2014; Van Leeuwen et al., 2015). Changes in soil quality affected by accelerated erosion are significant and have resulted in decreased production and land abandonment (Pimentel et al., 1995). Worldwide, annual cropped-soil erosion rates are about 30 $\text{Mg}\,\text{ha}^{-1}$, on average, ranging from 0.5 to 400 $\text{Mg}\,\text{ha}^{-1}\,\text{year}^{-1}$ (Pimentel et al., 1995; Cerdà et al., 2009a, 2009b; Biro et al., 2013; Leh et al., 2013; Mandal et al., 2013; Zhao et al., 2013; Lieskovský and Kenderessy, 2014). As a result, during the last 40 years about 30 % of the world's arable land has become unproductive and a great part of it has been abandoned (Kendall and Pimentel, 1994; WRI, 1994; Cerdà, 2000). Sustainable soil management in agricultural land is needed for a sustainable world (Costa et al., 2015). According to Myers (1993), soil erosion is 90 times greater in agricultural land than in natural forest areas. Rainfall-induced erosion is the most important factor of cultivated soil degradation in tropical zones, and particularly in the sub-humid areas such as sudanese savannas (Bilgo et al., 2006). Tropical soils are especially threatened by population growth and increased pressure on soil resources (Lemenih, 2004).

Cropping systems are generally characterized by high nutrient losses, especially for N, P and K (Smaling, 1993; Tabi et al., 2013). Long-term processes that adversely affect sustainability, such as decrease and eventual depletion of soil nutrient stocks, are not readily apparent and receive little attention (Ehabe et al., 2010). In the northern Cameroon savannas, inappropriate agricultural practices (e.g. monoculture crop production, non-adoption of soil-conservation management practices, overcutting of vegetation, unbalanced fertilization, the excessive use of groundwater for irrigation and, improper use of pesticides,. . .) on fragile soils contribute to soil organic matter losses and to increased water and wind erosion risks, leading to soil physical degradation and to the decline of the soil production potential (Boli, 1996). Loss of soil organic matter leads to decreased cation exchange capacity and weakening of soil structure (Roose, 1994). Exportation of crop residues reduces the stock of easily exchangeable elements, leading after four years to the mineralization of soil organic matter by 50 % and to the leaching of some of the released nutrients (Kang and Juo, 1982), exposing

therefore the soils to erosion (Harmand et al., 2000). Degradation of these fragile soils is expressed both in the rainy and the dry season and loss of land ranges from 0.5 to 40 $\text{Mg}\,\text{ha}^{-1}\,\text{year}^{-1}$ under crop on long ferruginous tropical glaze of sudano-sahelian regions (Boli et al., 1991). This lead to the development of infertile soils called *hardé soils*, the most striking sign of land degradation, characterized by vast expansion of bare soils (Boli, 1996; Tsozué et al., 2014). One of spontaneous responses to the decline of soil fertility is the extension of cultivated surface on lands sometime marginal, instead of increased or improved existing production systems (Dongmo, 2009). The expansion of agriculture, which operates continuously and without restitution of organic matter, contributes to soil erosion on a large scale. It increases in a socio-economic context characterized by poverty, growing population and increasingly unfavourable climatic conditions which prevailed in the northern Cameroon. However, farmland in sudano-sahelian zone of Cameroon has high potentialities, but only if farming systems rely on water conservation and maintenance of soil fertility through better valorisation of plant biomass, and forage or cultivated trees (Landais and Lhoste, 1990).

Practices as direct-seeding mulch-based cropping (DMC) have permitted better control of erosion, a significant reduction in the cost of production and restoration of soil fertility (Marasas et al., 2001; Brown et al., 2002). They have been introduced in the North Cameroon since the first decade of the 21st century. Experimentation of DMC systems in juxtaposition to conventional cropping systems that are tillage seeding (TS) and direct seeding (DS) therefore raises many uncertainties about the expected results. The main objective of this paper is to evaluate the impact of different types of management (DS, TS and DMC) at different levels of fertilization in *Sorghum*-cropped soils (*Sorghum* is a representative crop in the study area), on soil fertility and the rehabilitation of *hardé soils* in the Far North region of Cameroon.

2 Material and methods

2.1 Study site

The study was conducted in the experimental site of SODECOTON (Société de Développement du coton au Cameroon) at Kaélé, specifically in Zouana quarter (10°04′48″ N, 14°33′36″ E, 380 m a.s.l.), Mayo Kani Division, northern Cameroon (Fig. 1). This region belongs to Kaélé-Mindif pseudo-pediplain, with elevation ranging between 400 and 430 m a.s.l. The general climate is semi-arid, characterized by a mean annual rainfall of about 800 mm and a mean annual temperature of about 28 °C, with eight months dry season (Suchel, 1987). The relief is smooth, with slopes typically below 5 %. The vegetation is composed mainly of *Acacia seyal*, *Acacia hockii, Balanites aegyptiaca*, *Anogeissus leiocarpus*, *Sterculia setigera* and *Scleorcarya birrea* (Letouzey, 1985). The bedrock is a calc-alkaline granite constituted of potassium feldspar, plagioclase, quartz, amphibole, biotite and opaque minerals. Soils developed here are luvisols (WRB, 2006).

Sorghum was intercropped with *Brachiaria ruziziensis* also called Congo grass. It is a forage crop that is grown throughout the humid tropics (Husson et al., 2008; Naudin, 2012). It requires well-drained soils with low clay contents, moderate to high fertility and does not tolerate strong acidic conditions. It also requires a reasonably high rainfall (1000 mm or more per year), although it can resist drought periods.

