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Abstract

Soils of Tropical Africa have been formed mainly from Pre-Cambrian materials and others from erosion process. Because of the type of parent material, the soils are characterized by a poor native fertility surface crusting and low water holding capacity.

In Africa 65% of the agricultural land, 31% of the permanent pasture land, and 19% of the forest and woodland is affected by human-induced soil degradation. The nutrient depletion is the most important element in the land degradation equation.

With increasing population pressure on the land, the traditional farming system (natural fallow) to restore soil fertility is no longer possible. The present farming systems are unsustainable and destructive to the environment with negative plant nutrient balances resulting to a mining agriculture.

Many long term trials show that although application of mineral fertilizers is an effective mean of increasing yields in arable farming systems, mineral fertilizers alone cannot sustain yields in the long run. When mineral fertilizers are combined with crop residue or manure, added to cereal-legume intercropped or rotated, sustainable production can be obtained.

Any future interventions redressing distorted nutrient budgets, to be sustainable have to develop an integrated nutrient management, conceptualized as the judicious manipulation of the nutrient inputs and outputs processes.

Chapter 6
Long-Term Soil Fertility Trials in Niger, West Africa

Adamou Abdou, Saidou Koala, and Andre Bationo

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Key words: mineral fertilizer, Crop residue, manure, cropping system, soil fertility, long-term trial

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Introduction

Soil degradation, loss of organic matter, low soil fertility and yields, poverty, high CO2, global climatic changes are the main factors reducing crop production in the world. In the Sahel, low rainfall and its variability and distribution, dry spells and other adversities such as climatic factors affecting the rainy season affect crop production. Production losses are mainly due to drought (2/3) and cricket attack (1/3) (Nanga 2005). Water balance in the region is positive only 3 months of the year; meaning that water still a limitative factor for crop production in a region where 90% of the population is rural and depend on a subsidence rainfall agriculture. Millet is the main crop in CILSS countries with 45% of cereal production followed by sorghum (28%) and maize (11%). Niger is the second after Burkina Faso with 27% of cereal production. Niger, with a population of 12.94 millions in 2006, is one of the food deficit countries in the world (CILSS/Agrhymet 2005). Only 12% of the country has an annual rainfall of 600 mm and 10% with 350–600 mm. Cereal crop needs at least 300 mm if well distributed (Moustapha 2003). Cereal production in 2004/2005 was estimated to 2,449,900 tones with a negative balance of 223,350 tones, equivalent to 7.5% of Niger population needs or 2,991,600 tones (Nanga 2005). Niger is the poorest country in the world according to the UNDP classification based on IDH. 98% of the cereal production in Niger is from rainwater; rice that is the principal irrigated crop is less than 2% of the total cereal production. It depends to rainfall and in 2004, rice production decreased to only 0.5% of cereal production (FAO 2004).

Population pressure has reduced cultivable area and traditional fallow is no longer feasible. It's known that millet is a crop adapted to Sahel conditions but combined to soil fertility constraints; low rainfall can reduce crop productivity. In this context of soil degradation and poor climatic conditions, farmer's practice is not adapted. ICRISAT research is to find and propose to farmers adapted soil fertility technologies, water use efficiency and adapted varieties which combinations can significantly improve crops yields.

This study is to improve natural resources management in these poor soils and weather conditions. Soil nutrients such as phosphorus, nitrogen, manure in an erratic rainfall conditions are shown in the study on a long term basis.

Experiments addressing several research themes were carried out along a bioclimatic gradient at several benchmark locations in West Africa using commonly developed research protocols. The long-term on-station trials from which originated the technologies tested on-farm continued to run with the objective of identifying sustainability indicators and optimizing the use of organic and inorganic resources available to the land users. Soil samples from the long-term trials were collected for measurement of these parameters.

Since 2000, these long-term on-station trials and others in different sites were run under TSBF Network collaboration with ICRISAT with a challenge to help empower farmers and land managers to combat soil nutrient depletion and land degradation, which are both serious threats to food production on the continent.

The objective of these network activities is to develop and implement management options that both mitigate soil degradation, deforestation and biological resources losses and enhance local economies while protecting the natural resource base.

This document will first give the highlights of the longest on-station trials run by TSBF Network in Niger, West Africa. The second part will give a brief description of other trials from different locations. The results of these experiments are reported every year in an annual report.

Long-Term Millet Trials Phosphorus, Nitrogen, Crop Residue (CR), Manure and Soil Tillage

