Integrated water and soil conservation for food security in Niger, preliminary results

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ABSTRACT

As a result of growing population pressure and limited fertile land availability, Nigerien farmers increasingly rely on marginal lands for food crops production. These degraded lands, however, generally provide poor millet yields due to their low soil nutrient content and imbalanced partitioning of water in the root-zone. This study evaluates the agronomical, hydrological and soil quality parameters of water and soil conservation techniques (i.e. zaï, demi-lunes and no-till with scarification) which tackle these two major crop growth limitations by means of an in situ root-zone water balance experiment. Preliminary results from the first cropping season from June to October 2011 show overall low yields. The 2011 season was characterised by erratic rainfall with a severe dry spell during flowering stage. The control and manure treatment did not yield grain, but simply applying manure did increase dry matter production with a factor of 20. The highest grain yield was produced by the zaï, 134 kg/ha, which was 3 and 9 times better than respectively the grain yield of demi-lunes and no-till with scarification treatments. The zaï treatment moreover reduced cumulative actual evaporation as measured using mini-lysimeters during a 10 day drying cycle. In conclusion, until now the synergistic effect of the water-harvesting practices and the supply of manure show promising potential to rehabilitate and to increase the agronomic efficiency of marginal land in Niger. Future work will focus on the impact of the treatments on yield, soil quality properties and on the root-zone water balance.

INTRODUCTION

Rain fed agriculture is the dominant source of food in Sub-Saharan Africa (SSA) and is practised on approximately 95% of the agricultural land. However, the extreme low yields in small-scale holder farming systems and the alarming news on recent food insecurity in the Sahel demonstrate the inadequacy of current soil, water and nutrient management practices for sufficient food production.

The safeguarding of sufficient food production in Niger is mainly hindered by the ongoing severe land degradation and immense population pressure. In general, two different land use units used to exist, the fertile sandy soils in the valley and the degraded soils known as 'laterite' on higher topographical positions nearby or on the plateaus (Boubacar et al., 2005). The latter soils suffer from poor edaphic conditions and are therefore primarily reserved for pastures and fuel wood supply, of which the overexploitation undoubtedly has largely contributed to their further degradation. The increase in population, however, shortens vegetative fallow periods, and consequently hampers the natural soil restoration of the fertile soil, which leads in its turn to soil degradation and the exposure of the slightly clayey subsurface, forming a crust. This leads to land abandonment and limited fertile soil availability, forcing farmers to rely on marginal, unproductive and crusted degraded land (Amissah-Arthur et al., 2000, Tabor, 1995).

The key to improve crop production is to rehabilitate these lands by restoring both the water and nutrient balance. The improved water balance should favour green, productive water at the expense of blue water losses to maximize plant water availability by promoting the infiltration and retention of rainwater. While rainfall is now primarily lost as blue water through runoff (25-50%) and, once rainfall entered the soil, by percolation (10-30%) and evaporation (30-50%) (Rockstrom, 1999). Water management without improved nutrient management is, however, ineffective, since low organic matter contents restrict soil water retention and limits root development (Zougmore et al., 2003).

Several water and soil conservation techniques (WSC) tackling these two major crop growth limitations have been developed (Falkenmark et al., 2001). In Niger the low tech treatments with locally available materials and low investment costs are appropriate, as small-scale subsistence farmers are the major food producers (Roose et al., 1992). The dissemination of WSC techniques moreover generally encounters difficulties in terms of adoption constraints (Falkenmark et al., 2001). Although several in situ small-scale WSC are widely known and promoted, few studies provide scientific evidence and offer technical solutions regarding their design and global impact, especially in Niger and neighbouring countries. To our knowledge, very few studies moreover compared different suitable WSC treatments or followed water dynamics in and around the WSC technique. Understanding water dynamics is, however, a prerequisite to improve WSC and to evaluate their hydrological impact.

Most papers focus only on one WSC treatment (e.g.Adekalu et al., 2009, Roose et al., 1999, Sidibe, 2005, Sawadogo et al., 2008, Zougmore et al., 2003, Tabor, 1995, Forzieri et al., 2008), rather evaluate nutrient and nutrient water interactions in WSC (e.g.Fatondji et al., 2007, Fatondji et al., 2009) or are more socio economic (e.g.de Graaff et al., 2008, Tenge et al., 2007, Slingerland and Stork, 2000, Sidibe, 2005).