2.2 Experimental design and soil sampling

Field work consisted of direct observations, soil sampling, crop yield and rainfall data collection. According to Fig. 2, three soil samples were collected per experiment. Three fertilization rates (F1, F2 and F3) were applied to each cropping system (DS, TS and DMC), resulting in nine (9) experimental plots (3 fertilization rates × 3 types of management) (Table 1). On TS plots, tillage was done after a significant rain shower with an ox-drawn plough to 10–15 cm depth at the end of each June. On DS plots sorghum was

sown by hand with a hoe with no disturbance of the soil surface outside the mounds. Sowing was done in all plots at the beginning of each June. For TS and DS, ridging and weed control were performed by hand with a hoe at the end of July. In DMC and DS, herbicide for seed lift-off was sprayed before sowing (Diuron at 550 g ha^{-1} and glyphosate at 720 g ha^{-1}). In DMC plots, from the second year, *sorghum* was sown on the residual mulch. Remaining residues from the previous crop were retained on the soil surface, protected from grazing by a live fence and from fire by a firebreak. In DCM plots, weed control was done by hand or herbicide. Cropping systems and plots were separated respectively by a corridor of 3 m wide and earth mounds (Fig. 2). Two types of chemical fertilizer were used (NPK 22.10.15 and urea 46N 0P 0K) and applied each year from 2002 to 2012 in the half of July and supplement urea in DCM after one week. *Sorghum* and *Brachiaria* are described as nitrogen-demanding plants. This justifies the fact that fertilizer doses applied in the cropping systems have a high percentage of nitrogen (22 %) compared to potassium (15 %) and phosphorus (10 %), and there is an additional supply of nitrogen in the form of urea in the DCM system. In each plot, soil samples were collected in triplicate (Fig. 2) between 0 and 15 cm depth (Ap horizon) in January 2013 and mixed to obtain a composite sample. Ten composite soil samples were then collected in the dry season after crop harvest for laboratory analyses, one soil sample from the Ap horizon of each of the nine plots and a control soil sample in a plot which has not been cultivated since the beginning of the experiment in 2002.

After collection, soil samples were packaged in plastic bags, labeled and sent to laboratory for analyses. In the laboratory, bulk soil samples were air-dried at room temperature and then sieved (2 mm) to discard coarse fragments. Analyses were carried out on the fine fraction, and include particle size distribution, pH, exchangeable bases, cation exchange capacity (CEC) at pH 7, organic carbon, total nitrogen and available phosphorus.

For soil texture analysis, soil organic matter and carbonates were removed with hydrogen peroxide (30 %) and diluted hydrochloric acid (10 %), respectively. Then, soil samples were dispersed with sodium hexametaphosphate and particle size distribution was analyzed by the pipette method. Soil pH was measured potentiometrically in a 1 : 2.5 soil : solution ratio. Exchangeable bases and CEC were determined using atomic absorption spectrophotometry in a solution of ammonium acetate at pH 7. Total nitrogen was obtained after heat treatment of each sample in a mixture of concentrated sulphuric acid and salicylic acid. The mineralization was accelerated by a catalyst consisting of iron sulphate + selenium + potassium sulphate. The mineralization was followed by distillation via conversion of nitrogen into steam in the form of ammonia (NH_3), after alkalinization of mineralized extract with NaOH. The distillate was fixed in boric acid (H_3BO_3) and then titrated with sulfuric acid or diluted hydrochloric acid (0.01 N). Organic carbon was determined by Walkley and Black method (Walkley and Black, 1934). Soil organic matter (OM) content was obtained by multiplying soil organic carbon content by 1.724 (Walkley and Black, 1934). Available phosphorus was determined by Bray 2 method.

In order to identify the soil or the climatic parameters which previously limited growth and production of *Sorghum* and investigate possible changes after treatments, soils were evaluated for *Sorghum* following the method of Sys et al. (1991a, b, 1993). Soils' suitability for *Sorghum* was classified as highly (S1), moderately (S2), marginally (S3), actually not but potentially suitable (N1) and actually and potentially not suitable (N2), using simple limitation and parametric methods.

The differences among different treatments (DCM, DS and TS) were tested using one-way analysis of variance (ANOVA). This test was performed using statgraphic plus for Window 5.0 (Manugistics Inc. Rockville, MD). Correlations between yields and rainfall were to check if rainfall has an impact on yield levels obtained in each cropping system and each fertilization level. *Sorghum* yields under each type of management and annual rainfall data between 2002 and 2012 were obtained from the SODECOTON reports.

3 Results

3.1 Macroscopic organization of the soil profile of the experimental site

Generally, soils from the studied site showed an Ap-B-C profile. These characteristics are those of soils in the control plot:

0–15 cm: an Ap horizon, compact, characterized by a gray brown colour (10YR5/2), a sandy-loam texture, a very weakly matrix and tubular porosity; loose dry and friable moist; non sticky and non-plastic wet; presence of very rare millimetre nodules and rootlets; the boundary is distinct and irregular;

> 15 cm: a nodular B horizon, constituted of more than 90 % of nodules, embedded in a fine matrix with reddish brown colour (5YR5/4) and clayey texture. This matrix is hard dry, friable moist, sticky and plastic wet. Nodules are millimetre to centimetre, irregularly shaped, indurated and have globally a smooth and reddish fracture, sometimes with dark patches. There are fine weakly developed tubular pores and rare rootlets.

3.2 *Sorghum* yields

3.2.1 Yields at F1 level

At the fertilization level F1, from 2002 to 2003, *Sorghum* yields in DMC systems and in DS are below those obtained in the TS (Table 2). From 2004 to 2012, yields in DMC systems were greater than yields in DS and TS, except in 2011 where yields in DS were the highest. These yields range from 2067 to 1320 kg ha^{-1} in the DMC systems, from 1335 to 930 kg ha^{-1} in DS systems and from 1468 to 850 kg ha^{-1} in the TS system. However, in DMC systems, *Sorghum* yields in the years 2007, 2009 and 2011 were lower than in 2002. The highest yield was obtained in 2004, with 2067 kg ha^{-1} and the lowest one in 2009, with 700 kg ha^{-1}. In DS, the highest yield, 1335 kg ha^{-1}, was obtained in 2005 while the lowest yield, 540 kg ha^{-1}, was obtained in 2008. In 2003, yield were better in the TS than in the other cropping systems (1523 kg ha^{-1}). In 2011, they were very low, reaching a value of 380 kg ha^{-1}, value not obtained in any cropping system. Globally, the average yields of *Sorghum* in different cropping systems from 2002 to 2012 are 1239 kg ha^{-1} for DMC systems, 863 kg ha^{-1} for DS and 960 kg ha^{-1} for TS. There is a significant difference ($p = 0.05$, df = 2) between yields in DMC, DS and TS. Yields are moderately variable in DMC (CV = 32 %) and DS systems (CV = 28 %), and highly variable in TS system (CV = 40 %) (Table 2).

