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Mulching upland rice for efficient water management: A collaborative approach in Benin

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ABSTRACT

Since the 2007 food crisis, the Government of Benin has created enabling conditions that urge small scale farmers to intensify rice production in inland valleys. Unsuitable irrigation infrastructures and lack of willingness to act collectively has led farmers to complain about water shortage. Adoption of mitigating technologies offered by government (extension) and scientists (e.g. Benin Agricultural Research Institute, AfricaRice) has been low due to the institutional context within which farmers are working. A socio-technical approach which combines technical and institutional dimensions was used to identify and test mulching as a potential method for improving irrigation water efficiency in growing rice in upland parts of Benin's inland valleys. Rice farmers (from three production areas), an extension agent and a researcher formed a multi-stakeholder platform and collaborated to test the application of mulch (three doses) and the use of a lowland rice variety in replacement of an upland rice variety during two growing seasons. Multiple methods derived from researchers and farmers' perspectives were used to evaluate trial results: quantitative scientific evidence was combined with qualitative evaluation using indicators agreed upon by the collaborative group. Results show that the lowland rice variety IR-841 with 10 Mg ha^{-1} 'rice-straw' mulch allows farmers to better use available water in the upland areas and increase yields. Although the preference for IR-841 over the special bred upland variety Nerica-4 is risky because of its high water demand and the uncertainty in rainfall, farmers use IR-841 for profit maximisation. Beyond its technical output, the joint experimentation facilitated the interaction of knowledge, experiences and practices among the involved actors.

1. Introduction

1.1. Context

Rice plays a critical role in contributing to food security, income generation, poverty alleviation and socioeconomic growth in many African countries (Fagade, 2000). In most of these countries, rice supply cannot keep up with demand. In Benin the rice self-sufficiency rate is about 53%, resulting in the need for annual imports to meet the growing rice demand (MAEP, 2010). Given the large amount of rice Benin currently buys on the international market (e.g. 522,772 metric tonnes were imported in 2010); an increase in local rice supply is of great relevance for increasing food security.

Following the apparent success of the Green Revolution in Asia (Issaka et al., 2008), the Government of Benin (GoB), supported by Chinese funded projects, made major investments in irrigation systems to increase domestic rice production. In 1976, nearly 2250 ha of irrigation schemes were built in inland valleys (Sodjinou et al., 2008). Inland valleys have specific characteristics that offer high potential for rice production (Abe et al., 2009) one of which is that they can be divided into a lowland part (where gravity irrigation is practised), and an upland part where farmers can grow either rainfed upland rice or apply irrigation (using pumped water) (Fig. 1). In the latter case farmers can select between an upland rice variety (usually with a short growing cycle, e.g. Nerica-4) and a lowland variety (usually with a longer growth period, e.g. IR-841).

The irrigation schemes were designed in the 1970s for one rice crop season (the most favourable season) and the central authority was responsible for maintenance and repair. Eventually, due to structural adjustment politics and termination of Chinese projects, maintenance was handed over to local farmers. Since these farmers were not organised to handle this, the maintenance levels quickly dropped, the infrastructure deteriorated over time and the schemes were abandoned.

Benin's dependence on rice imports has attained a critical monetary level following the global food crisis of 2007–2008 (*Direction Générale des Prévisions et des Statistiques Agricoles* (DGPSA), 2008;

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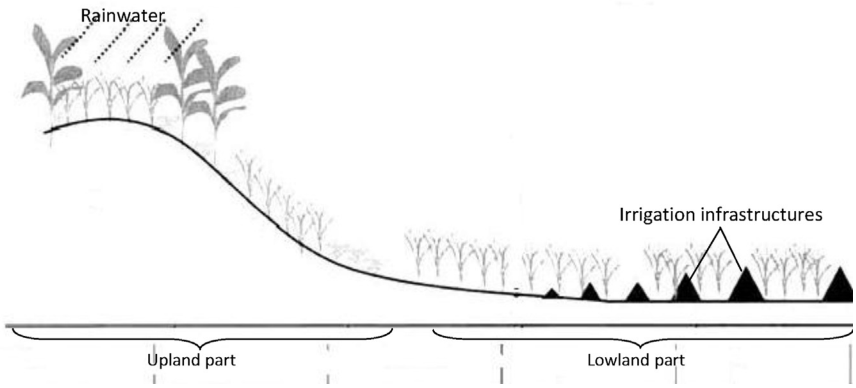

Fig. 1. Schematic topography of inland valleys in Benin.

