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# Effects of SWC practices and soil fertility management on rain water productivity of maize hybrid

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In the evaluation of Soil and Water Conservation (SWC) techniques, little attention is paid to the rain water productivity of crops. The aim of this research work, is to assess the combined effects of SWC practices and soil fertility management on rain water productivity of maize hybrid. On-farm experiments were carried out in the districts of Houndé and Péni both located in the Hauts-Bassins region in Burkina Faso. The treatments were built as association of two SWC technologies combined with three fertilization options. The SWC combinations were: Stone rows and zaï pits (SR+Zaï), Grass strips and zaï pits (GS+Zaï), Earth bunds and contour ploughing (EB+CP). The fertilization options were: 5 t ha<sup>-1</sup> organic fertilizer (OM), OM + 100 kg ha<sup>-1</sup> urea (46% N), OM + 200 kg ha<sup>-1</sup> NPK (14-23-14) + urea. The treatments were laid out in a randomized block design where each farmer constituted a replication. As result, the combination of GS+ Zaï+ OM+ NPK+ Urea gave 26% additional maize grain yield and maize rain water productivity of 4.51 kg ha<sup>-1</sup> mm<sup>-1</sup> in the South-Sudan agro-ecological zone. While the combination of SR+ Zaï+ OM+ NPK+ Urea increased maize yield by 106 % and water productivity of maize was 6.61 kg ha<sup>-1</sup> mm<sup>-1</sup> in the North-Sudan agro-ecological zone. To improve maize yields and water productivity in rainfed agriculture, the use of the combination of soil and water conservation techniques and optimum organic and mineral fertilizer application is recommended.

**Key words:** Crop, water use, nutrients, maize yield, harvest index, Burkina Faso.

## INTRODUCTION

The majority of the population in Burkina Faso is small-scale farmers practicing rainfed agriculture. High inter-

annual variability and erratic rainfall distribution result in water-limiting conditions during the cropping season. Soils have also very low fertility, limiting nutrients availability to crops. Food security is then under threat due to the low water availability and increasing soil degradation. The degradation of the soils has a negative

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impact on the incomes of the rural populations as agriculture is their sole means of existence.

Many technologies were developed to control the degradation of the natural environment, such as soil and water conservation practices (SWC); sand dunes stopping techniques, zaï pits, earth bunds, stone rows, reforestation, grass strips (Kaboré/Sawadogo et al., 2012; Serme et al., 2015; Zougmore et al., 2004). Indeed, Zougmore et al. (2004) have proved the effectiveness of the stone rows and grass strips on the reduction of runoff and erosion control. In addition, these technologies are effective in keeping rain water in the plots to reduce crop water stress. Improved varieties of sorghum, maize, cowpea and millet with shortened cycles and high yields have been developed by agricultural research to cope with the reduction of rainy season length.

The use of SWC techniques help to prevent the loss of farmlands due to water erosion, increase infiltration of the rainwater, trap rich sediments and organic matter carried away by the water overflow. For instance, in the north-Sudan ecological zone of Burkina Faso, grass strips contribute to reduce runoff by 51% and soil erosion by 34% and constitute fodder for the animals and straw for domestic use. It also replaces the stone rows where the stones are unavailable (Kaboré/Sawadogo et al., 2012; Reij et al., 2005). Soil and water conservation techniques were mainly promoted in the dry semi-arid area, while the more humid zone was considered not appropriate for these technologies as the mean annual rainfall exceeds 900 mm. In the current condition of climate uncertainties and general trend of land degradation, refinement and upscaling of SWC are needed for all the agro-ecological zones to increase crop production and food security at the farmers' level. In the evaluation of the impact of SWC techniques, little attention was paid to the rainwater productivity of crops subjected to these technologies. Water productivity is assessed generally in irrigated systems. The aim of this research work, from 2012 to 2014, was to assess the combined effects of SWC practices and soil fertility management on rainwater productivity of maize hybrid. It will contribute to the refinement and adaptation of the SWC practices to the different agro-ecological zones and to food security.

