Abstract

An experiment conducted in farmers’ fields during two consecutive years was comparing sowing crops on simple ridging (one local technique of soil tillage in the area of the study) to sowing crops in half-moon (an innovative technique) to see their effects on the intercropping system performance and on the rain water use efficiency (RWUE). The slope of experiment fields all located on abandoned land for decades, was less than 3%. Experiment was conducted in the field of 12 collaborating farmers in a dispersed Fischer block lay out where each farmer was representing one replication. Crop yield and decade rainfall amount were recorded in each site. Data analysis has shown the good yield of sorghum-cowpea intercropping in half moon. Crop management and rainfall distribution were the causes of bad performance of crops sown on simple ridging. Rain water use efficiency was the best in the half moon cropping system. In conclusion, the proposed alternative cropping system is involving intercropping in half moon and the application of mineral fertilizer microdose to improved varieties. This allows the use of abandoned land. The use of cowpea one grain legume crop in the system allows improving farmer income and stimulating the use of mineral fertilizer in sorghum cropping.

Keywords

Farmer
Half-moon
Simple ridging
Water use efficiency

Introduction

Mali covers an area of 1.241 million km² and extends between the 10th and 25th degree of north latitude, between 4th degree longitude east and 12th degree west longitude. It has a population of 14,528,662 which increases at a rate of 3.6% / year (INSTAT, 2011). With such a rate, the population will double every 20 years with a constantly increasing food demand. This development is not without adverse consequences on natural resources. In traditional shifting agriculture, it will require more land, water, fertilizer, labor. These
various resources are not inexhaustible because the limits of village agricultural soils are known. Rainfed agriculture is central to food production in sub-Saharan Africa (Cooper and Al, 2008). The rainfall of the study area varies between 300 and 1000 mm and is characterized by great inter-annual variability and poor distribution in space. The length of the growing season varies between 75 and 120 days (Sivakumar, 1991). In Mali, cropland is poor in nutrients necessary for good plant growth (Van Der Pool, 1992). The average yield of millet and sorghum is 600 kg of grain/ha. But the cereal balance of the 2006/2007 crop year showed a cereal surplus of 613,000 tons of cereals combined (Ministry of Agriculture, 2008). The maintenance of such a cereal surplus is not without its problems. Continuous land use, runoff and erosion create differences in fertility within and between cropping areas (Penning De Vries and Djitéye, 1982). The combination of rainfall and low fertility factors in cropland is reflected in the yield variability of the major crops (millet, sorghum, cowpea and maize) of small-scale producers from one year to the next.

It is therefore necessary to look for cropping systems that increase the production of smallholder farmers through the efficient use of available resources at the level of their farms. The association of cultures is a system of cultivation widely practiced by peasants. It provides farmers with agronomic, economic benefits and increases the efficient use of resources. The cultivation of more than one species of plant simultaneously in the same field during the same growing season is a means of sustainable production improvement (Baldy, 1963). But a combination of this system with soil and water conservation techniques appears to give more sustainability to the production of the system.

Our working hypothesis is that the combination of crop association and water conservation techniques in the field would improve crop yield, peasant income and efficient use of rainwater. The objective of this research is to evaluate different techniques of tillage, the agronomic effects and the productivity of sorghum-cowpea association, and the effects of this association on the efficient use of rainwater (RWUE: rain water use efficiency).

**Materials and methods**

To undertake this experimentation among farmers, the Institute for Rural Economy, the research institution for the IDRC-funded Integrated Water and Nutrient Management for Sustainable Agricultural Production in the Sahel project, Developed a partnership with NGOs (1) Grassroots Research and Community Development Assistance Group (GRAADECOM) in Sikasso in the south, (2) Mali Association for the Promotion of the Sahel (AMAPROS) in Ségou in The center and (3) SAHEL21 of Didiéni in the north (see Fig. 1). These NGOs were responsible for the identification of collaborating farmers and experimental sites in their respective areas of intervention and labor logistics.

![Fig. 1: Area of experiment in Mali (Source : LABOSEP of Sotuba, 2000).](image-url)
The experimental site

Experimentation was carried out in three agro-climatic zones and the experimental villages received average rainfall of two years (Fig. 1). The village of Siellé in the Sahelian zone, supervised by the NGO SAHELE21, received an average 452 mm of rain in 32 days (Fig. 2).

The village of Ntogosso in the southern limit of the Sahelian zone, which is supervised by the NGO AMAPROS, received an average height of 465 mm of rain/year in 40 days (Fig. 3). The village of Siramana in the Sudanian zone supervised by the NGO GRAADECOM had an average rainfall of 975 mm/year in 62 days (Fig. 4). In the three sites, the agricultural campaigns were characterized by droughts at the end of the cycle of vegetation.