Fields close to the village receiving high organic matter due to human and animal activities are more productive compared to the others. Prudencio (1993) have observed such fertility gradient between fields closest to the homestead (home gardens/infields) and those furthest (bush fields/outfields). Soil organic carbon contents of between 11 and 22 g/kg have been observed in home gardens compared with 2–5 g/kg soil in bush fields. Fofana et al. (2006) in a comparative study at Karabédji-Niger on degraded lands (bush fields) and non degraded (infields) have observed that millet grain yield across years and fertilizer averaged only 800 kg/ha in bush fields and 1,360 kg/ha on infields. Recovery of fertilizer N (RFN) applied varied considerably and ranged from 17% to 23% on bush fields and from 34% to 37% on infields. Similarly, recovery of fertilizer P (RFP) was 18% for bush fields and 31% for infields over 3 years cropping. It's clear that degraded soils are poor in organic carbon their response to fertilizer are less and the recovery of fertilizer applied is very low. Soil degradation was defined by FAO (2002) as the loss of soil productivity capacity in term of decreased fertility, biodiversity and natural resources. Yield loss due to soil degradation in Africa varied from 2% to 50% the last 10 years [AU3] [AU4] (Scherr 1999). Bationo et al. (2006a, ~~b~~) in Scherr (1999) and in Oldeman et al. (1992) in a description of the level of degradation of arable soils in Africa and in the rest of the world have shown a proportion of 38% in the world and 65% in Africa. During the last 30 years, nutrients losses in Africa soils are equivalent to 1.400 kg/ha N (urea), 375 kg/ha of SSP (phosphorus) and 896 kg/ha of KCl (potassium). In Niger, Henao and Baanante (2006) have estimated nutrients losses to 56 kg/ha (NPK) during 2002–2004 cropping season.

Long term average of millet and sorghum grain yields are respectively 400 and 190 kg/ha; but in 2002 and 2003 with respective cereal production 3,336,956 and 3,561,660 tones in Niger, average millet and sorghum grain yields were respectively 461 and 476 kg/ha (FAO 2004). Research at ICRISAT (rapport annuel 1985) have shown that in the semi-arids zones of the Sahel where annual rainfall is over 300 mm, nutrients are more limitative than water in crop production. At Sadore (Niger), with 560 mm of annual rainfall, 1.24 kg of millet grain per mm of water was harvested without fertilizer and 4.14 kg of millet grain per mm of water when fertilizer was used (Bationo et al. 2006a, b).

Table 6.1 Long-term on-station trials at Sadore, Niger, West Africa

Type of trials	Site	Starting date	End
Long-term operational scale research	Sadore	1986	On-going
Long-term cropping system	Sadore	1993	On-going
Long-term crop residue management	Sadore	1982	On-going

In Oumou and Ed Heinemann (2006), Africa account for only 3% in the world fertilizer consumption with 13% of world arable soils and 12% of world population. Sub-saharan Africa (excluding South Africa) account for less than 1% in the world fertilizer consumption equivalent to 9 kg/ha compared Asia 148 kg/ha and Pacific. In 2002, fertilizer consumption in Niger was 1.1 kg/ha only; and one tone of fertilizer cost 400 $ compared to 90 $ in Europe whereas a Nigerien is living with less than 1 $ per day making fertilizer less affordable.

If fertilizer is affordable for farmers, the hill placement of small quantity (4 kg P/ha) can double millet grain yield. Tabo et al. (2006) have shown that micro-dose (4 kg P/ha) increased millet and sorghum grain yields up to 43–120% and farmer's income were improved trough Warrantage by 52–134% in the studied countries (Burkina Faso, Mali et Niger) (Table 6.1).

Long-Term Management of Phosphorus, Nitrogen, Crop Residue, Soil Tillage and Crop Rotation in the Sahel

Since 1986 a long-term soil fertility management was established by ICRISAT Sahelian Center to study the sustainability of pearl millet based cropping systems in relation to management of N, P, and crop residue, rotation of cereal with cowpea and soil tillage. The data in Table 6.2 give the main treatments in this trial. In this split-split-plot design the split-split plot consisted of crop residue application or no crop residue application consisting of leaving half of the total crop residue produced in the plot and the sub-sub plot was with or without nitrogen application. Four replications are used in this experiment.

Results

Very low yields were observed on control plots in both grain and TDM yields. The other treatments show high yields with better yield for T7 and T9 combining rotation, phosphorus and respectively animal traction (AT) and hand cultivation (HC) (Fig. 6.1). [AU5]

Nitrogen effect is similar on both grain and TDM yields showing better yield on plot receiving N. But when annual rainfall was combined to yields, the higher TDM yield was observed with the higher annual rainfall; whereas millet grain was not

Table 6.2 Network collaborative trials indifferent sites in Niger (West Africa), 1999–2008

Type of trials	Site	Started	End
On-farm evaluation of cropping systems technologies	Sadore Karabedji Gaya	2003	Ongoing
Placement of phosphorus and manure	Karabedji	1999	Ongoing
Placement of phosphorus and PUE	Karabedji	2000	Ongoing
On-farm evaluation of cropping systems technologies, KKM project	Maradi	2008	Ongoing
On-farm evaluation of soil fertility restoration technologies	Karabedji Gaya	1999	Ongoing
Comparative effect of mineral fertilizers on degraded and non degraded soils	Karabedji	1999	Ongoing
Fertilizer equivalency and optimum combination of low quality organic and inorganic plant nutrients	Banizoumbou Karabedji Gaya	2001	Ongoing
Optimum combination of phosphate rock and inorganic plant nutrients	Banizoumbou, Gaya Karabedji, Sadore	2005	Ongoing
Corral experiment (demonstration)	Sadore	1988	Ongoing