## MATERIALS AND METHODS

### Sites description

The experiments were carried out on-farm in the districts of Houndé (11°29'0" N, 3°31'13" W; 328 m a.s.l) and Péni (10°57'0" N, 4°28'60" W; 430 m a.s.l), both located in the Hauts-Bassins region in the west of Burkina Faso (Figure 1).

Houndé belong to the North-Sudan savanna agroecological zone, with a mean annual rainfall, during the last ten years, of 926 mm unimodal distributed between April and October. During the rainy season 2014, when the water productivity evaluation was done, the site of Houndé received 981 mm precipitation distributed on 63 rainy days. Monthly mean maximum and minimum temperatures ranged from 30 to 38°C and from 19 to 26°C,

respectively. The soils include lixisols, poorly evolved erosional soils, and hydromorphic mineral to gleysols overlying material of varied texture (CILSS and OMM, 2001). The main characteristics of the soils used are given in Table 1.

The district of Péni is located in South-Sudan savanna zone, with an annual mean rainfall of 1084 mm, during the ten last years, and unimodal distributed between Mars and October. During the rainy season 2014, the site of Péni received 1488 mm precipitation distributed on 60 rainy days. Monthly mean maximum and minimum temperatures ranged from 30 to 37°C and from 19 to 26°C, respectively. The main soil types are lixisols poorly to fully leached, hydromorphic mineral to gleysols and ferralsols; partly desaturated overlying variable textured material (CILSS and OMM, 2001).

The savanna landscape is often park-like with many big trees including *Faidherbia albida* (known for its reverse phenology bearing leaves during the dry season but shedding leaves with the start of the rains), *Adansonia digitata*, *Butyrospermum paradoxum* subsp. *parkii*, *Lannea microcarpa* and *Tamarindus indica*. In the shrubby stratum, combretaceae are well represented. The most regular species are: *Acacia dudgeoni*, *Acacia gourmaensis*, *Acacia seyal*, *Bombax costatum*, *Combretum micranthum*, *Combretum glutinosum*, *Combretum nigricans*, *Grewia bicolor*, *Guiera senegalensis* and *Sterculia setigera* (Fontes and Guinko, 1995).

### Experimental design

The selection of the technologies has been based on the soil and water conservation (SWC) technologies evaluation results from different projects and research institutes (Traore and Adama, 2008). For instance, ridging, look liking earth bund, is common in the western part of Burkina Faso and stones are available in the hilly areas. The grass *Andropogon gayanus* is available in most of the Sudanese zone in West Africa. The SWC technologies used were:

- i) Stone rows: They are rows of stones fixed on contour lines with rows spacing 30 - 50 m, depending on slope (Figure 2);
- ii) Zaï pit: zaï is a micro basin of 30 to 40 cm diameter for 10 to 15 cm depth, dug in quincunx on lines with 80 cm spacing. The earth from the pit is disposed in the form of a crescent towards the upstream in order to capture the runoff water (Figure 2).
- iii) Grass strips: They are biological barriers composed of herbaceous (*Andropogon gayanus* or other grass), set in the fields following the contour lines. The strips are 30 - 50 m spacing depending on the slope (Figure 3).
- iv) Earth bunds: They are built on contour lines and have 80 cm wide, 30 cm height and 33 m spacing (Figure 4).

The treatments were built as association of two SWC technologies combined with three fertilization options. Three levels of SWC association were used as follows:

- i) Stone rows built on contour lines and zaï pits; SR+Zaï.
- ii) Grass strips of *Andropogon gayanus* built on contour lines and zaï pits; GS+Zaï.
- iii) Earth bunds built on contour lines and contour ploughing; EB+CP.