Plant varieties used

The varieties used in sub-block I of the experiment were sorghum CSM388 and cowpea Sankaranke all of late cycle (100 to 120 days) in Siramana in the rainier southern zone, sorghum Jakumbè and cowpea Korobalen all of early cycle (90 to 100 days) in the Sahelian zones of NTogosso and Siellé. The improved varieties came from the Institute of Rural Economy. In sub-block II (under control block), local varieties of sorghum and cowpea were used.

Experimental apparatus

The experimental device was a dispersed Fischer block where each farmer represented a repetition. The block was divided into two sub-blocks of three treatments each (pure sorghum crop, pure cowpea crop and the sorghum-cowpea crop combination). The elementary parcel was 14 m × 8 m on the side. Experimentation was carried out in 12 collaborating peasants (4 in Siellé, 4 in Siramana and 4 in NTogosso). In the improved system block (T1, T2 and T3), crops were sown in the half-moon made at the beginning of the rainy season.

In the T1 (pure sorghum crop), sorghum was sown at 0.75 m × 0.5 m and split at 2 plants/pole. The half moon has 4 rows of seedlings and has 42 pockets of sorghum i.e., 126 pits/elementary plot and 11,250 pods/ha. The DAP was supplied at a rate of 2 g/pit, 252 g/elementary plot and 22.5 kg/ha.

In T2 (pure cowpea crop), cowpea is sown at 0.75 m × 0.5 m and split at 2 plants/pocket. The half moon has 4 rows of seedlings, 42 cowpea pits, i.e., 126 pits/elementary plot and 11,250 pods/ha. The DAP was supplied at a rate of 2 g/pit, 252 g/elementary plot and 22.5 kg/ha.

In the T3 (sorghum-cowpea crop association), sorghum is sown at 0.75 m × 0.5 m and split at 2 plants/pole. In the half moon, there were 4 seed lines with 42 pockets of sorghum (126 pairs/elementary plot per hectare 11,250 pairs and 22,500 plants). At a rate of 2 g/pound, sorghum received 22.5 kg of DAP/ha. Cowpea was sown in each second row of sorghum. There were 1 m between pockets on the line and 1.5 m between lines. In the plot, there are 21 cowpea pits (63 pockets/plot per hectare 5,625 pockets and 11,250 plants). The cowpea received 11.25 kg of DAP/ha at the rate of 2 g/pit.
In the control block (T4, T5 and T6), the crops were planted on a simple trenching of the crop season. There were 11 rows of seedlings in each elementary plot. In pure cultivation, sorghum and cowpea were sown at a distance of 0.8 m between rows and 0.8 m on the line, and split at 2 plants per pole (15 625 pods/ha, i.e., 31,250 plants/ha). In the association, sorghum main crop was sown at its pure culture density (0.8 m × 0.8 m, started at 2 plants/pk). Cowpea was sown in each second inter-sorghum pitch (1.6m between pole and 1.6m between lines: 3,906 pods/ha and 7,812 plants/ha). The experimental design is shown in Fig. 5.

Planting was carried out during the second and third decades of July and harvests during the second and third decades of October. The input was made with Excel and the analysis of variance with the software INSTAT v3.6.

**Rain water use efficiency**

This variable measures the capacity of the cropping system to convert water into grain or plant biomass. It includes both the use of water stored in the soil and the rain received during the growing season (GRDC 2009). It is determined by the formula below:

\[
\text{Rain water use efficiency (RWUE)} = \frac{\text{Total yield of grain or biomass in kg}}{\text{Total rainfall height in mm}}
\]

**The Land Equivalent Ratio (LER)**

It makes it possible to evaluate the productivity of the associations in relation to the monocultures and is defined as the area necessary for each crop to produce in monoculture the same yield as one ha of the same crop in a system of association.

It is calculated as follows:

\[
\text{LER} = \frac{\text{Culture yield of A in combination}}{\text{Pure culture yield of A}} + \frac{\text{Crop yield of B in association}}{\text{Pure culture yield of B}}
\]

If the LER is <1, the culture association is not advantageous over the pure culture. If LER> 1: a larger area would be needed to produce the same amount of product when the plants are grown in monoculture compared to the associations. In such cases, the associations give better yields compared to the performance of the same crops in monoculture systems (Fairhurst, 2017).

**Results and discussion**

**Crop yield**

**Sorghum grain:** The yield of sorghum varied significantly between tillage techniques and between sites (Table 1). The best yield was obtained at Siramana with 1731.5 and 1012.5 kg of grain / ha respectively in the half-moon and single ridges. Sorghum benefits more from the micro-dose of fertilizer (2 g of DAP / pole at sowing) in the half-moon.

Compared to the half-moon, the sorghum-cowpea crop was grown on simple ridges prepared at the beginning of the crop season, resulting in yield reductions of sorghum grain of -102% at Siellé, -71% at Siramana and -44% in NTagosso.