To deal with the above mentioned research gaps, we studied the hydrological impact of three small-scale WSC techniques together with their impact on physical, chemical and biological soil quality and yield by means of an onsite root zone water balance experiment. This paper presents some preliminary results
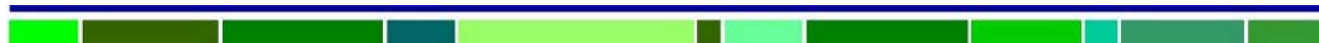
Table 1: Some physical and chemical properties of the site's soil

Sand (g kg^{-1})	Silt (g kg^{-1})	Clay (g kg^{-1})	Vol gravel (%)	ρb (Mg m^{-3})	pH (KCl)	CaCo$_3$ (%)	OC (%)
791	113	96	12.7	1.8	3.9	1.03	0.22

regarding the effect of WSC techniques on yield, biological soil quality, and infiltration and evaporation rate assessed during a first growing season in 2011.

METHODS AND MATERIALS

Environmental settings

A field experiment was set up in 2011 near Sadoré village, Niger (13°15'N, 2°17'E) on a degraded patch of 'laterite' land with a slope of 1%. The soil has a shallow rooting depth of 25 cm, due to the presence of a lateritic iron pan and is very acidic, poor in organic C and gravelly (Table 1). The region is subjected to a sudano-sahelian (BShw) climate with a long, hot dry and a short cropping season (June-October). Rainfall is highly variable in space and time and has an annual average of 550 mm, whereas potential evaporation amounts to almost 2000 mm per year. The zone is dominated by smallholder farms smaller than 2 ha, where mainly millet (*Pennisetum glaucum* (L.) R. Br.) is cropped with or without cowpea or groundnut as intercrop.

Experimental design and treatments

The experiment was laid out according to a randomized block design with five treatments and three replications. Plots are 12 by 16 m with earthen 0.3-m wide and 0.1-m high ridges separating them. The treatments include: Zaï + manure (Z), Demi-lunes + manure (DL), No till with scarification + manure (NTS), Control + manure (CM), and Control (C).

The Zaï treatment, an indigenous Sahelian technique, consists in digging pits of about 25 cm diameter and 15 cm deep during the dry season. The pits trap wind and water-driven soil, leaves and organic particles, similar to the demi-lunes, also known as half-moon shaped bunds. The DL bunds are, according to the design of Zougmoré et al. (2003), 4 m in diameter and spaced at 2 m on the contour line and 4 m between two successive lines. The bund is constructed with the earth scooped from the basin (5-10 cm depth), in which the manure is mixed with the top soil. The NTS treatment can be considered as a conservation agriculture practice, of which two key principles, year round soil cover and as little soil disturbance as possible are adopted. Furrows of 5-7 cm deep and 10 cm wide are scratched for this treatment to break the soil crust and loosen the top soil, which is again mixed with manure. As such, conditions to facilitate germination are created. Furthermore, stubble is left on the field to keep the soil covered year round to prevent soil erosion, excessive evaporation and supply organic matter into the soil. Control treatments with and without manure allow the separate evaluation of nutrient and water management. They do not disturb the soil except scooping while seeding.

Crop management was executed by local farmers. Animal manure was applied at the optimal application rate (3 t ha^{-1} or 300 g per pocket) suggested by Fatondji et al. (2007) in all treatments except C, after which the millet variety 'Sadoré local' was sown on 18 June after the first onset of rain. Pockets were planted at the typical density of 10 000 per ha for all treatments and were subsequently thinned to 3-7 plants per pocket approximately 5 weeks after planting. On 12 October millet was harvested.

Data collection

At harvest, total dry weight as well as seed dry weight was recorded of a 4 x 6 m subplot to evaluate yield. Furthermore, saturated (Ks) and unsaturated (Kψ) hydraulic conductivity were determined for all treatments, by means of infiltration measurements with a Model 2825 tension infiltrometer adaptor module (Soilmoisture Equipment, Santa Barbara, CA) with a diameter of 0.20 m and attached to the Mariotte system of a Guelph permeameter. For each treatment, 10 to 12 replications of infiltration measurements were executed with three successive negative pressure heads, −0.29, −0.59, and −1.18 kPa, and for at least 15 min or until the infiltration rate of three consecutive time intervals was constant (as suggested byVerbist et al., 2009). All measurements were conducted between 14 Sept. and 25 Oct. Saturated and unsaturated hydraulic conductivity were subsequently calculated with the method of Logsdon and Jaynes (1993), a method based on Woodings equation for unconfined steady state flow, which was found to perform accurately by Verbist et al. (2009).