The three levels of fertilization options were:

- i) Organic fertilizer available at farmers level (mixture of cow dung and crop residues); OM
- ii) OM + urea (46% N)
- iii) OM + NPK (14-23-14) + urea

The experiment design was a randomized block design where each farmer constituted a replication. In each district, 15 farmers hosted

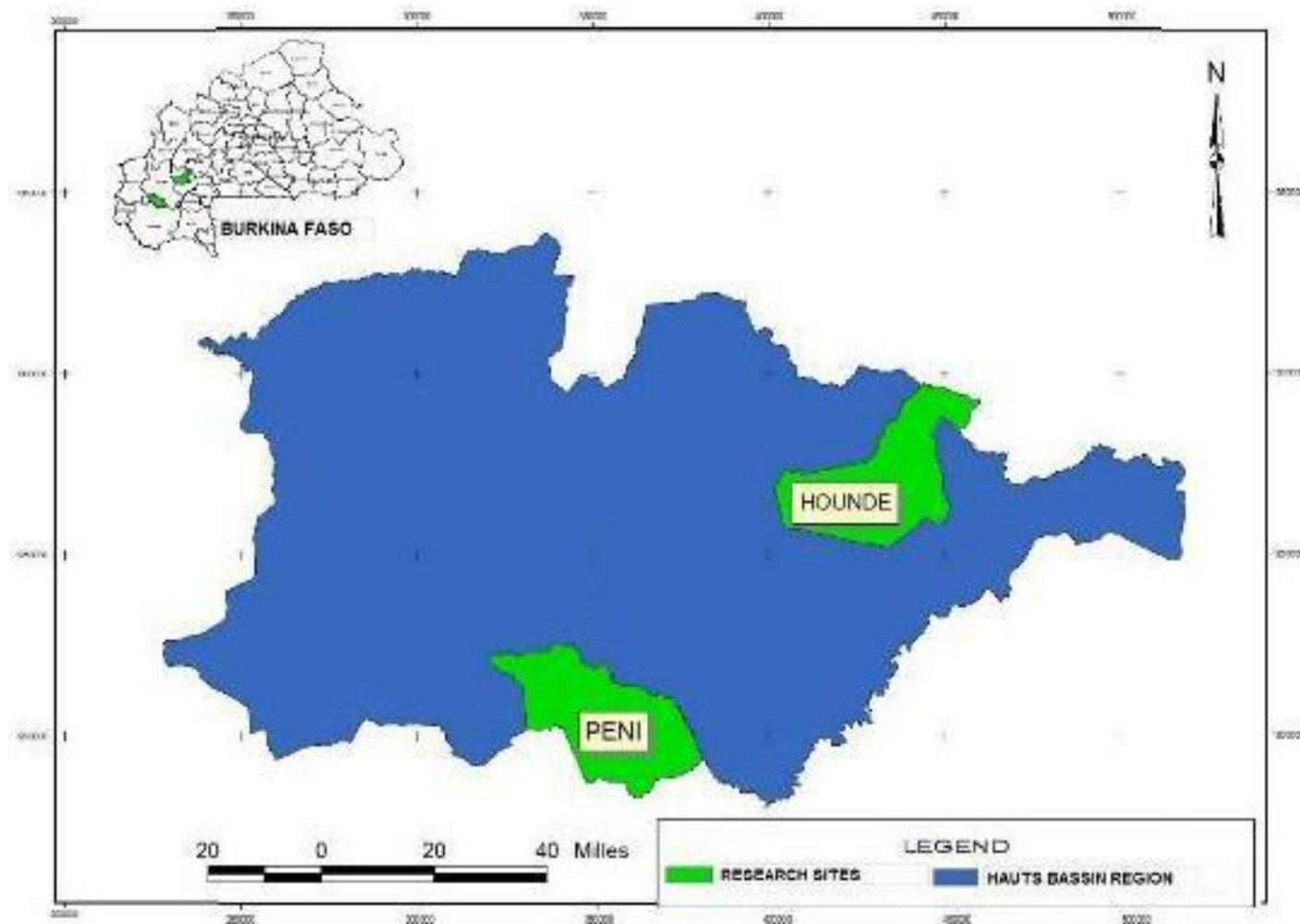


Figure 1. Location of the experimentation sites in Burkina Faso.

Table 1. Soils chemical and physical characteristics at Péní and Houndé, 0-20 cm depth.