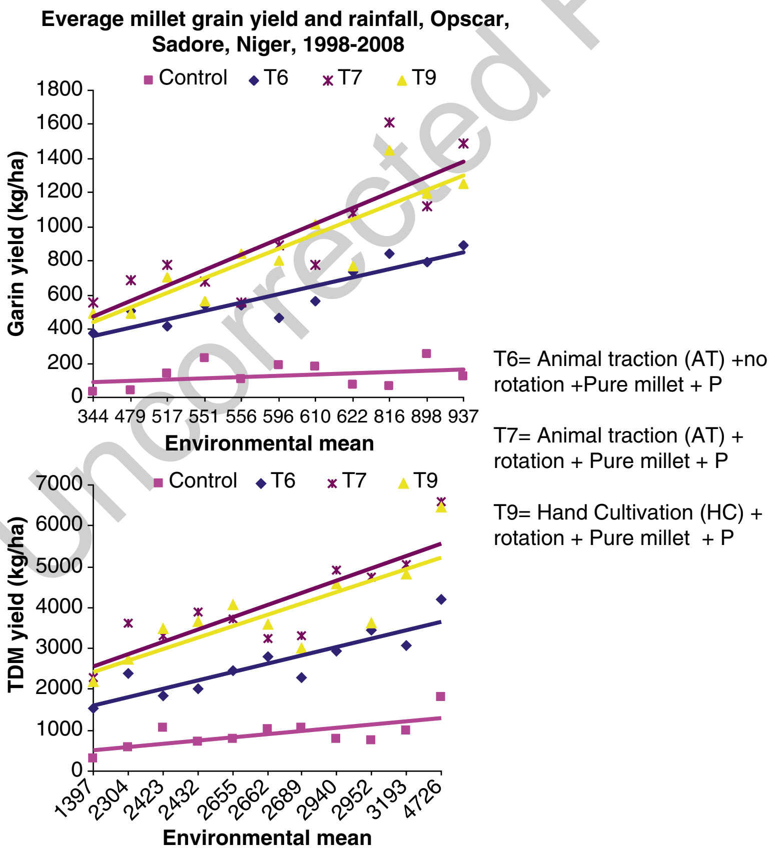


Fig. 6.1 Environmental mean on pearl millet grain and TDM yields under some technologies, Sadore, Niger, 1998–2008

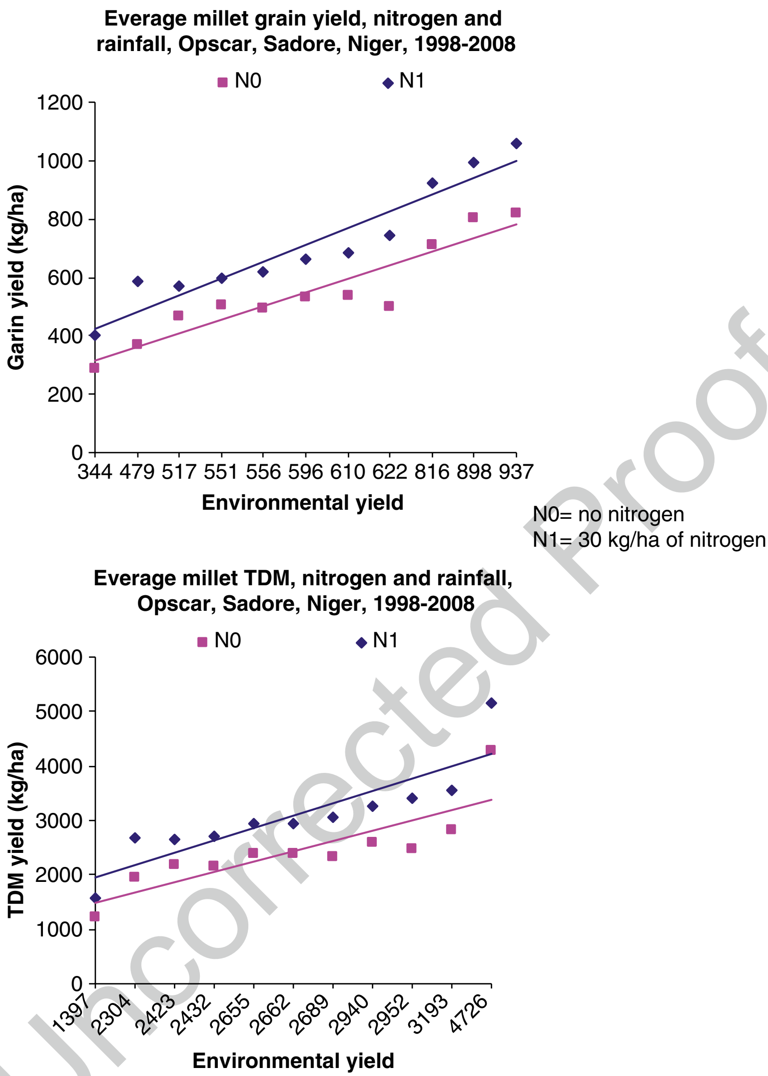


Fig. 6.2 Environmental mean on pearl millet grain and TDM yields under nitrogen use, Sadore, Niger, 1998–2008

subjected to higher rainfall. It shows that plant growth was better when nutrient and rainfall are combined; but grain production was subjected to other factors than annual rainfall only (Fig. 6.2).