3.2.2 Yields at F2 level

Sorghum yields at fertilization level F2 were expressed in the same way as in fertilization level F1. In the years 2002 and 2003, *Sorghum* yields in DMC systems and DS were lower than those obtained in the TS (Table 2). Higher yields in DMC systems were reached in 2004 (2625 kg ha^{-1}). In the same interval of time, *Sorghum* yields in DS increased from 605 kg ha^{-1} (2002) to 2202 kg ha^{-1} (2005), and then declined until 940 kg ha^{-1} (2012). 2011 has experienced the worst agricultural yields, in DS and TS, with 130 and 430 kg ha^{-1} respectively. Highest yields were recorded in 2005 (2202 kg ha^{-1}). In the TS, yields were often above 1000 kg ha^{-1}, except for the years 2006, 2007 and 2011 where they were respectively 778, 753 and 430 kg ha^{-1}. It was also in 2005 that the yields were better (1889 kg ha^{-1}). In general, the average yields of *Sorghum* in DMC systems, DS and TS from 2002 to 2012 were respectively 1658, 1139 and 1192 kg ha^{-1}. With reference to F1, there is an increase yields of 419 kg ha^{-1} for DCM, 276 kg ha^{-1} for DS and 232 kg ha^{-1} for TS. There is a significant difference ($p = 0.03$, df = 2) between yield in DMC, DS and TS. Yields are moderately variable in DMC (CV = 27 %), but highly variable in DS (CV = 47 %) and TS systems (CV = 36 %) (Table 2).

3.2.3 Yields at F3 level

From 2002 to 2012, the difference of *Sorghum* yields at F3 fertilization level between DMC systems, DS and TS were not very meaningful. The yields were 1208 to

1980 kg ha^{-1} in DCM systems, 1819 to 1900 kg ha^{-1} in DS and 1823 to 1690 kg ha^{-1} in the TS (Table 2). The difference in yields between the three treatments was remarkable from 2004, where yields under TS became lower than those under the other systems. In DMC and DS systems, *Sorghum* yields were about 2000 kg ha^{-1}. In DS, maximum yield (3733 kg ha^{-1}) was achieved in 2004, in comparison with the rest of treatments. Therefore, sorghum yields tend to be equal in DMC and DS systems at fertilization F3. Between 2002 and 2012, the average yield of *Sorghum* was 2270 kg ha^{-1} in DMC systems, 2138 kg ha^{-1} in DS, but only 1780 kg ha^{-1} in the TS. With reference to F2, there is an increase yields of 612 kg ha^{-1} for DMC, 999 kg ha^{-1} for DS and 588 kg ha^{-1} for TS. With reference to F1, there is an increase yields of 1031 kg ha^{-1} for DMC, 1275 kg ha^{-1} for DS and 820 kg ha^{-1} for TS. Globally, there were differences in average yields but however no significant differences were shown between the three treatments ($P = 0.16$, df = 2). Yields are moderately variable in all the three systems. CV values are 21 % in DMC system, 32 % in DS and TS in systems (Table 2).

3.3 Physical and chemical characteristics of soils

Concerning the impact of land management on the soil texture, sand contents of soils in all plots were high and ranged from a low value of 41 % in DS and F1 fertilization level to a high value of 66 % in the same cropping system but in F3 fertilization level. Clay and silt contents are globally low, varying between 11 and 31 % and 19 and 35 %, respectively (Table 3). Textural classes were sandy clay loam to loam (DMC), clay loam to sandy loam (DS) and sandy loam (TS and control sample). Generally, pH (1 : 2.5 soil : water) is 5.2 to 5.7 under DMC, 4.9 to 5.3 under DS, 5.2 to 5.3 under TS and 5.6 in the control sample (Table 3). Calcium and magnesium dominate the exchange complex. High values of sum of bases were obtained in the control sample (8.1 cmol(+) kg^{-1}) and in the DMC system (6.95–11.01 cmol(+) kg^{-1}). CEC values were weak and high values were recorded in the control sample (20.16 cmol(+) kg^{-1}), in all fertilization levels of the TS system (18.08–20.48 cmol(+) kg^{-1}) and the F1 fertilization level of DMC system (19.28 cmol(+) kg^{-1}) (Table 4). Base saturation rates were relatively low in both DS (33.04 to 34.18 %) and TS (23.14 to 35.80 %), when compared to the control sample (40.17 %) and the DMC system (49.15 to 68.13 %). The CEC clay of different soils were high and ranged from 47.2 to 152.2 cmol(+) kg^{-1} (Table 4). Total nitrogen and soil organic matter values were globally weak, but were high in the control sample (0.54 and 2.69 % respectively) and in the DMC system (0.41 to 0.52 % and 2.74 to 2.85 % respectively) than in the two conventional systems (0.26 to 0.41 and 0.84 to 2.00 % respectively) (Table 4). Available P values were low and high values were recorded in the conventional systems.

3.4 Correlation between *Sorghum* yields and rainfall

Yields in each cropping system were considered separately for each fertilization level, and compared with cumulated rainfall in the studied site for eleven years (Table 2). No significant correlations were found between cumulated rainfall and yields (Fig. 3). All values are below 0.5. This means that cumulated rainfall did not have any impact on the agricultural yields. The results obtained may be a consequence of different managements in the study site, which could have an impact on soils.