Sites	OM %	N <sub>total</sub> %	K <sub>total</sub>	K <sub>avail</sub>	P <sub>total</sub>	P <sub>Brayl</sub>	pH <sub>water</sub>	Clay %	Silt %	Sand %
			(g kg <sup>-1</sup> )							
Péní	1.38	0.074	0.581	0.139	0.349	0.0089	5.43	16.40	25.90	57.70
Houndé	1.46	0.092	1.459	0.080	0.715	0.0036	6.57	19.10	42.40	38.50

Source: Authors' data; OM = organic matter.

the experiments of 1 ha size per farmer, divided into four treatments. The elementary plot size was 50 x 100 m equivalent to 0.25 ha.

In the district of Houndé the treatments tested were:

- i) Farmers' practices (oxen ploughing and application of mineral fertilizer); Control
- ii) SR + Zaï + OM (5 t ha<sup>-1</sup>)
- iii) SR + Zaï + OM + urea (100 kg ha<sup>-1</sup> in two fractions)
- iv) SR + Zaï + OM + NPK (200 kg ha<sup>-1</sup>) + urea
- v) GS + Zaï + OM (5 t ha<sup>-1</sup>)
- vi) GS + Zaï + OM + urea (100 kg ha<sup>-1</sup> in two fractions)

- vii) GS + Zaï + OM + NPK (200 kg ha<sup>-1</sup>) + urea

The combination involving stone rows (SR) in addition to the control plot were conducted in 9 farms and the one involving grass strips were in 6 farms.

In the district of Péní; the following treatments were applied:

- i) Farmers' practices (oxen ploughing and application of mineral fertilizer); Control
- ii) EB + CP + OM (5 t ha<sup>-1</sup> each 2 years)
- iii) EB + CP + OM + urea (100 kg ha<sup>-1</sup> in two fractions)
- iv) EB + CP + OM + NPK (200 kg ha<sup>-1</sup>) + urea



**Figure 2.** Stone row combined with zaï pits.



**Figure 4.** Earth bund built on contour line.



**Figure 3.** Grass strip built on contour line.

- v) GS + Zaï + OM (5 t ha<sup>-1</sup> each two years)
- vi) GS + Zaï + OM + urea (100 kg ha<sup>-1</sup> in two fractions)
- vii) GS + Zaï + OM + NPK (200 kg ha<sup>-1</sup>) + urea

The same proportions of combinations were made in Péni like in Houndé with 9 farmers for EB. The crop variety used (maize Bondofa) was a hybrid variety from INERA research stations. It has white grains and a growing cycle of 95 days to maturity, its potential yield is 7 t ha<sup>-1</sup>. The maize was sown at 40 x 80 cm spacing and thinned at two plants per hill.

### Maize yields evaluation

For maize grain and straw yields evaluation, two subplots of 5 m x 5 m = 25 m<sup>2</sup> were taken in each elementary plot, in the way to avoid farm trees effect. The weight of the grain and the straw harvested on these plots were extrapolated to 1 ha to get the different yields.

### Rain water productivity determination

The rainwater productivity (WP) is defined here, as the amount of grain produced per ha and per mm of rain received from the maize plantation to the harvest (maturity). Water productivity was calculated by dividing grain yield by total rainwater received as follows (Abideen et al., 2014; Kambou et al., 2014; Van Halselma and Vincent, 2012):

$$WP \text{ (kg ha}^{-1} \text{ mm}^{-1}\text{)} = \frac{\text{Grain yield (kg ha}^{-1}\text{)}}{\text{Total rainwater received (mm)}}$$

This calculation of WP considered the time between sowing and harvesting, the rain received during this time on each farm, and minimize the runoff and the drainage beyond the maize rooting zone.

### Grain yield

The grain yield from each plot harvested from the harvestable area was calculated and the yield extrapolated to kg ha<sup>-1</sup> using the formula below:

$$\text{Grain yield (kg ha}^{-1}\text{)} = \frac{\text{Grain yield (kg)}}{\text{Area (ha)}}$$

### Harvest index

The harvest index (HI) calculated as the ratio of the grain weight to the above ground dry matter including the grain and the straw weights.