In order to assess the treatments' impact on biological soil quality, nematodes were studied. Soil samples for nematode analysis, composed of two subsamples next to the plant and in between two plants, were therefore subjected to an active extraction. Nematodes were then recuperated on a 25 μm sieve and analyzed by microscope. Since plant parasitic nematodes were absent, only the nematode count was computed.

A microlysimeter experiment based on the method of Boast and Robertson (1982) was set up to compare differences in evaporation rate. The method allows calculating actual evaporation (Ea) in the course of a drying cycle, by weighing and re-installing undisturbed soil cores. These cores, known as microlysimeters are capped at the bottom to prevent drainage. Water loss is then only possible due to evaporation at the surface, which can be recorded by difference in weight over time. On each plot an experiment area of 1 m^2 was brought to field capacity and covered by plastic to prevent evaporation. After 24h drainage, two microlysimeters per plot, one next to the plant and one randomly, were inserted as described by Stroosnijder (2009). The microlysimeters were 8 cm in diameter, had a 10 cm length and were daily weighed with a field balance during a 10 day evaporation cycle.

RESULTS AND DISCUSSION

Millet production

Although straw yield significantly increased due to manure application, the harsh soil conditions were not suitable for millet production under the control treatments CM and C (Table 2). Germination only encountered minor difficulties, but burning of the seedlings seemed to be the biggest problem. The young roots could not reach enough water in the hard soil to cool the leaves,

Table 2: Effect of WSC treatment on millet performance in 2011(with standard deviations between brackets). / represents zero straw yield, as it was left on the field as soil cover.

	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})	% not germinated	% seedlings burned
Z	134 (37)	1672 (118)	1 (1)	0 (1)
DL	40 (13)	1149 (106)	0 (0)	0 (0)
NTS	15 (10)	/	1 (1)	5 (8)
CM	1 (1)	406 (379)	5 (7)	51 (46)
C	0 (0)	11 (10)	6 (6)	13 (10)

Figure 2. Effect of WSC treatment on field saturated hydraulic conductivity for 2011. (in) and (out) represent values measured respectively in and outside the water catchment area (bar = average and line = standard deviation).

a problem typically worsened by adding nutrients. The poor result of the NTS treatment is ascribed to the absence of stubble in the first year; the effect of a ground cover is only expected for the second crop season. Note that straw yield is missing in Table 2 since it was left on the field and cannot be included as yield. The highest grain yield was produced by Z, 134 kg/ha, which was more than three times higher than the grain yield of DL. These yields are overall low compared to average yields, 300-500 kg ha^{-1}, and those reported in literature, ± 500-1500 kg ha^{-1} for DL (Zougmore et al., 2003) and ± 300- 660 ha^{-1} for Z (Fatondji et al., 2007). Also straw yields were low, but were on the other hand in the same range as reported in literature. The poor grain yield is explained by both a severe dry spell and low annual rainfall. From 27 Aug. until 5 Oct., during the generative (mid-season) stage, only 7 mm rain fell, and seasonal rainfall only reached 400 mm compared to 550 mm average, whereas millet crop water requirement is 475 mm.

Biological soil quality

Since nematodes were absent before application of the treatments, cultivation increased nematode population (Fig. 1). Only free-living species occurred, which play an important role in organic matter decomposition process; plant parasitic species were absent Manure increases soil life, but the moisture conditions of Z and DL which was better in those treatments compared to the others, are clearly most favorable for biological soil quality.
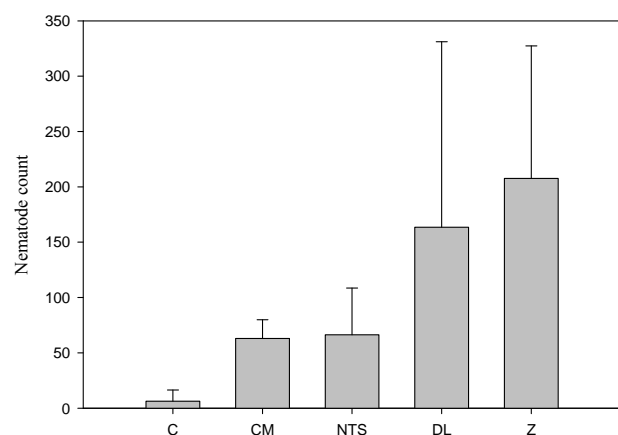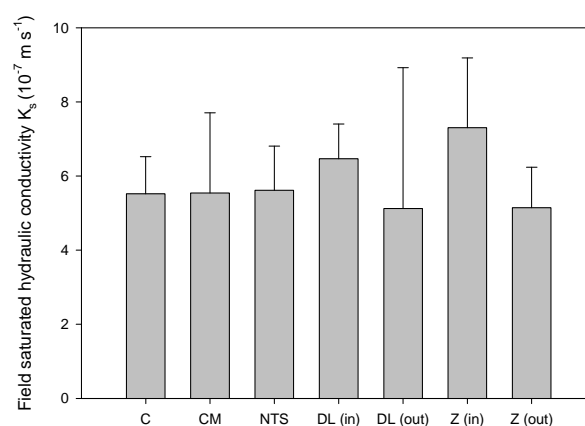
Infiltration