3.5 Suitability evaluation for *Sorghum* production

In order to appreciate the repercussions of different managements on soil fertility, a land suitability evaluation was done. The morphological description and chemical data available suggested that the studied soils were globally sandy, acidic and their soil organic matter content is low. They received acceptable rainfall level throughout the year.

The mean annual temperature and the mean annual rainfall of the study site are within 28 °C and 800 mm respectively, hence they all fall within S1 (Highly suitable) class with reference to temperature and rainfall requirements (Table 5). All soils were not flooded and were well drained and therefore qualified for the S1 class when drainage and flooding were considered (Table 5). Looking at the textural class as the

evaluation criteria, soils of the control sample, soils under TS and soils of the fertilization level F3 under DS qualified into S2 class, while those under DMC and soils of the fertilization levels F1 and F2 under DS qualified into S1 class (Table 5). Coarse materials (nodules) constitute about 90 % of the volume in the B horizon, corresponding to N2 class (Table 5). The soil depth was over 50 cm, corresponding to S1 class (Table 5). Considering the soil pH, only the control plot and the soil under F2 and DCM were evaluated as S1 class, while soils under TS and the fertilization levels F1 and F3 of DCM, and F3 of DS were evaluated as S3 class, and F1 and F2 of DS were qualified as N1 class (Table 5). All the other soil fertility characteristics, namely apparent CEC, base saturation, sum of exchangeable cations and organic carbon belong to S1 class (Table 5). As for soil salinity, ESP values were low (< 1 %), belonging then to the 0–10 interval, which permit to qualify all the soils into highly suitable class S1 (Table 5).

Globally, all studied soils were permanently not suitable (N2) for *Sorghum* due to the high percentage of coarse fragments (nodules) (Table 5). In addition, F1 and F2 of the DS system were currently not suitable (N1) due to low soil pH values (5.1 and 4.9 respectively), while F1 and F3 of DMC system, F3 of DS system and F1, F2 and F3 of TS were marginally suitable (S3) for *Sorghum* due to the same low soil pH values (5.2–5.3) (Table 5). Only F2 of DMC system and the control plot were not subjected to soil fertility problems due to soil pH problems (Table 3). Their pH were weakly acidic (5.6–5.7) (Table 3).

4 Discussion

4.1 Supply of nutrients

The percentage of nitrogen in the fertilizer doses applied was high (22 % of N in NPK) and there is and additional supply of nitrogen in the DCM system in the form of urea (46 % of N in urea). It results in high yields of *Sorghum* and biomass produce by *Brachiaria* depending on the availability of nitrogen to plants as shown by crop yields in the fertilization level F3 of the DMC system. The effect of organic matter, incorporated or mulched, has long been recognized and practised, but recent research in Indonesia only deals with organic matter management in relation to Al-, P-, and K-behaviour (Sri Adiningsih et al., 1987 in Sudjadi et al., 1989), not with N-supply processes in soils (Sudjadi et al., 1989). Several researchers have reported that organic matter application, whether incorporated or applied as mulch or as part of alley cropping, increased crop yields and with a positive interaction with lime, P, or K. Higher yields require more nitrogen, so it can be concluded that the system releases more nitrogen to produce higher yields (Sudjadi et al., 1989). It was noted that in order to increase the levels of nitrogen or organic matter in the soils it is necessary to increase P reserves through fertilizer application (Sudjadi et al., 1989). However, if nitrogen is the most important nutrient for crop growth and yield levels, it is also an element difficult to manage in fertilization. As optimal doses of nitrogen and phosphorous can stimulate the growth and productivity of crops (Naudin et al., 2010), likewise, their excess can increase their transfer from the soils to water (Silburn and Hunter, 2009; Novara et al., 2013). In addition, continuous nitrogen use is known to result in rapid soil acidification on low buffered soils as shown by low pH values obtained in the studied soils (Jones, 1976).

4.2 Impact of cropping systems on *Sorghum* productivity

Correlation values between crop yields and rainfall are low. This means that the results obtained are those of different management put in place in the studied site. Finally, DMC systems have higher yields of *Sorghum* in all levels of fertilization. The mean values from 2002 to 2012 are 1239 $\mathrm{kg\,ha^{-1}}$ in the fertilization level F1, 1658 $\mathrm{kg\,ha^{-1}}$ in the fertilization level F2 and 2270 $\mathrm{kg\,ha^{-1}}$ in the fertilization level F3. The increase in crop yields in DMC system is in line with results already observed in many other agro-ecologies such as Brazil (Blancaneaux et al., 1993), Madagascar (Reboul, 1997; Naudin et al., 2011), USA, Canada, Australia, Argentina, India, Turkey and many other countries in the world (Derpsch and Friedrich, 2009). This increase of yields showed that cropping systems have an impact on the *Sorghum* yields. Nevertheless, high yields

also cause loss of mineral elements during crops exportation. So, if the DMC system can increase crop yields, seed exportation might be more important and therefore that of mineral elements. Thereafter, subsequent supply of nutritive substances would be necessary. On the opposite site, crop yields in conventional systems are below those of DMC systems during some years. Also, yields obtained in the DS are sometimes lower than those obtained in TS. This could be due to soil cultivation. Indeed, the operations of returning and loosening the soil in the TS have been described as allowing good growth and good rooting of plants, in addition to the fact that they eliminate weeds susceptible to compete with the cultivated plants (Michellon et al., 2011). Poor yields of *Sorghum* in DS on the contrary might be due to no-till and insufficient biomass in this cropping system.