### Laboratory analysis

Soil organic carbon was measured using the Walkley and Black method on composite samples from three sampling points per plot, total organic N by the Kjeldahl method, soil total P was measured

**Table 2.** Effects of soil and water conservation techniques on maize yields at Houndé.

SWC Techniques	Grain Yields (kg ha <sup>-1</sup> )	Straw yields (kg ha <sup>-1</sup> )	Harvest index
GS+Zaï	3065 <sup>ab</sup>	2899	0.49
SR+Zaï	3768 <sup>a</sup>	2979	0.58
Control (ploughing)	2157 <sup>b</sup>	2357	0.47
LSD	1428	1031	0.11
CV%	31.9	24.9	15.1
F Probability	0.02	0.19	0.11
Significance	S	NS	NS

NB: Numbers following by the same letter in a column are not statistically different. NS=Not Significant, CV%=Coefficient of Variation, LSD= *Low significant difference*, S= significant; GS= Grass Strip; SR= Stone Rows.

by acid extraction and soluble P by the Olsen–Dabin method (Baize, 1988). Soil particles size distribution was analyzed using Robinson pipette method on air dried soil sieved on 2 mm mesh and following the procedure described by Mathieu and Pieltain (1998). The pH<sub>water</sub> was measured in a 1:2.5 soil:water suspension, using potentiometric method (Baize, 1988).

#### Data analysis

Statistical analyses, ANOVA was performed using Genstat 12 (General Statistic) software. The comparison of means was done based on the test of Newman Kuehl and the least significant difference with the probability of significance at 5%.

## RESULTS

### Effects of soil and water conservation technologies on maize straw and grain yields at Houndé and Péni

At Péni there were no significant differences between soil and water conservation technologies (SWC) for maize straw and grain yields (results not shown). The highest grain yield was harvested on the combination GS+Zaï (3733 kg ha<sup>-1</sup>) that gave 6475 kg ha<sup>-1</sup> straw yield. The control plot gave 3317 kg ha<sup>-1</sup> and 6630 kg ha<sup>-1</sup> grain yield and straw yield, respectively.

At Houndé, the maize grain yields were significantly different between SWC practice plots, but not different for the straw yields. The highest maize grain yield was harvested on SR+Zaï technologies plot and the lowest on the control. The treatments SR+Zaï and GS+Zaï gave 75% and 42% grain yield increase, respectively, over the control (Table 2). There were no significant differences between SWC techniques for the harvest index. However there was a trend of its improvement with the combination SR+Zaï as compared to the other technologies (Table 2).

### Treatments effects on maize yields at Péni and Houndé

The maize hybrid, Bondofa variety, yielded on the

average 3645.6 kg ha<sup>-1</sup> at Péni and 3236.9 kg ha<sup>-1</sup> at Houndé. Both at Péni and Houndé there were significant differences between treatments (combination of SWC techniques and fertilization option) for maize grain yields but not for the straw yields (Tables 3 and 4).

At Péni, the treatments GS+ Zaï+ OM+ NPK+ Urea and EB+CP+ OM+NPK+ Urea yielded more than 4 kg ha<sup>-1</sup> maize grain and the other treatments gave less than this value. They produced respectively 26 and 23% additional grain yields over the control. The highest straw yield was recorded on the treatment GS+ Zaï+ OM+ NPK+ Urea (8070 kg ha<sup>-1</sup>) and the lowest on the treatment EB+CP+ OM with 4590 kg ha<sup>-1</sup> (Table 3). There were no significant differences between treatments for the harvest index. The lowest harvest index was recorded in the treatment GS+ Zaï+ OM+ NPK+ Urea with the highest grain and straw yields (Table 3).

At Houndé the highest grain yield was harvested on the treatments SR+ Zaï+ OM+ NPK+ Urea (4457 kg ha<sup>-1</sup>) following by the treatment SR+ Zaï+ OM+ Urea (3824 kg ha<sup>-1</sup>) and the lowest was recorded on the control (2157 kg ha<sup>-1</sup>) (Table 4). The same treatments gave the highest and lowest straw yields. The treatments SR+ Zaï+ OM+ NPK+ Urea yields improvements were 106 % and 55 % over the control, respectively for the grain and straw. The harvest index did not differ significantly between treatments. The treatment SR+ Zaï+ OM+ Urea gave the highest maize harvest index (Table 4).