The hard, crusted soil limits infiltration greatly resulting in low values of saturated hydraulic conductivity (Ks) compared to typical values in the order of magnitude of 10^{-5} m s^{-1} for loamy sand soils (Radcliff and Rasmussen, 2001) (Fig. 2). The crust inside the water catchment area of Z and DL is, however, broken, which results in slightly higher Ks values. Bigger changes are expected in the future as the treatments and the manure are believed to enhance soil quality and improve infiltration capacity.

Evaporation

The Z treatment reduced cumulative evaporation during a 10 day drying cycle from 7.3 mm to 8 mm and to 6.6 mm compared to respectively DL and the other treatments. The lowest evaporation rate, however, occurred in the furrow of the NTS treatment, whereas evaporation inside the demi-lunes and the zaï-pits was greater than outside the catchment. Both observations are

Figure 1. Effect of WSC treatment on nematode count in 2011 (bar = average and line = standard deviation).
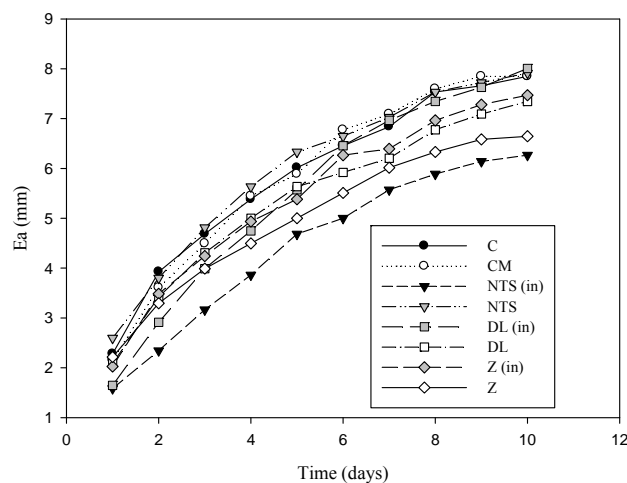

Figure 3 Effect of WSC treatment on actual evaporation rate in 2011. (in) represents values measured in the catchment and in the furrow of respectively DL, Z and NTS treatment.

explained by self-mulching behaviour, although it is most striking inside the NTS furrows, which quickly appeared as dry bands after rainfall.

CONCLUSIONS

First years' results show that improved nutrient management alone is not enough to ensure crop production. The synergistic effect of the supply of manure and the water-harvesting practices, on the other hand, does show promising potential to rehabilitate and to increase the agronomic efficiency of marginal land in Niger. The zaï technique thus far proves to posses the most suitable abilities to mitigate the limited total amount of rainfall and its uneven distribution in time. Nevertheless a thorough investigation on hydrological impact of the studied WSC techniques is needed to confirm if and how they use the limited available rainwater more efficiently. The evolution of the impact on soil physico-chemical and biologic characteristics in the coming years will moreover give further insight to their potential to restore encrusted 'laterite' soils.

REFERENCES

Adekalu, K. O., Balogun, J. A., Aluko, O. B., Okunade, D. A., Gowing, J. W. & Faborode, M. O. (2009) Runoff water harvesting for dry spell mitigation for cowpea in the savannah belt of Nigeria. *Agricultural Water Management,* 96, 1502-1508.

Amissah-Arthur, A., Mougenot, B. & Loireau, M. (2000) Assessing farmland dynamics and land degradation on sahelian landscapes using remotely sensed and socioeconomic data. *International Journal of Geographical Information Science,* 14, 583-599.