Crop Residue (CR) effect was similar to N effect showing an increased yield when CR was applied. The higher TDM yield was also obtained with higher annual rainfall but grain yield doesn't follow the same trend (Fig. 6.3).

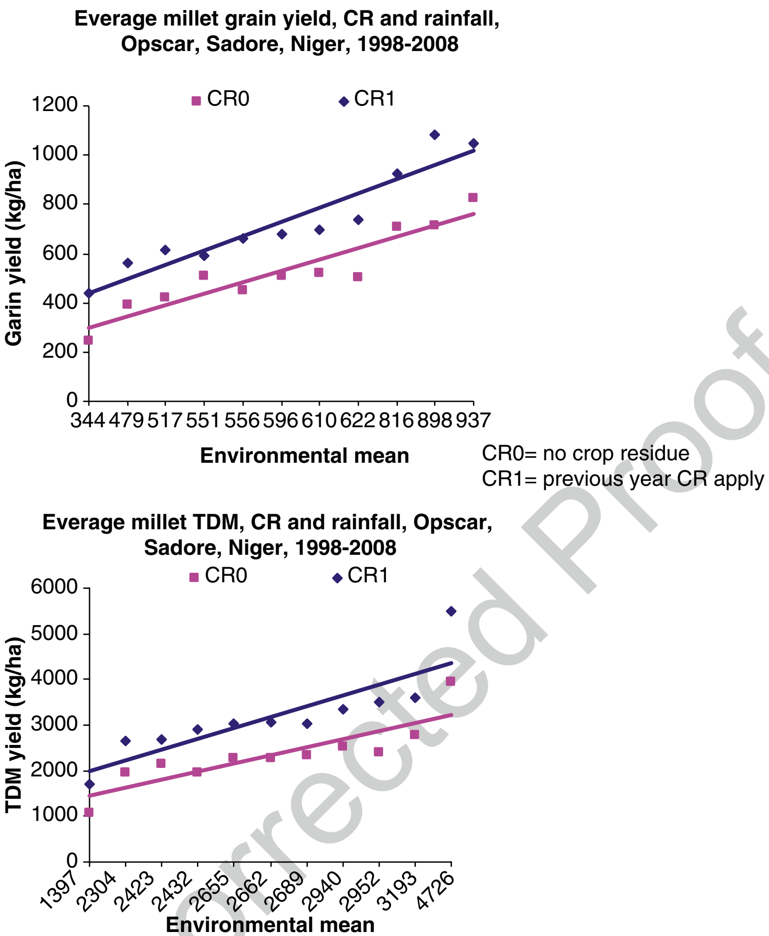


Fig. 6.3 Environmental mean on pearl millet grain and TDM yields under Crop Residue (CR) use, Sadore, Niger, 1998–2008

Long-Term Management of Manure, Crop Residues and Fertilizers in Different Cropping Systems

Since 1993 a factorial experiment was initiated at the research station of ICRISAT Sahelian Center at Sadore, Niger. The first factor was three levels of fertilizers (0, 4.4 kg P + 15 kg N/ha, 13 kg P + 45 kg N/ha), the second factor was crop residue applied at (300, 900 and 2,700 kg/ha) and the third factor was manure applied at (300, 900 and 2,700 kg/ha). The cropping systems are continuous pearl millet, pearl millet in rotation with cowpea and pearl millet in association with cowpea. Three replications were used for this experiment.

Results

Cropping systems have shown a good performance of rotation compared to the two other systems in both grain and TDM yields and during the whole period. There is no correlation between annual rainfall and millet grain and TDM production. The last 2 years were showing low yields whereas their annual rainfall were similar or higher than other years (Fig. 6.4).

Although there is no significant difference between the different rates of CR, the higher yield was obtained with 2,700 kg/ha of CR. Annual rainfall was not correlated again to millet grain and TDM yields (Fig. 6.5).

Manure application shows a large difference of millet grain and TDM yields with high yield for 2,700 kg/ha of manure. No correlation between annual rainfall and millet production; each factor varying independently (Fig. 6.6).

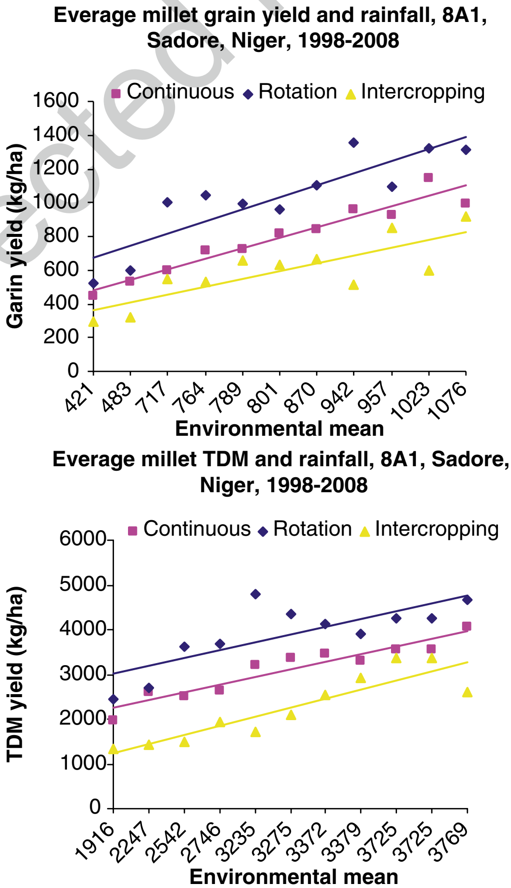


Fig. 6.4 Environmental mean on pearl millet grain and TDM yields under different cropping systems, Sadore, Niger, 1998–2008