**Grain of cowpea:** It is at Siramana where the best yields of cowpea grain have been recorded (831 and 362 kg / ha respectively in the half-moon and single ridges). The addition of 2 g of DAP / pellet to sowing
significantly improved the yield of cowpea in the half-moon. The shift from single crop cultivation to single-row crops resulted in yield reductions of -44% at Siellé, -229% at Siramana and -174% at NTogosso (Table 2).

### Table 1. Yield of sorghum grain in sorghum-cowpea association in peasant fields, Mali

<table>
<thead>
<tr>
<th>Villages</th>
<th>In the half moon</th>
<th>In simple ridging</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2011 (**), 2012 (*)</td>
<td>Average</td>
</tr>
<tr>
<td>Siellé</td>
<td>1100</td>
<td>1325</td>
</tr>
<tr>
<td>Siramana</td>
<td>1825</td>
<td>1638</td>
</tr>
<tr>
<td>NTogosso</td>
<td>625</td>
<td>600</td>
</tr>
<tr>
<td>Standard error</td>
<td>138.9</td>
<td>189.6</td>
</tr>
<tr>
<td>CV%</td>
<td>23.5</td>
<td>31.9</td>
</tr>
</tbody>
</table>

(*): Significant difference at 5%.

**Pure culture of sorghum in the half moon:** Siellé= 2011: 1425 kg/ha and 2012: 1525 kg/ha; Siramana= 2011: 2000 kg/ha and 2012: 2075 kg/ha; NTogosso= 2011: 1000 kg/ha and 2012: 800 kg/ha

**Pure culture of sorghum on single log:** Siellé=2011: 700 kg/ha and 2012: 850 kg/ha; Siramana= 2011: 1175 kg/ha and 2012: 1200 kg/ha; NTogosso= 2011: 425 kg/ha and 2012: 525 kg/ha.

### Table 2. Cowpea grain yield in the sorghum-cowpea association in peasant fields, Mali

<table>
<thead>
<tr>
<th>Villages</th>
<th>In the half moon</th>
<th>In the simple ridging</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2011 (**), 2012 (*)</td>
<td>Average</td>
</tr>
<tr>
<td>Siellé</td>
<td>475</td>
<td>500</td>
</tr>
<tr>
<td>Siramana</td>
<td>912</td>
<td>750</td>
</tr>
<tr>
<td>NTogosso</td>
<td>375</td>
<td>275</td>
</tr>
<tr>
<td>Standard error</td>
<td>137.1</td>
<td>74.07</td>
</tr>
<tr>
<td>CV%</td>
<td>36</td>
<td>29.1</td>
</tr>
</tbody>
</table>

(*): Significant difference at 5%.

**Pure Cowpea Crop in the Half Moon:** Siellé= 2011: 575 kg/ha and 2012: 625 kg/ha; Siramana= 2011: 1200 kg/ha and 2012: 1125 kg/ha; NTogosso= 2011: 350 kg/ha and 2012: 575 kg/ha

**Cultivation of pure cowpea on single log:** Siellé=2011: 450 kg/ha and 2012: 425 kg/ha; Siramana = 2011: 825 kg/ha and 875 kg/ha; NTogosso = 2011: 275 kg/ha and 2012: 350 kg/ha.

### Land equivalent ratio

In the half-moon, the equivalent surface ratios recorded were 1.63 at Siellé, 1.56 at Siramana and 1.43 at NTogosso (Fig. 6). The average partial LER of cowpea is 0.76 vs. 0.78 for sorghum, the main crop. The half-moon appears as a technique favorable to a good grain yield of the additional crop.

On simple ridges, the equivalent surface ratios obtained were 1.54 at Siellé, 1.27 at Siramana and at NTogosso (Fig. 7). The average partial LER of cowpea is 0.52 vs. 0.84 for sorghum. The performance of cowpea in this tillage system was the lowest.

Fig. 6: Equivalent area ratio in the sorghum-cowpea association in the half-moon in Mali.
Rain water use efficiency

Table 3 shows the RWUE values obtained at the different sites by combining sorghum-cowpea crops in the half-moon. The combination of cultures yielded mean values of 3.77 kg of grain/mm of rain at Siellé; 2.67 in Siramana; 2.01 to NTogosso.

Pure sorghum yielded as average RWUE (kg of grain/ha/mm of rain), 2.69 at Siellé 2.10 at Siramana and 1.32 at NTogosso. Pure cowpea crop yielded average RWUE of 1.33 at Siellé, 1.20 at Siramana and 0.99 at NTogosso. The mean values of RWUE obtained in the combination are higher in all sites than in pure sorghum and cowpea cultures taken individually.

Table 3. Information on rain water use efficiency in intercropping system in Mali.