Boast, C. W. & Robertson, T. M. (1982) A micro-lysimeter method for determining evaporation from bare soil - description and laboratory evaluation. *Soil Science Society of America Journal,* 46, 689-696.

Boubacar, Y., Larwanou, M., Hassane, A. & Reij, C. (2005) Sahel study, Niger pilot study report.

De Graaff, J., Amsalu, A., Bodnar, F., Kessler, A., Posthumus, H. & Tenge, A. (2008) Factors influencing adoption and continued use of long-term soil and water conservation measures in five developing countries. *Applied Geography,* 28, 271-280.

Falkenmark, M., Fox, P., Personn, G. & Rockström, J. (2001) Water harvesting for upgrading of rainfed agriculture, problem analysis and research needs. IN Siwi (Ed.) *report 11.* Stockholm.

Fatondji, D., Martius, C., Bielders, C. L., Vlek, P. L. G., Bationo, A. & Gerard, B. (2007) *Effect of planting technique and amendment type on pearl millet yield, nutrient uptake, and water use on degraded land in Niger.*

Fatondji, D., Martius, C., Zougmore, R., Vlek, P. L. G., Bielders, C. L. & Koala, S. (2009) Decomposition of organic amendment and nutrient release under the zaï technique in the sahel. *Nutrient Cycling in Agroecosystems,* 85, 225-239.

Forzieri, G., Gardenti, M., Caparrini, F. & Castelli, F. (2008) A methodology for the pre-selection of suitable sites for surface and underground small dams in arid areas: A case study in the region of kidal, Mali. *Physics and Chemistry of the Earth,* 33, 74-85.

Logsdon, S. D. & Jaynes, D. B. (1993) Methodology for determining hydraulic conductivity with tension infiltrometers. *Soil Science Society of America Journal,* 57, 1426-1431.

Radcliff, D. E. & Rasmussen, T. C. (2001) Soil water movement. IN Warrick, A. W. (Ed.) *Soil physics companion.* CRC Press LLC.

Rockstrom, J. (1999) On-farm green water estimates as a tool for increased food production in water scarce regions. *Physics and Chemistry of the Earth Part B-Hydrology Oceans and Atmosphere,* 24, 375-383.

Roose, E., Dugué, P. & Rodriguez, L. (1992) La c.C.E.S. Une nouvelle strategie de lutte anti-erosive appliquee a l'amenagement de terroirs en zonde soudano-sahellienne du burkina faso. *Revue Bois et Forêts des Tropiques,* 233, 49-62.

Roose, E., Kabore, V. & Guenat, C. (1999) Zai practice: A west african traditional rehabilitation system for semiarid degraded lands, a case study in Burkina Faso. *Arid Soil Research and Rehabilitation,* 13, 343-355.

Sawadogo, H., Bock, L., Lacroix, D. & Zombre, N. P. (2008) Restoring soil potentialities using zaï and compost in yatenga (Burkina Faso). *Biotechnologie Agronomie Societe Et Environnement,* 12, 279-290.

Sidibe, A. (2005) Farm-level adoption of soil and water conservation techniques in northern Burkina Faso. *Agricultural Water Management,* 71, 211-224.

Slingerland, M. A. & Stork, V. E. (2000) Determinants of the practice of zai and mulching in north burkina faso. *Journal of Sustainable Agriculture,* 16, 53-76.

Stroosnijder, L. (2009) Field method to determine the soil evaporability factor ß Wageningen University.

Tabor, J. A. (1995) Improving crop yields in the sahel by means of water-harvesting. *Journal of Arid Environments,* 30, 83-106.

Tenge, A. J., Okoba, B. O. & Sterk, G. (2007) Participatory soil and water conservation planning using a financial analysis tool in the west usambara highlands of Tanzania. *Land Degradation & Development,* 18, 321-337.

Verbist, K., Baetens, J., Cornelis, W. M., Gabriels, D., Torres, C. & Soto, G. (2009) Hydraulic conductivity as influenced by stoniness in degraded drylands of chile. *Soil Science Society of America Journal,* 73, 471-484.

Zougmore, R., Zida, Z. & Kambou, N. F. (2003) Role of nutrient amendments in the success of half-moon soil and water conservation practice in semiarid Burkina Faso. *Soil & Tillage Research,* 71, 143-149