### Rain water productivity of maize at Péni and Houndé

Both at Péni and Houndé there were significant differences between treatments for rainwater productivity of maize (Table 5). On the average WP of maize was 3.90 kg ha<sup>-1</sup> mm<sup>-1</sup> at Péni and 4.64 kg ha<sup>-1</sup> mm<sup>-1</sup> at Houndé.

At Péni the treatment GS+ Zaï+ OM+ NPK+ Urea had the highest WP (4.51 kg ha<sup>-1</sup> mm<sup>-1</sup>) of maize followed by GS+ Zaï+ OM+ NPK+ Urea (4.31 kg ha<sup>-1</sup> mm<sup>-1</sup>) and the lowest WP (3.28 kg ha<sup>-1</sup> mm<sup>-1</sup>) was recorded on the treatment EB+CP+ OM (Table 5).

At Houndé the highest WP (6.61 kg ha<sup>-1</sup> mm<sup>-1</sup>) of maize

**Table 3.** Treatments effects on maize yields at Péni.

Treatments	Grain yields (kg ha <sup>-1</sup> )	Straw yields (kg ha <sup>-1</sup> )	Harvest index
GS+ Zaï+ OM	3367 <sup>ab</sup>	6095	0.39
GS+ Zaï+ OM+ NPK+ Urea	4192 <sup>a</sup>	8070	0.35
GS+ Zaï+ OM+ Urea	3642 <sup>ab</sup>	5260	0.42
EB+CP+ OM	3017 <sup>d</sup>	4590	0.42
EB+CP+ OM+NPK+ Urea	4067 <sup>a</sup>	5960	0.42
EB+CP+ OM+ Urea	3917 <sup>ab</sup>	5730	0.43
Control (Ploughing+NPK+Urea)	3317 <sup>ab</sup>	6630	0.36
LSD	906	2626	0.07
CV%	11.3	19.0	9.05
F Probability	0.03	0.08	0.07
Significance	S	NS	NS

NB: Numbers following by the same letter in a column are not statistically different. NS=Not Significant, CV%= Coefficient of Variation, LSD= *Low significant difference*, S= significant; GS= Grass Strip, EB= Earth Bund, CP= Contour Ploughing, OM= Organic Matter; NPK= Nitrogen, Phosphorus, Potassium.

**Table 4.** Treatments effects on maize yields at Houndé.

Treatments	Grain yields (kg ha <sup>-1</sup> )	Straw yields (kg ha <sup>-1</sup> )	Harvest index
GS+ Zaï+ OM	2232 <sup>b</sup>	2432	0.43
GS+ Zaï+ OM+ NPK+ Urea	3507 <sup>ab</sup>	3132	0.52
GS+ Zaï+ OM+ Urea	3457 <sup>ab</sup>	3132	0.51
SR+ Zaï+ OM	3024 <sup>ab</sup>	2457	0.54
SR+ Zaï+ OM+ NPK+ Urea	4457 <sup>a</sup>	3657	0.56
SR+ Zaï+ OM+ Urea	3824 <sup>a</sup>	2824	0.63
Control (Ploughing+NPK+Urea)	2157 <sup>b</sup>	2357	0.47
LSD	1590	1171	0.14
CV%	27.1	21.9	14.5
F Probability	0.01	0.08	0.16
Significance	<b>S</b>	<b>NS</b>	<b>NS</b>

NB: Numbers following by the same letter in a column are not statistically different. NS=Not Significant, S= significant, CV%= Coefficient of Variation, LSD= *Low significant difference*; GS= Grass Strip, SR= Stone Rows, OM= Organic Matter, NPK= Nitrogen, Phosphorus, Potassium.

was recorded on the treatment SR+ Zaï+ OM+ NPK+ Urea, while the lowest (3.10 kg ha<sup>-1</sup> mm<sup>-1</sup>) was recorded on the control. The improvement of WP by this treatment reached twice the WP of the control (Table 5).