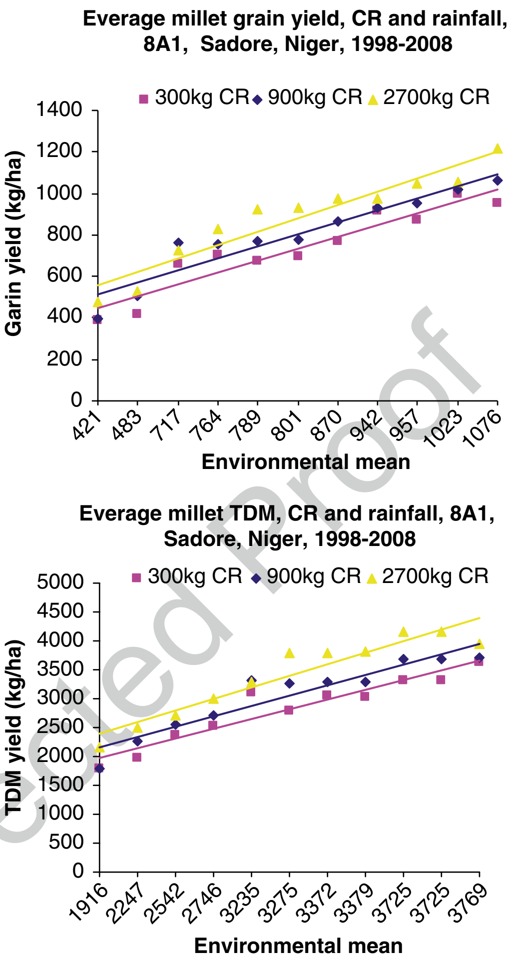


Fig. 6.5 Environmental mean on pearl millet grain and TDM yields under different rates of CR, Sadore, Niger, 1998–2008

The uses of fertilizer have shown a very large difference between the control and the plot receiving P and N with a very high yields for the high rate. It’s clear that N and P application have increased millet grain and TDM yield independently to the annual rainfall (Fig. 6.7).

Long-Term Crop Residue (CR) Management

This crop residue (CR) trial established since 1982 show a large cumulative effect on the soil (organic carbon, protection against erosion…) over these years. Four replications and four treatments consisting to: traditional, sole application of CR, sole application of fertilizer (F) and CR+F. Each plot was split-plot to include rotation with half cowpea and half millet rotated every year. CR application consisted to leave the previous year millet Stover in the plot.

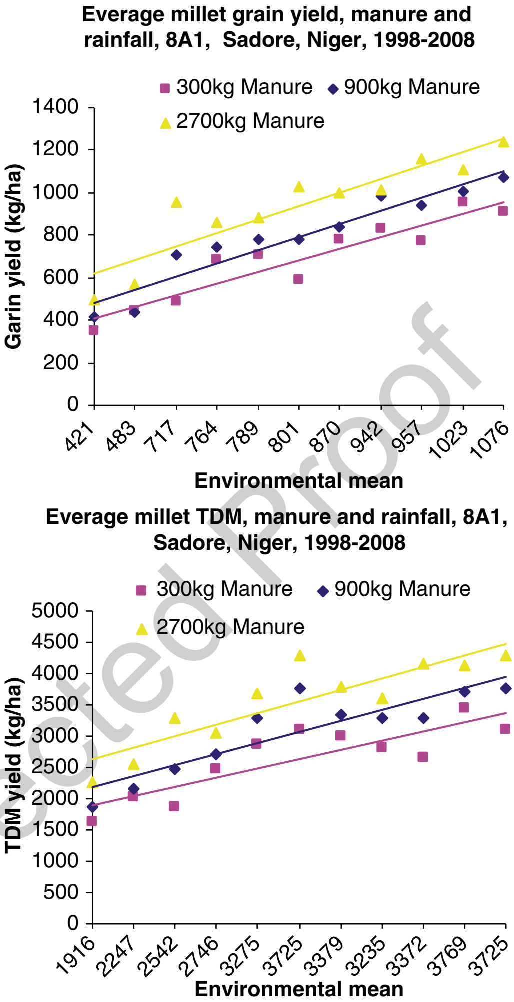


Fig. 6.6 Environmental mean on pearl millet grain and TDM yields under different rates of manure, Sadore, Niger, 1998–2008

Results

Data collected from 1984 to 2007 shows a significant difference between treatments. Yields in the control plot still low every year whereas Fertilizer + CR gave the higher yield and intermediary yield for the two other treatments: Figs. 6.8 and 6.9.