4.3 Impact of fertilization levels on *Sorghum* productivity

Sorghum yields increase with levels of fertilization. This means that subsequent inputs of phosphorus and potassium, but especially nitrogen, are crucial for the productivity of *Sorghum*. Also, high levels of nitrogen fertilizer in addition to urea as it is the case in the *Sorghum* + *Brachiaria* association, justify the high yields obtained in DMC systems. Moreover, in the fertilization levels F1 and F2, the mean yield values of *Sorghum*, which are respectively 960 and 1192 $\mathrm{kg\,ha^{-1}}$ in the TS, are higher than those of DS where 863 $\mathrm{kg\,ha^{-1}}$ was obtained for F1 and 1139 $\mathrm{kg\,ha^{-1}}$ for F2. Together with till method, fertilization levels have a positive effect on *Sorghum* yields in the TS compared to no-till system. Furthermore, the mean *Sorghum* yields in DS at fertilization level F3 (2138 $\mathrm{kg\,ha^{-1}}$) rivals that of DMC systems (2270 $\mathrm{kg\,ha^{-1}}$) and exceed mean yields in the TS in the same fertilization level (1780 $\mathrm{kg\,ha^{-1}}$). So, it can be deduced that no-till farming techniques would need fertilizer supplements to express their productive potential. Combined with quantities of herbicide that require DS as indicated by Barruiso et al. (1994), this system would induce excessive use of chemical elements. This involves expenses and highlights the risks of environmental pollution (Thapa and Yila, 2012). For nitrogen mainly, non-compliance dates and modes of spreading in rainfed crops cause losses by runoff likely to reach surface waters (Greenwood et al., 1980 in Pallo et al., 2008). Despite the increase in *Sorghum* yields using fertilizers, yields of fertilization levels F3 are very unstable. This instability is more pronounced in TS (1823 kg ha^{-1} in 2002, 2736 kg ha^{-1} in 2005, 755 kg ha^{-1} in 2007). This suggests that even if mineral fertilizers contribute to increased yields, they can also reduce in long-term soil productivity due to the degradation of the soil properties (Thapa and Yila, 2012). *Sorghum* yields in the long term would not be limited only on the quantity of fertilizer; it would need other types of fertilizers susceptible to offset losses caused by the exportation of crops.

4.4 Consequences of land management on water availability

Coarse texture leads to the loss of water by infiltration. In addition, Soutou et al. (2005) and Naudin et al. (2005) reported a good porosity, especially in DMC systems at the beginning and during the growing season, and only at the beginning of the growing season in the TS system. Indeed, in the DMC systems, roots of cover crops contribute to the infiltration of water, increasing water availability (Abrecht and Bristow, 1990; Scopel et al., 1999) and water use efficiency (Fischer et al., 2002). In dry climates, the soil is more humid under DMC (elimination of surface runoff, limited evaporation and increased water retention capacity) (AFD/FFEM, 2007), in line with Gao et al. (2014) which state that the deposition of fine soil particles during vegetation restoration as increasing clay contents in this system, leads to an increase of the water-holding capability of soils. The roots of cover plants also capture deep moisture, thus improving the water balance (AFD/FFEM, 2007; Brevik et al., 2015). Furthermore, plant cover reduces evaporation since the soil is protected from direct sunlight and sharp thermal peaks, decreases the mechanical impact of raindrops on the soil and improves water infiltration, thus reducing runoff and soil loss (AFD/FFEM, 2007; García-Orenes et al., 2009; Perkins et al., 2013; Olang et al., 2014; Costa et al., 2015). Tillage in the TS ensures temporarily better water regime in the soil. Infiltration conditions described here would be limited when taking in consideration the risks of water drainage into depth,

which become then inaccessible to crops due to the high percentage of nodules below the Ap horizon. In this case, the risk must be compensated by plants with highly developed roots.

4.5 Consequence of land management on the mineralization of soil organic matter

Soil organic matter is an essential component of soil quality, governing processes like carbon sequestration, nutrient cycling, water retention, and soil aggregate turnover (Van Leeuwen et al., 2015). Low mineral element contents in the soil are accentuated by low levels of soil organic matter. Soil organic matter contents ranging from 0.84 % in the fertilization level F2 of the DS to 2.95 % at the same fertilization level in DMC systems are outright below the 7.24 % reported by Reboul (1997) under extremely well developed cover after three (03) years of DMC systems trial in the highlands of Madagascar. High organic matter mineralization rate in Zouana might be due to environmental conditions, characterized by high temperatures (28 °C) and humidity brought by rains in the beginning of the agricultural campaign. Moreover, Bikay (2004) found that in the site of Zouana, biological activity is high in DMC systems with *Brachiaria*. This is in line with observations of García-Orenes et al. (2010) which state that addition of available organic substrates would promote the growth and activity of indigenous microorganisms. The accumulation of biomass on the soil surface in the DMC systems, while increasing soil biological activity, intensifies the mineralization process of organic matter, leading thus to rapid mineralization of soil organic matter, which will therefore improve soil structure (García-Orenes et al., 2009; Costa et al., 2015) and plant nutrition (Chabanne et al., 2001; Séguy et al., 2001). In addition, $C/N < 6$ suggests that the organic matter has high microbial decomposition rate in the soil (Tabi et al., 2012). This activation of biological activity is enhanced by nitrogen fertilizer supply, such as urea used in this study. The organic matter losses by mineralization are responsible for low minerals contents, nitrogen leakage in the atmosphere and carbon emission in the form of CO_2. In addition, the decrease of the CEC and the agricultural potential of the soil, are also due to the degradation of soil organic matter. In these soils, characterized by low soil organic matter content, the organo-mineral particle-size fractions should then be considered of great significance both in amount and in their capacity as medium- and long-term reservoirs for organic-bonded plant nutrients (Christensen, 1987; Caravaca et al., 1999), by physically protecting some organic matter fractions (Hassink, 1997). Also, benefits of mulch as contributors to increase soil carbon contents (Neto et al., 2010) or provision of nitrogen for subsequent crop growth (Maltas et al., 2009), are directly proportional to the amount of mulch and its content of each element. In addition, the studied soil textures are sandy, and the small quantity of clay might not allow high formation of clay-humic complexes. Indeed, clay protects organic matter, leading to a higher proportion of clay-stored organic carbon in cultivated soil, especially in the tillage treatments (Tiessen and Stewart, 1983; Cerri et al., 1989). This is in line with Silva et al. (1994) who reported losses of 41 % (clay soils), 76 % (loamy soils), and 80 % (sandy soils) of the original soil organic carbon stock five years of heavy harrowing for cultivation of *Soybean*.