## DISCUSSION

Maize is a crop sensitive to water stress and to soil fertility, particularly to soil nitrogen content and N supply through fertilization (Hammad et al., 2011; Sarr et al., 2011). Because of water requirement for maize crop, it is grown in the South Sudan agro-ecological zone where the mean annual rainfall is more than 900 mm. Likewise, to meet soil fertility requirement for maize cropping, in unsuitable areas for maize, it is farmed around the

houses in villages to benefit from the domestic wastes. Maize high demand of water and nutrients is well known (Ashraf et al., 2016; Hammad et al., 2011; Mansouri-Far et al., 2010). In 2014 at Péni, soil and water conservation (SWC) practices did not have significant differences for maize grain and straw yields. Whereas at Houndé, there were significant differences between SWC practices for maize grain yields. This can be due to the difference in rainfall characteristics between the two sites. During the year 2014, the site of Houndé received less rainfall than Péni. Water was not a limiting factor at Péni, so that SWC practices did not induced significant improvement in maize yields. Probably this was not the case in Houndé where the combination SR+Zaï and GS+Zaï gave 75 and 42% grain yield increase over the control, respectively. Soil and water conservation techniques increase water

**Table 5.** Rain water productivity of maize at Péni and Houndé.

Péni		Houndé	
Treatments	WP (kg ha <sup>-1</sup> mm <sup>-1</sup> )	Treatments	WP (kg ha <sup>-1</sup> mm <sup>-1</sup> )
GS+ Zaï+ OM	3.59 <sup>ab</sup>	GS+ Zaï+ OM	3.21 <sup>c</sup>
GS+ Zaï+ OM+ NPK+ Urea	4.51 <sup>a</sup>	GS+ Zaï+ OM+ NPK+ Urea	4.84 <sup>abc</sup>
GS+ Zaï+ OM+ Urea	3.90 <sup>ab</sup>	GS+ Zaï+ OM+ Urea	4.79 <sup>abc</sup>
EB+CP+ OM	3.28 <sup>b</sup>	SR+ Zaï+ OM	4.43 <sup>bc</sup>
EB+CP+ OM +NPK+ Urea	4.31 <sup>a</sup>	SR+ Zaï+ OM+ NPK+ Urea	6.61 <sup>a</sup>
EB+CP+ OM + Urea	4.21 <sup>ab</sup>	SR+ Zaï+ OM+ Urea	5.49 <sup>ab</sup>
Control	3.53 <sup>ab</sup>	Control	3.10 <sup>c</sup>
LSD	0.997		2.17
CV%	11.69		26.89
F Probability	0.04		0.02
Significance	S		S

NB: Numbers following by the same letter in a column are not statistically different. WP= Water Productivity, S= significant, CV%= Coefficient of Variation, LSD= *Low significant difference*; GS= Grass Strip, EB= Earth Bund, CP= Contour ploughing, SR= Stone Rows, OM= Organic Matter, NPK= Nitrogen, Phosphorus, Potassium.

availability to crop by reducing the runoff, increasing rain water infiltration and stock into the soil. Improvement of water availability increase maize nutrition and thereby the grain and biomass yields. This effect seems limited in the areas with high annual mean rainfall ( $\geq 1000$  mm).

The combination of SWC technologies with organic and mineral fertilization, improved maize grain yields both at Péni and Houndé. At Péni, the treatments GS+ Zaï+ OM+ NPK+ Urea and EB+CP+ OM+NPK+ Urea yielded respectively 26 and 23% additional grain yields over the control. At Houndé the treatments SR+ Zaï+ OM+ NPK+ Urea and GS+ Zaï+ OM+ NPK+ Urea grain yields improvement were 106 and 63% respectively over the control. Yet, the yields improvement due to the combination of SWC practices and soil fertility management was better at Houndé than Péni, maybe because of the difference in water stress severity. This means that the efficacy of SWC practices decrease with the increase in the mean annual rainfall. The highest yields were recorded in the combination where organic matter, NPK and urea fertilizer were applied, probably because of the improvement in water nutrition and nutrients uptakes that lead to more maize tissue formation. This is in phase with the finding supporting that water supply is important for crop production as much as nutrients in semi-arid condition (Mansouri-Far et al., 2010; Hammad et al., 2011). Nutrients availability to crop or uptake may be modified by water supply through irrigation or water harvesting technologies in rainfed agriculture (Erkossa et al., 2011; Serme and Ouattara, 2016) and then, conditions crop performance. Zougmore et al. (2004) indicated the limited effect of SWC technologies on crop yields without nutrients supply in the condition of Sub-Saharan Africa. The combination of SR+Zaï with the application of organic and mineral fertilizer improved the translocation of water and nutrients