De Schutter, 2009). In response, the GoB, national and international research institutes and NGOs have intervened with the objective of improving the production of local rice. Their propositions included multiple cropping (up to 3 crops a year) and an higher use of inputs like fertilizer and water. Indeed, since 2008, local rice production has increased (from 73,853 metric tonnes in 2008 to 167,000 tonnes in 2011) because of improved input facilities (seed, fertiliser, etc.) made available to farmers through a range of programmes set up after the food crisis (PUASA, Nerica Project, PAPI, PASR, etc.). Additional technologies and techniques with potential to further increase rice production have also been developed and offered by government and the scientific community. An attractive price is offered to farmers and a public company is charged to buy all the rice harvest to provide material for the industrial mill that the government promoted. The projects also introduce facilities for the rice farmers to have access to credit.

Although rice production has increased, the adoption of technologies offered by government (extension agents) and scientists (e.g. Benin Agricultural Research Institute, AfricaRice) has remained low; it means that the full potential for yield increases has not been realised. Totin et al. (2012) diagnosed several constraints that inhibit farmers from further intensification. The major issues were shortage of water and lack of collective maintenance of the irrigation infrastructure. Traditionally, farmers only cultivated once a year, in the most favourable season (season 1), which probably explains why they did not mention water scarcity during interviews conducted in an earlier study (Djagba, 2006). As a result of input intensification, which has extended the potential to grow rice across all three seasons, rice farmers nowadays complain about a lack of irrigation water. Finding ways to address these constraints has the potential to increase adoption of new technologies that can enable further advances in local rice production.

Even before considering the water scarcity and infrastructure maintenance issues, it is important to realise that one of the reasons for the stagnating production is the fact that not all inland valleys are suitable to grow three crops a year. This is illustrated in Table 1 for three irrigation schemes of different inland valleys: Koussin-Lélé (106 ha), Bamé (33 ha), and Zonmon (88 ha). All farmers grow rice in the lowland part of their valleys. Whether they also use the upland part depends on the water level in the river and on the rainfall pattern. Season 1 is traditionally the main growing season. There is little rain (plenty of sunshine; few diseases) and enough water in the river from the preceding wet season. Therefore farmers in all valleys can grow rice in the lowland sections in this season. In the second season, the water level in the river drops and problems begin to arise with the availability of irrigation water. During this season only 32% of the farmers in Koussin-Lélé are able to cultivate rice in the lowlands, there is no rice cropping at all in Zonmon, but in Bamè there are no problems because there is enough irrigation water to cover the water demand in rice farming in the lowland area, especially since a number of farmers have moved away from these lowland areas and started rice production in the uplands (Totin et al., 2012). The third season is the rainy season. This causes flooding in 100% of the lowland parts of the valleys in Koussin-Lélé and Zonmon and 75% in Bamè. Thus no crop can be grown in the lowlands during this season. However, the abundant rain permits rainfed rice production in the upland parts of Koussin-Lélé and Bamè valleys. In these three inlands valleys, there are large differences in the way farmers are dealing with the water scarcity.

The 'water scarcity' paradigm needs careful definition because there are two sources of water: the river and the rain. Hence, we distinguish between two types of water scarcity: meteorological and technical. The first occurs when rainfall is much less than the mean or when the timing of a season shifts; there is some evidence of longer term shifts beginning to occur under climate change that adds additional uncertainty to the normal variability (Nyakudya and Stroosnijder, 2011). Reduced rainfall results in less water in the river for gravity irrigation, and less water for the rainfed crop as well. Technical water scarcity occurs when there are technical failures in the irrigation infrastructure, such as when the water intake is at too high a level, or the collapse of a canal bank. In addition, mistimed or inadequate canal cleaning can cause serious shortages of water in the fields that are at the highest elevation within the command area. Another technical form of water scarcity occurs when there is insufficient water that can be pumped into the upland part of the inland valley.

The diagnostic study conducted in the three inland valleys mentioned in Table 1 established that production could be improved for the upland areas if there were a better control of the irrigation water. According to the farmers, several options exist which could help to improve soil moisture in the upland part of their valleys. The farmers' ideas have inspired this study.