Rainfall significance was shown in multiple ways: better rainfall was supposed to give better yields. It's not always the case, different situations were observed while combining yields and annual rainfall. With the lowest environmental mean of millet grain: 324 and 296 kg/ha respectively in 1993 and 2003, the corresponding rainfall were not very low: 541.7 and 534.3 mm but enough for a good production

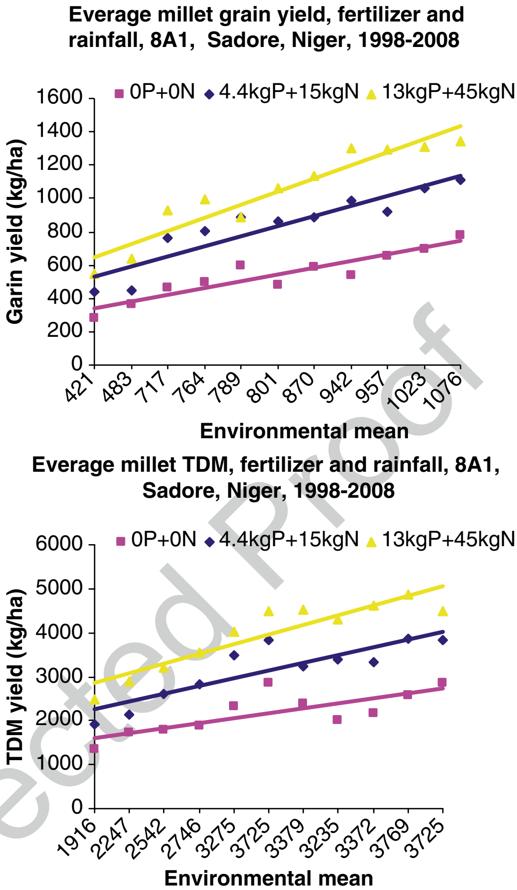


Fig. 6.7 Environmental mean on pearl millet grain and TDM yields under different rates of fertilizer, Sadore, Niger, 1998–2008

as in 1996 where a similar rainfall (543.9 mm) gave 1,362 kg/ha of grain. The worst annual rainfall was recorded in 2000 with 392.7 mm but millet grain yield was 753 kg/ha. In 1994 millet TDM yield was very low: 2,514 kg/ha with exceptional annual rainfall of 793.8 mm. It's clear that other internal factors such as rainfall repartition and drought spell affect more crop production than cumulative rainfall only. A survey on the daily rainfall demonstrated that when a contradiction occurred on the relation between annual rainfall and crop production, some explication can be found in its repartition.

For example the good yield in 1996 was related to a very good repartition although the annual rainfall was only 543.9 compared to 1994 where annual rainfall was 793.8. Similarly, the bad repartition of the same amount of annual rainfall gave very low yields in 1993 and 2003. The drought spells that occurred during the grain filling period affected more grain yield and those in the plant growth period affected more TDM yield.

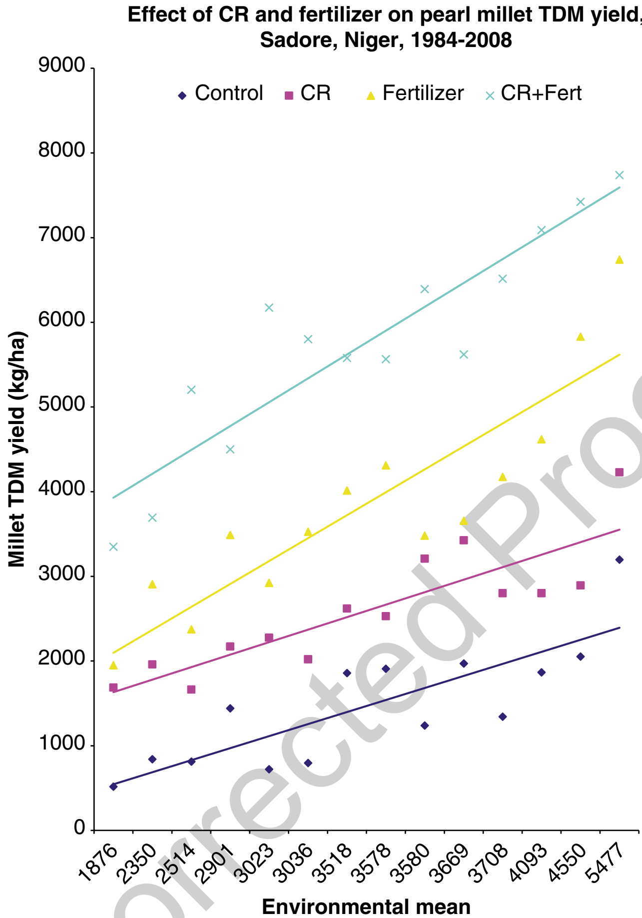


Fig. 6.8 Environmental mean on pearl millet TDM yield under CR and fertilizer uses, Sadore, Niger, 1984–2008

Other Trials in Different Sites

1. **Placement of phosphorus and manure (karabedji, Niger)**
   A complete factorial experiment was carried out with three levels of manure (0, 3, 6 t/ha) three level of P (0, 6.5 and 13 kg/P ha) using two methods of application (broadcast and hill placement).