to maize grain formation instead of biomass production as expressed in better harvest index. At Péni, the lowest HI obtained on GS+ Zaï+ OM+ NPK+ Urea plot is maybe due to other limiting factors of maize growth and development (Maobe et al., 2010; Ion et al., 2015).

The average WP of maize was  $3.90 \text{ kg ha}^{-1} \text{ mm}^{-1}$  at Péni and  $4.64 \text{ kg ha}^{-1} \text{ mm}^{-1}$  at Houndé. Rainwater productivity of maize seems to decrease with high annual rainfall. Water productivity increase with the reduction of water losses. Thus, the risk of runoff and drainage increases with the amount of water supply and the non-application of SWC techniques. Similarly, Samila et al. (2009) found in Egypt, in irrigation condition, that maize water productivity increase gradually as less water volume was applied up to 30% of the required irrigation. At Péni, the combination of GS+ Zaï+ OM+ NPK+ Urea corresponding to GS+ Zaï+ (5 t manure + 74N-46P-28K)  $\text{ha}^{-1}$  had the highest WP ( $4.51 \text{ kg ha}^{-1} \text{ mm}^{-1}$ ) and at Houndé SR+ Zaï+ OM+ NPK+ Urea corresponding to SR+ Zaï+ (5 t manure + 74N-46P-28K)  $\text{ha}^{-1}$  had the best WP ( $6.61 \text{ kg ha}^{-1} \text{ mm}^{-1}$ ). Water management in combination with nutrients supply improved maize water productivity. The water productivity improvement was 28 and 113% over the control at Péni and Houndé respectively, indicating the effect of the rainfall amount on WP. In Ethiopia on nitisols and with mean annual rainfall of 1451 mm, Erkossa et al. (2011) obtained, in the same range of our results, maize grain water productivity increase of 48 and 54%, with near optimal and non-limiting soil fertility, respectively. Improvement of water productivity of maize depends on water supply, soil fertility management and also on the potential of the variety used. The maize water productivity, in our study, was low as compared to the water productivity of 8.2 and  $8.2 \text{ kg ha}^{-1} \text{ mm}^{-1}$  of traditional and hybrid maize varieties, respectively, obtained in irrigated conditions by Abideen

et al. (2014) on station, in Pakistan with the application of 160N-80P-0K kg ha<sup>-1</sup> fertilizer. There is room to improve maize productivity, in semi-arid Africa, with higher productive variety and optimizing water and fertilizers use.

## Conclusion

Soil and water conservation practices (SWC) had limited effect on maize yields in South-Sudan savanna zone where the mean annual rainfall exceed 1000 mm. But in the agro-ecological zone where the mean annual rainfall is less than 950 mm, these practices improved maize grain yields up to 75% over the control (oxen ploughing). The combination of GS+ Zaï+ OM+ NPK+ Urea corresponding to GS+ Zaï+ (5 t manure + 74N-46P-28K) ha<sup>-1</sup> that gave 26% additional maize grain yield and 28% improvement of maize water productivity is adapted to the South- Sudan agro-ecological zone. While the combination of SR+ Zaï+ OM+ NPK+ Urea corresponding to SR+ Zaï+ (5 t manure + 74N-46P-28K) ha<sup>-1</sup> that increased maize yield by 106% and water productivity of maize by 113% is the better practice for the North-Sudan agro-ecological zone. To improve maize yields and water productivity in rainfed agriculture in the semi-arid zone of Africa, the use of the combination GS+ Zaï+ (5 t manure + 74N-46P-28K) ha<sup>-1</sup> and SR+ Zaï+ (5 t manure + 74N-46P-28K) is recommended.

## CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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