1.2. Theoretical framework

In the last two decades, numerous studies have been conducted to explain why some technologies developed by researchers do not spread at all (Chambers, 1994; Pimbert, 1994; Douthwaite et al., 2001) and how the small farmers' use of agricultural technologies can be improved (World-Bank, 2007). Scientists are now aware that despite the effort that is spent on research and development activities, only a few of the technologies developed are used and consequently, rural poverty remains an intractable problem in many places (Douthwaite et al., 2002; Lundy et al., 2005; Hounkonnou et al., 2012). Among the many causes of this situation is the limited cooperation between researchers and the farmers (Walters and Holling, 1990; Douthwaite et al., 2002).

Table 1
Rice cropping seasons with corresponding water resources in three inland valleys of Benin.

Season	Months	River water	Rain water	Koussin-Lélé lowland	Koussin-Lélé upland	Bamè lowland	Bamè upland	Zonmon lowland	Zonmon upland
1	October–February	Medium	Relatively dry	100% irrigated	–	100% irrigated	–	100% irrigated	–
2	March–June	Low	Medium	32% irrigated	–	100% irrigated	50% rainfed	–	–
3	July–September	High	Peak	100% flooded	22% rainfed	75% flooded	100% rainfed	100% flooded	–

Since the late 1960s, "science" had been considered as the preserve of educated elites working in research stations, overlooking the capacity of farmers to innovate (McCown, 2001; Dormon et al., 2007; Waters-Bayer and Bayer, 2009). The linear thinking assumes that researchers and experts produce information materials for the transfer of knowledge to farmers through the extension system (Gibbons et al., 1994). This mode of thinking draws a straight and one-directional line between science and practice and a clear task division: researchers are supposed to generate the knowledge; extension workers concentrate on their transfer, while the farmers' role is merely to apply them. It seems from this perspective that researchers learn enough about farmers' needs and conditions. They then embed this knowledge in a technology and provide operating instructions that are sufficiently 'finished' to require little or no subsequent local adaptation (Chambers and Jiggins, 1987; Douthwaite et al., 2001). However, it is common to see farmers putting 'finished' innovations into practices by embedding their own knowledge in them. Illustratively, cotton farmers in Benin were found to adapt the recommended bollworm control options by mixing half the dose of the recommended synthetic pesticides with locally available botanicals to suit their socioeconomic conditions (Sinzogan et al., 2004). The linear thinking approach has been extensively criticised (Röling, 1988; Lundy et al., 2005; Klerkx et al., 2010; Kilelu et al., 2011).

Currently, the dominant linear model of innovation has been replaced by other bodies of thought to better understand rural complex development phenomena (Kefasi et al., 2012; Leeuwis and Aarts, 2011; van Mierlo et al., 2010). Farmers, extension workers and researchers are recognised as elements of an agricultural information system which have to collaborate to achieve large impacts (Röling, 1988). In line with this new thinking, several participative approaches have been suggested to enhance the cooperation between end users and scientists, so that they can learn from each other (Gerber, 1992; Roling et al., 2004; Leeuwis, 2004). Collaboration of actors from different backgrounds provides a viable research model which emphasises on reciprocity, relationships, learning and creativity (Fish et al., 2010). Kefasi et al. (2012) and Adjei-Nsiah et al. (2008) recommend the multi stakeholder platform as a mean to strengthen social interaction and learning.

Ashby and Pretly (2006) show that when the participatory approaches are well applied, they are able to make considerable impact locally. However, Roling et al. (2004) explained that, although the participation technologies development is used in the agricultural sector, the impact of research has been limited because of the neglect of the institutional dimension. In other words, small farmers can make an effective use of technologies, unless the institutional context changes (Hounkonnou et al., 2012).