4.6 Evolution of physical and chemical properties of soils and *Sorghum* suitability

On the particle size distribution view point, clay contents are more expressed in the DMC and DS than in the TS whose content is similar to that of the control sample. The larger amount of biomass in the DMC and DS might induce higher biological activity that would foster an increase in clay contents by biological upwelling. In fact, Bikay (2004) shows that termites represent the more abundant macro-fauna under DMC. They are more active in semi-arid and arid regions than other macro-fauna (Lal, 1988). They influences soil texture by bringing the fine fraction to the surface, for constructing mounds and feeding galleries (Lal, 1988). Except the fertilization level F2 in DS where the pH is acidic (4.9), pH are globally weakly acidic, and a value identical to that of the control sample (5.6) is even obtained in the fertilization level F2 of DCM system (5.7). This shows that land management had negative effects on soil acidity. Indeed, during the mineralization of the soil organic matter, ammonia is formed and transformed thereafter into ammonium ions which are nitrified, and hydronium ions are produced in soil solution making the soil acidic (Asuming-Brempong, 2014). Acidification may also be attributed to increasing use of acidifying N mineral fertilizers, leaching of bases and continuous mining of bases through export of *Sorghum* harvest (Tabi et al., 2013). Urea is known to be acidifying but some fertilizer as ammonium sulphate acidifies about two times than urea (Fageria et al., 2010). This acidity leads to the decrease of soil fertility where soils are currently not suitable (F1 and F2 of the DS system) and marginally suitable (F1 and F3 of DMC system, F3 of DS and F1, F2 and F3 of TS systems) for *Sorghum*. At this stage an inverse situation can occur, leading again to the progressive conservation of the organic matter concomitantly to the increase of the soil acidity. Indeed, soil acidity also influences the amount of organic matter stored in the soil by retarding decomposition processes (Jordan, 1985) by (1) reducing the microbial and fauna activity, (2) producing scleromorphous leaves containing small amounts of proteineous substances (N, P and S) and large amounts of structural material; C/N (and also C/P) ratios of such materials are high in the range of 20–30 instead of the usual range of 10–15, and (3) forming relatively stable Al-organic matter complexes.

The sum of exchangeable bases and base saturation rate are globally higher in the DMC system than in conventional systems where their values are almost similar. The absence of tillage in the DMC system greatly reduces the risk of runoff and erosion, which would inevitably lead to the decrease in nutrient losses and thus in soil exchangeable bases (Scopel and Findeling, 2001). This rate is not far from that of the control sample (40 %). High base saturation rate in the DMC system is attributed to upwelling of minerals from deep horizons via *Brachiaria* root systems (AFD/FFEM, 2007). Soils are desaturated in conventional systems, especially in the TS system where the values obtained are around 20 %. Soils desaturation in conventional systems could be attributed to leaching of nutrients released at the end of the agricultural campaign, accentuated by a low biomass rate. In addition, since soil textures of samples are sandy, sandy soils generally have low nutrients, while clayey soils usually have high nutrient due to their high adsorption capacity and low leaching losses (Shamsuddin and Bhatti, 2001).

The average soil organic matter content (2.84 %) in DMC systems is of the same order of magnitude as the proportion of the control soil (2.69 %). These soil organic matter contents in DMC systems, higher than those of DS and TS systems, means that the vegetation cover permit to maintain the soil organic matter content (Mekuria and Aynekulu, 2013), favoured by regular supply of mulch (AFD/FFEM, 2007). The soil fertility quality in DMC systems is partly due to soil organic matter contents that concur to increase the sum of exchangeable bases values and particularly, those of the CEC (Thompson et al., 1989. Asadu et al., 1997). The increase in clay content of DMC systems also contribute in the physical protection of soil organic matter. The soil organic matter mean proportion in the DS (1.35 %) and TS (1.88 %) suggests a loss of soil organic matter. This is due to the predominance of sandy texture in these conventional systems that limit the soil organic matter residence time. In addition, the low biomass and accelerated mineralization make DS less favourable to preservation of soil organic matter. This is confirmed by the average carbon content, which is lower, 0.71 % against 1.09 % in the TS and 1.65 % in DMC systems. Soil erosion imputable to conventional agricultural practices also leads to a loss of soil organic matter. In addition, repeated tillage in the TS cropping system fragments the soils and favours soil organic matter mineralization (Houyou et al., 2014). Globally, phosphorus levels are low in the soil. This is due to plants uptake which leads to the decrease of phosphorus contents in the soil at the end of the agricultural campaign.

5 Conclusions

The study aimed at analyzing the impact of different types of management (DS, TS and DMC) at different levels of fertilization on *Sorghum* yields, soil fertility and the rehabilitation of *hardé soils* in the Far North region of Cameroon. On the crop yields view point, the average yields of *Sorghum* between different cropping systems from 2002 to 2012

are 1239 kg ha^{-1} for DMC systems, 863 kg ha^{-1} for DS and 960 kg ha^{-1} for TS in the fertilization level F1, 1658 kg ha^{-1} in DMC systems, 1139 kg ha^{-1} in DS and 1192 kg ha^{-1} in TS, in the fertilization level F2, and 2270 kg ha^{-1} in DMC systems, 2138 kg ha^{-1} in DS, but only 1780 kg ha^{-1} in the TS in the fertilization level F3. On the soil fertility point of view, it is noted that there is an acidification of soils in different experimental plots due to losses of mineral elements through leaching, exportation of crops and use of nitrogen fertilizer, and an improvement of physical and chemical properties of soils in the DMC systems from F1 to F3 fertilization level contrary to the other systems. Globally, DMC systems have higher yields of *Sorghum* in all levels of fertilization, increasing from F1 to F3. Correlation values between crop yields and rainfall are low, meaning that the results obtained are those of different management systems carried out in the studied site. The study soils which are previously permanently not suitable (N2) for *Sorghum* due to the high percentage of nodules, are in addition marginally suitable to currently not suitable for *Sorghum* due to low soil pH values after different management systems.