   The data collected give the response of millet to P and manure for the two methods of application. For pearl millet grain the hill placement of manure performed better than broadcasting and with no application of P fertilizer.

   The data for cowpea are showing also the same effect as for pearl millet. A very high yield of cowpea fodder can be produced with hill placement of

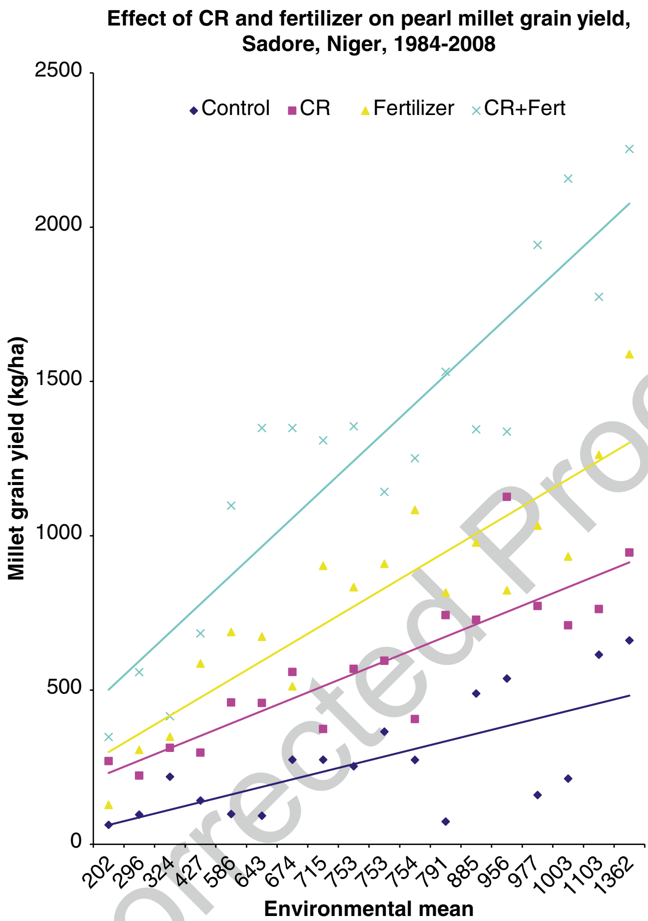


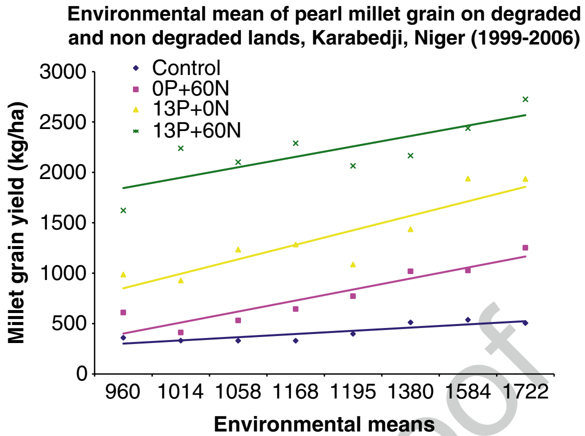
Fig. 6.9 Environmental mean on pearl millet grain yield under CR and fertilizer uses, Sadore, Niger, 1984–2008

manure and by the way using it for feeding animals can delay the difficult affordability of manure.

2. **Placement of phosphorus and PUE (Karabedji, Niger)**
   Phosphate Rock (PR) was broadcast (bc) and/or hill placed (HP). For pearl millet grain P use efficiency for broadcasting SSP at 13 kg P/ha was low but hill placement of SSP at 4 kg P/ha gave a higher PUE. It also increased when NPK hill placed at 4 kg P/ha was combined to PR broadcast. For cowpea fodder PUE was also better with P hill placed. Those data clearly indicate that P placement can drastically increase P use efficiency and the placement of small quantities of water-soluble P fertilizers can also improve the effectiveness of phosphate rock.