Our hypothesis is that working both on technical and institutional issues can facilitate the effective use of irrigation water in the rice plots. We are aware that irrigation water management is not only a technical issue. Then, the idea is not only to work on the technical aspect of effective water use in rice farming through a participatory technology development, but we also build on the institutional context to enlarge farmers' opportunities. In that perspective, an earlier study had identified some institutional barriers that hinder the efficient use of the irrigation water in rice farming. They are related to lack of collective action (e.g. canal cleaning, in the lowlands; collective use of equipments in the uplands) and power relations among the farmers (Totin et al., 2012). It is not the purpose here to address these institutional barriers. We focus in this paper on the participatory water management experiment in collaboration with farmers and an extension agent. However, beyond the technical value of the joint experiment ground on both the scientific and endogenous perspectives, it aims to provide evidence for farmers that much can be gained by working together. This is the main difference between the participatory technology development as commonly used and the pathway we follow in this study. Essential to the approach used is that the design of the technical field experiment, its implementation and evaluation of results are done through collaboration between farmers, extension agents and researchers. Our approach was guided by the following research questions: (i) what water management option would the farmers select and want to test? (ii) What experimental set-up would come out of the collaborative discussion? (iii) What evaluation criteria would be developed and accepted by the stakeholders involved in the collaboration? (iv) What were the results of the tested water management option? (v) How were these results perceived by the different stakeholders? (vi) What lessons were learnt from this research method?

2. Materials and methods

2.1. Selection of the water management option to be tested

We invited all the rice farmers from three inland valleys (Koussin-Lélé, Bamè, and Zonmon) and local extension agents to a meeting in order to reflect on practical techniques which, in their experiences, increase water use efficiency in rice plots. These valleys are located near Covè in South Benin (Fig. 2).

In total, 25 rice farmers (3 from Koussin-Lélé; 15 farmers from Bamè and 7 from Zonmon) and one extension agent attended this meeting; a summary of the findings is presented in Table 2.

It can be seen that practices vary between the valleys. In Koussin-Lélé, 2 from 3 farmers located in the tail section of the

Table 2
Water management activities in rice cultivation in three studied inland valleys in Benin.

Koussin-Lélé	Bamè	Zonmon
- *Lowlands*: - Irrigation scheduling - Use of mulch in early growth stage	- *Lowlands*: - Not transplanting rice all at the same time to regulate the water need - Production during the dry season because of abundant water - *Uplands*: - Production during the wet season and use of pump to supply irrigation water during the dry season	- *Lowlands*: - Transplanting following the retreat of the water level after flooding. - Use of pumps to irrigate when needed