<table>
<thead>
<tr>
<th>Localities</th>
<th>Grain yield in kg/ha</th>
<th>Intercropping</th>
<th>Sole crops</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sorghum kg/ha</td>
<td>Cowpea kg/ha</td>
<td>RWUE*</td>
</tr>
<tr>
<td>Siellé</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2011 (404 mm)</td>
<td>1100</td>
<td>475</td>
<td>3.90</td>
</tr>
<tr>
<td>2012 (500 mm)</td>
<td>1325</td>
<td>500</td>
<td>3.65</td>
</tr>
<tr>
<td>Siramana</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2011 (880 mm)</td>
<td>1825</td>
<td>912.5</td>
<td>3.11</td>
</tr>
<tr>
<td>2012 (1070 mm)</td>
<td>1638</td>
<td>750</td>
<td>2.23</td>
</tr>
<tr>
<td>NTogosso</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2011 (460 mm)</td>
<td>625</td>
<td>375</td>
<td>2.17</td>
</tr>
<tr>
<td>2012 (470 mm)</td>
<td>600</td>
<td>275</td>
<td>1.86</td>
</tr>
</tbody>
</table>

RWUE*: Rain water use efficiency (mm): Total rainfall received during the growing season.

Table 4. Information on rain water use efficiency in the intercropping system on simple ridges in farmers’ fields in Mali.

<table>
<thead>
<tr>
<th>Localités</th>
<th>Grain yield in kg/ha</th>
<th>Intercropping</th>
<th>Sole crops</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sorghum kg/ha</td>
<td>Cowpea kg/ha</td>
<td>RWUE*</td>
</tr>
<tr>
<td>Siellé</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2011 (404 mm)</td>
<td>525</td>
<td>375</td>
<td>2.23</td>
</tr>
<tr>
<td>2012 (500 mm)</td>
<td>675</td>
<td>300</td>
<td>1.95</td>
</tr>
<tr>
<td>Siramana</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2011 (880 mm)</td>
<td>1025</td>
<td>325</td>
<td>1.53</td>
</tr>
<tr>
<td>2012 (1070 mm)</td>
<td>1000</td>
<td>400</td>
<td>1.31</td>
</tr>
<tr>
<td>NTogosso</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2011 (460 mm)</td>
<td>375</td>
<td>112.5</td>
<td>1.06</td>
</tr>
<tr>
<td>2012 (470 mm)</td>
<td>475</td>
<td>125</td>
<td>1.28</td>
</tr>
</tbody>
</table>

RWUE*: Rain water use efficiency

Table 4 shows the RWUE values obtained at the various sites by combining sorghum-cowpea crops on a single ridge. This association yielded mean values of 2.09 kg of grain/mm of rain at Siellé; 1.42 to Siramana; 1.17 to NTogosso. Pure sorghum yielded as average RWUE (kg of grain/ha/mm of rain), 1.41 at Siellé 1.22 at Siramana and 0.91 at NTogosso. Pure cowpea yielded average RWUE of 0.98 to Siellé, 0.88 to Siramana and 0.67 to NTogosso. The mean values of RWUE obtained in the combination are higher in all sites than in pure
sorghum and cowpea cultures taken individually. The pure cropping system and crop association use almost the same amount of water. However, the RWUE is the best in the cropping association system (Singh et al., 2013; Natarajan and Willey, 1980).

We observed a decrease in yield of sorghum and RWUE in the half moon at Siramana during the rainiest season (2012). Excessive rainfall can lead to flooding of crops and negatively affect crop development and yield (Zougmoré and Zida, 2011). The values of RWUE obtained in 2011 are all higher than those of 2012 in the three sites and it is on ridging that the lowest RWUE was recorded. The transport of a considerable soil from the ridges carried out of the field by heavy rains was observed at the sites. This is consistent with the problem of soil conservation and nutrients affecting RWUE that Bowman and Scott (2009) had raised. The superiority of the RWUE in the half-moon is supported by good water infiltration, a good availability of nutrients to the plants and a reduction in the variability of the rains that this technique generates (Moumini et al., 2011).

Low crop - water productivity observed in the northern and southern parts of the Sahelian zone in the study area reflects low crop productivity (Bowman, 2007). The villages of Siellé and N'Togosso have similar total rainfall but the RWUE values are highest at Siellé. This indicates a difference in the distribution of rainfall between sites and a need for additional water supply to crops during end-of-season crop droughts especially in the low RWUE village.

**Conclusion**

This study shows that the combination of sorghum and cowpea crops uses rainwater more efficiently than individual crops. In both tillage systems, the combination of crops, pure sorghum cultivation and pure cowpea cultivation represent the decreasing order in the efficient use of rainwater. These results are consistent with those obtained by Ofori et al. (2014) on maize-cowpea association in Ghana.

**Conflict of interest statement**

Authors declare that they have no conflict of interest.

**Acknowledgement**

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