3. **Farmer's evaluation of soil fertility restoration technologies (Karabedji and Gaya, Niger)**
Past research results indicated a very attractive technology consisting of hill placement of small quantities of P fertilizers. With DAP containing 46% P2O5 and a compound NPK fertilizer (15-15-15) containing only 15% P2O5, fields trials were carried out by farmers on 46 plot per treatment at Karabedji to compare the economic advantage of the two sources of P for millet production. As hill placement can result in soil P mining another treatment was added consisting of application of phosphate rock at 13 kg P/ha plus hill placement of 4 kg P/ha as NPK compound fertilizers.
The data clearly shows that there was no difference between hill placement of DAP and 15-15-15 indicating that with the low cost per unit of P associated with DAP, this source of fertilizer should be recommended to farmers. The basal application of Tahoua Phosphate rock gave about additional 200 kg/ha of pearl millet grain. The combination of hill placement of water-soluble P fertilizer with phosphate rock seems a very attractive option for the resource poor farmers in this region. The data is showing the variation of yield of each plot in farmers fields as compared to the farmer's practices and clearly shows that the application of Tahoua PR with hill placement of water soluble P outperformed the other treatments in most instances.
At Gaya, with 50 plots per treatment the same effect can be observed and DAP seem better than NPK and confirm the choice on this source.
4. **Cropping systems and mineral fertilizers evaluation (Sadore, Karabedji, and Gaya, Niger)**
Farmers' practices were compared to a three cropping systems consistency on pure millet crop with planting density at recommended level to be rotated next year with a pure cowpea, a fourth plot with millet and cowpea intercropped but not as farmer's practice. Here four lines of cowpea are to be rotated with two lines of millet. Tahoua Phosphate rock at 13 kg P/ha and NPK hill placed at 4 kg P/ha were applied for each plot except farmer's practice.
The data indicates that millet grain yield can be increased two to three fold with this system and higher biomass can be yielded specially for cowpea introducing crop-livestock integration. The same trial was implemented at Karabedji and gave a similar effect as Sadore. At Gaya, cowpea was replaced by groundnut due to the lake of grain production some particular years. These data shows how the yield of the technologies evaluated fluctuated as compared to the farmers' practices with the high density and rotation systems dominating the other systems in most instances.
5. **Combining PR and inorganic plant nutrients for millet and cowpea production (karabedji, Banizoumbou, Sadore and Gaya, Niger)**
The data indicate the comparative advantage to combine PR and inorganic plant nutrients for the low suffering soils in the Sahel. Although the experiment started later than the others (2005), the sole application of inorganic or

Fig. 6.10 Environmental mean of pearl millet grain on degraded and non degraded lands, Karabedji, Niger (1999–2006)



PR P sources gave approximately the same yields in both millet grain and cowpea fodder while the combination of PR (50%) and inorganic P (50%) gave better yield.

6. **Interaction of N, P and manure (karabedji, Banizoumbou and Gaya Niger)** A factorial experiment of manure (0, 2 and 4 t/ha), nitrogen (0, 30 and 60 kg N/ha) and phosphorus (0, 6.5 and 13 kg P/ha) was established in the three sites to assess the fertilizer equivalency of manure for N and P. The data shows a very significant effect of N, P and manure on pearl millet yield. But everywhere the analysis demonstrated that P is the most limiting factors. Manure and nitrogen accounted less in the system and their effect were better when combined with P.
7. **Comparative effect of mineral fertilizer on degraded and non-degraded soils (Karabedji, Niger)** This is also a long-term soil fertility managed trial as started in 1999 and still running. Mineral fertilizers were applied on two major type of soils: Farm close the village (non-degraded) where household waste, human excreta and farm yard manure are commonly used and farm far from the village degraded and without any organic material added. The results show a high significant effect of the application of Phosphorus on pearl millet grain and total dry matter yields. P significance is higher but nitrogen significance is linked to the availability of P or organic fertilizer in the soil. The system (degraded and non-degraded) shows a very high significance meaning that organic fertilizers are important. The data show that the application of P increased significantly both millet grain and total dry matter yields and it is more important in fertile soils where it is combined with organic fertilizer. Nitrogen alone gives no significance but when combined with P the result is clear (Figs. 6.10 and 6.11).

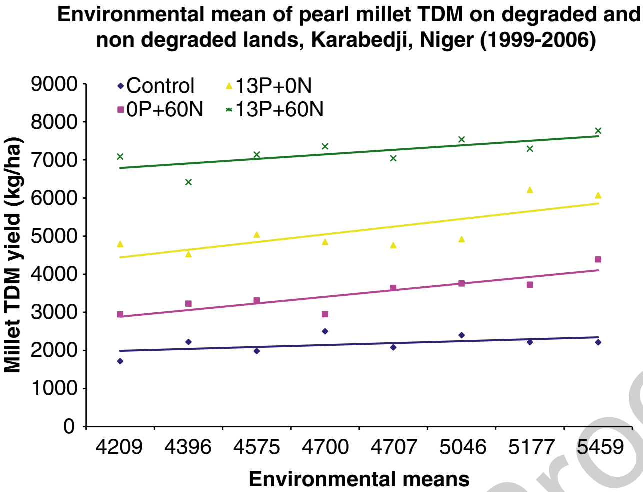


Fig. 6.11 Environmental mean of pearl millet TDM on degraded and non degraded lands, Karabedji, Niger (1999–2006)

Conclusion

The different soil fertility technologies tested in the different experiments and sites have improved the millet grain and TDM yields. Results have shown that the yield in the control plot is always lower than the environmental mean while improved technologies gave higher yields. Both organic and inorganic amendments have increased millet production but their effects were different from a year to another. Organic amendment performance was lower than inorganic but their combination was better.

Cropping systems experimented have shown a very good performance for the rotation where the previous leguminous crop gives additional nitrogen and organic amendment to the soil.

The annual rainfall and yields variations were not correlated meaning that factors other than rainfall have affected millet production. The illustration was made in 2007 where millet was planted in July 14th and rain stopped in September 14th. The poorest environmental mean was observed this year with only 2 month of rain while millet cycle was at least 3 month. In most of the cases that yields were low, rain stopped early or long drought spell occurred during the cropping season. The performance of the technologies tested will be better if these negative factors were addressed.

All data presented here were yields data; some soil samples were periodically took but no analysis was made due to budget constraint. If soil analysis was done, it could help in following soil fertility status.

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