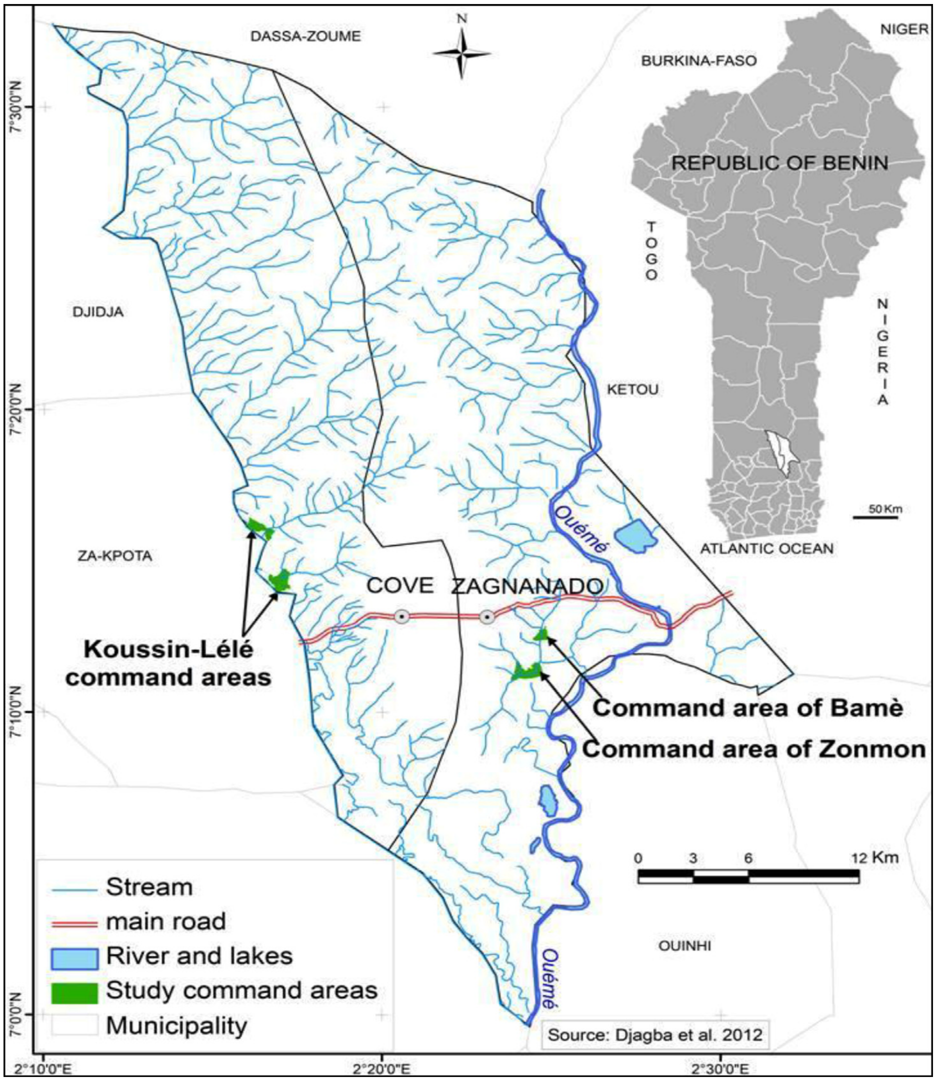

Fig. 2. Map of the Covè and Zangnanando districts showing the irrigation command areas.

(*Source*: Djagba, 2006).

command area apply mulch in their plots to the exposed soil surface at the early growth stage of the rice, in order to maintain the desired soil moisture level. In Bamè, in the face of land scarcity in the lowland part of the valley, some rice farmers use individual portable pumps connected to pipes to bring water from wells in the lowland to the upland. This technique was copied from the irrigation practices of vegetable farmers along the southwest Atlantic coast and adapted to local conditions (Atidégla et al., 2010). This practice has facilitated the use of groundwater as a supplemental water source, and enabled rice farmers to begin producing in the upland part of the valley, where there is more land available. It also allows farmers to produce rice all year round. However, the practice incurs considerable extra fixed and recurrent costs (pump, fuel and maintenance) and, in spite of its effectiveness, its use has not become widespread. Farmers are interested in cultural practices that save water. Bamè farmers have also been experimenting with different rice varieties. Farmers prefer to cultivate their upland plots with IR-841, a rice variety that is only recommended for use in the lowland. In Zonmon only the lowlands are used at this point, and the farmers start transplanting the rice nursery following the retreat of the water level after flooding. They use individual pumps when irrigation is needed.

After discussing various options for increasing water use efficiency, those who participated in this first meeting were invited to form, together with the facilitating researcher and an extension agent, a platform for collaborative learning and action research. In total, ten farmers (all men: 2 from Koussin-Lélé; 6 from Bamè and 2 from Zonmon) chose to join the platform. We present here what the group decided since it affects the set-up of the technical experiment presented in Section 2.2. The group decided to explore the use of mulch in upland plots as a water saving option and also evaluate its effect on weeds in rice fields. The idea behind this joint experiment was to facilitate multi stakeholders learning process about an efficient water use option. If results are positive, mulching could enable the further expansion of rice production in the upland part of the valleys and strengthen cooperation among the farmers.

2.2. Experimental set-up

The field experiments were conducted by the multi stakeholder platform during the wet and dry periods from May 2011 to February 2012. The six farmers from Bamè, drawing attention to the land pressure in the lowland part of their valley (4.5 ha for nineteen rice farmers) and water scarcity in the upland part

Table 3
Treatments in the research experiment. All plots with farmer's irrigation practices but with different rice variety and mulch dose (during two seasons in 2011–2012, Benin).

Treatments	Definition of treatments (Doses of mulch with rice varieties)
Ne-0	Nerica-4 + 0 Mg/ha of mulch
IR-0	IR-841 + 0 Mg/ha of mulch
Ne-5	Nerica-4 + 5 Mg/ha of mulch
IR-5	IR-841 + 5 Mg/ha of mulch
Ne-10	Nerica-4 + 10 Mg/ha of mulch
IR-10	IR-841 + 10 Mg of mulch

(as presented in Table 1), requested that the experiment be conducted in their area (in Bamè) where water scarcity is a critical issue. The other members of the platform agreed that this most problematic area would be a good experimental site. Further, the platform decided that the experiment should be in a location that all farmers could reach so that they could learn together and interact conveniently.