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Table 1. Different levels of fertilization (Source: SODECOTON).

Level of fertilization	DS	TS	DMC
F1	100 kg ha^{-1} NPK 22.10.15	100 kg ha^{-1} NPK 22.10.15	100 kg ha^{-1} NPK 22.10.15 + 25 kg ha^{-1} of urea
F2	200 kg ha^{-1} NPK 22.10.15	200 kg ha^{-1} NPK 22.10.15	200 kg ha^{-1} NPK 22.10.15 + 50 kg ha^{-1} of urea
F3	300 kg ha^{-1} NPK 22.10.15 + 50 kg ha^{-1} of urea	300 kg ha^{-1} NPK 22.10.15 + 50 kg ha^{-1} of urea	300 kg ha^{-1} NPK 22.10.15 + 100 kg ha^{-1} of urea

DS: direct seeding; TS: tillage seeding; DMC: direct-seeding mulch-based cropping systems.

Table 2. Yields in kg ha^{-1} at different level of fertilization (F1, F2, F3) and mean annual rainfall over the studied site from 2002 to 2012 (Source: SODECOTON).

Years	Rainfall	Level of fertilization F1			Level of fertilization F2			Level of fertilization F3		
	(mm)	DMC	DS	TS	DMC	DS	TS	DMC	DS	TS
2002	546	918	689	1062	776	605	1078	1208	1819	1823
2003	863	1146	1104	1523	1423	1521	1797	1729	1875	2083
2004	710	2067	1134	1507	2625	1528	1587	2852	3733	2444
2005	711	1473	1335	1468	1932	2202	1889	2435	2739	2736
2006	1003	1530	764	526	2034	1090	778	2901	2545	1735
2007	868	844	564	800	1430	1252	753	2035	2097	755
2008	998	1420	540	820	1380	800	1220	2670	1270	1730
2009	738	700	700	600	1390	1535	1050	2500	2500	1750
2010	1147	1470	860	1030	1730	920	1370	2390	1370	2010
2011	805	750	880	380	1730	130	430	2280	1680	820
2012	835	1320	930	850	1780	940	1150	1980	1900	1690
Mean	838	1239	863	960	1658	1139	1192	2270	2138	1779
CV		0.32	0.28	0.40	0.27	0.47	0.36	0.21	0.32	0.32
SD		396	242	384	448	535	429	477	684	569

DS: direct seeding; TS: tillage seeding; DMC: direct-seeding mulch-based cropping systems;
CV: coefficient of variation; SD: standard deviation.

Table 3. Particle size distribution and acidity of the studied soils.

	Fertilization level	Particle size distribution (%)				Acidity		
		Sand	Silt	Clay	Textural classes	pH_{H_20}	pH_{KCl}	Δ pH
DMC	F1	62	18	20	Sandy clay loam	5.2	4.4	−0.8
	F2	51	22	27	Sandy clay loam	5.7	4.6	−1.1
	F3	45	33	22	Loam	5.3	4.0	−1.3
DS	F1	41	28	31	Clay loam	5.1	3.8	−1.3
	F2	60	20	20	Sandy clay loam	4.9	3.6	−1.3
	F3	66	19	15	Sandy loam	5.3	4.2	−1.1
TS	F1	54	35	11	Sandy loam	5.2	3.9	−1.3
	F2	61	23	16	Sandy loam	5.3	3.8	−1.5
	F3	62	25	13	Sandy loam	5.2	4.1	−1.1
Control sample	–	64	21	15	Sandy loam	5.6	4.4	−1.2

DS: direct seeding; TS: tillage seeding; DMC: direct-seeding mulch-based cropping systems.

Table 4. Chemical properties of the studied soils.

	Fertilization level	Exchangeable bases cmol(+) kg^{-1}					CEC7 Soil cmol(+) kg^{-1}	V(%)	CEC Clay cmol(+) kg^{-1}	Organic matter				P_2O_5 (ppm)	ESP (%)
		Ca^{2+}	Mg^{2+}	K^+	Na^+	S				OC (%)	OM (%)	N (%)	C/N		
DMC	F1	5.52	3.44	0.17	0.12	9.25	19.28	47.97	79.9	1.65	2.85	0.41	4.02	0.35	0.62
	F2	9.76	0.96	0.17	0.12	11.01	16.16	68.13	47.2	1.71	2.95	0.52	3.28	0.49	0.74
	F3	4.96	1.76	0.11	0.12	6.95	14.14	49.15	49.8	1.59	2.74	0.43	3.69	0.78	0.84
DS	F1	4.56	0.96	0.06	0.12	5.7	17.52	33.04	51.0	0.86	1.48	0.41	2.09	0.75	0.68
	F2	2.64	2.16	0.03	0.12	4.95	14.48	34.18	67.5	0.49	0.84	0.35	1.4	1.12	0.82
	F3	3.60	3.04	0.06	0.12	6.28	18.48	33.98	112.5	0.80	1.37	0.33	2.42	0.95	0.65
TS	F1	5.28	0.48	0.88	0.12	6.76	18.88	35.80	152.2	1.10	1.90	0.26	4.23	0.55	0.63
	F2	4.08	0.24	0.03	0.12	4.47	18.08	24.72	98.5	1.16	2.00	0.34	3.41	0.82	0.66
	F3	3.92	0.64	0.06	0.12	4.74	20.48	23.14	142.0	1.01	1.74	0.37	2.72	0.81	0.58
Control sample	–	7.36	0.56	0.06	0.12	8.1	20.16	40.17	113.6	1.56	2.69	0.54	2.88	0.30	0.59

DS: direct seeding; TS: tillage seeding; DMC: direct-seeding mulch-based cropping systems.

Table 5. Land suitability evaluation.

		DMC			DS			TS			Control sample
	Fertilization level	F1	F2	F3	F1	F2	F3	F1	F2	F3	–
Climate (c)	Precipitation during crop cycle (mm)	S1									
	Mean temperature during crop cycle (°C)										
Topography (t)	Slope (%)	S1									
Wetness (w)	Flooding	S1									
	Drainage										
Physical soil characteristics (s)	Texture/Structure	S1						S2			
	Coarse fragm (vol%)	N2									
	Soil depth (cm)	S1									
Soil fertility characteristics (f)	Apparent CEC (cmol(+) kg^{-1} clay)	S1									
	Base saturation (%)										
	Sum of base cations (cmol(+) kg^{-1}soil)										
	pH H_2O	S3	S1	S3	N1		S3	S3	S3	S3	S1
	Org. carbon (%)	S1									
Salinity (n)	ESP (%)	S1									
Suitability		N2sS3f	N2s	N2sS3f	N2sN1f	N2sN1f	N2sS3f	N2sS3f	N2sS3f	N2sS3f	N2s

DS: direct seeding; TS: tillage seeding; DMC: direct-seeding mulch-based cropping systems.

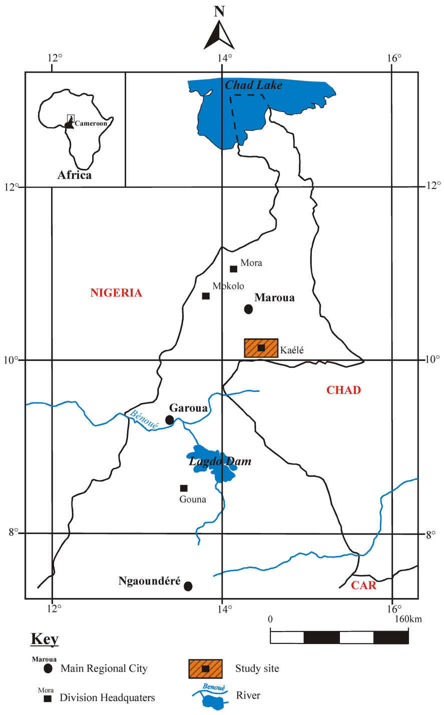

Figure 1. Location of the study site.

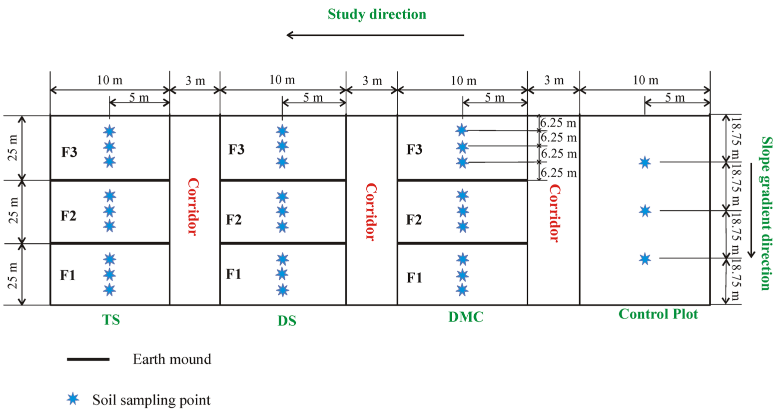

Figure 2. Study and soil sampling plan.

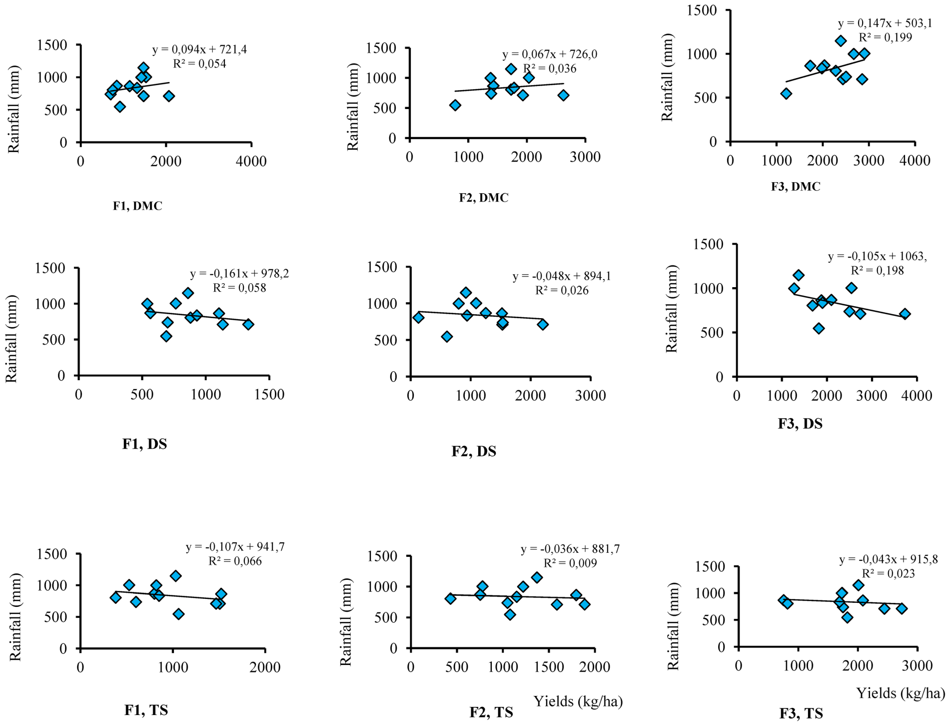

Figure 3. Plots of annual rainfall vs. yields in the 3 cropping systems and corresponding levels of fertilization.