The platform also identified materials for mulching. The first step in this process involved farmers and the extension agent deciding on criteria to ensure that the mulching material would fit the rice farmers' conditions. The key criteria were availability, ease of access, and the possible effects of application in rice plots. Because of the prevalence of rodents, the farmers decided that use of a *Vigna* substratum (Roy et al., 1988) might not be suitable in their context. The extension agent suggested the use of paddy husks (the main waste product of paddy hulling) as the mulch, but the transportation of this material, from the processing area to the rice plots, was assessed as being too demanding. A few years ago, one of the rice farmers from Bamè had received training on rice cultivation 'best practices' from a Belgian NGO (*Vredeseilanden*) involved in the promotion of the rice production chain in Benin. The trainer had recommended the use of the straw to fertilise the soil and to manage soil moisture. This farmer suggested that we test this material. Because the material is already available in the field after each harvest, its use would not demand additional transportation cost or effort. This suggestion was adopted by the platform. The platform further agreed to use three doses of mulch, 0, 5, and 10 Mg ha^{-1} with three replications (Table 3).

The researcher and the extension agent proposed the commonly used scientific design of a completely randomised block. Participants were briefed on the reasons why researchers considered it necessary to use this design. This proposal was accepted, so the trial was designed to consist of eighteen plots of 10 m × 10 m with 3 replicates.

In all three valleys involved in this research, IR-841 (a long-duration variety of 120 days) has become widely sown since 2008 because of its taste. Although the extension agents had recommended using the IR-841 variety in the lowland area only, Bamè farmers have chosen to sow it also in the upland area. The joint experiment gave an opportunity to validate their choice. The extension agent involved in the research, suggested including a rice variety that had been selected for upland area conditions (Nerica-4), so as to evaluate its performance (e.g. yield, water demand) against IR-841. Nerica-4, a short-duration, 90-day variety promoted by AfricaRice, the Benin Agricultural Research Institute and many NGOs, was selected for inclusion.

The platform also wanted to assess the effect of the mulch on weed control; specifically, to check the extent to which the additional cost of mulch application could be recovered from a reduction in weeding costs. For this reason platform members decided not to apply herbicide in the experimental plots, although the farmers usually apply *Herbextra 2,4-D sel d'amine* 720 g l^{-1} at the first weeding stage. Otherwise the platform followed farmers' regular practices, e.g. application of 150 kg ha^{-1} of NPKSB 14-23-14-5-1 mixed with half dose of urea (25 kg ha^{-1}) two weeks after transplanting; the other half dose of urea was applied during the flowering stage. In total, 27 kg of NPKSB 14-23-14-5-1 and 9 kg of urea were applied, meaning 7.92 kg of nitrogen used.

The same dose of water was applied to the whole experimental area. The first irrigation was applied the day before transplanting and subsequent irrigations were applied according to the crop requirements depending upon the weather conditions. We used the same area for the two experimental periods. However, the treatments (dose of mulch + rice variety) were randomly selected for each period (Fig. 3). The mulch applied during the first period was completely broken down and remnants were mixed with the soil before the second period.

2.3. Evaluation criteria

Through a series of meetings the platform discussed and negotiated not only the experimental design, but also the data collection, analysis and evaluation as well as the respective roles of the stakeholders. The findings of the mulch experiments were analysed from the perspectives of the different stakeholders involved. We supposed that people judge technologies partly by building on their own knowledge and experience, on the basis of the socio-economic, institutional and political environment in which they operate (Wynne, 1991; Waters-Bayer and Bayer, 2009). The members of each stakeholder category (rice farmers, extension agent and researcher) decided their own assessment criteria. Some criteria (e.g. yield, drought stress, and economic return) were common to all stakeholder categories. The researcher in addition collected data related to the weed biomass in each treatment.

Farmers chose a representative to record and report their regular observations made in the experimental plots in order to be able to judge the effectiveness of the options tested. At each platform meeting they shared their findings and concerns and discussed ways forward. The researcher and the extension agent determined more quantitative data.

Yield was measured with 5 quadrants (of 1 m^2) per plot in the direction of the two diagonals, in order to integrate as much as possible the variability in the plot. All the panicles of the rice plants were harvested in each quadrant. These were dried in the field for 2 days, as farmers themselves do, and then the grain yield was weighed for each quadrant and an estimate was made of the overall yield for each treatment. Weed samples were manually collected (hand weeding – twice, at 30 and 60 days after transplanting (DAT)) in each quadrant. The fresh weed biomass was then oven dried at 70 °C for 72 h and the dry biomass recorded. The financial advantage of using mulch was assessed by comparing how much farmers earn from their usual practice compared to the return they could get when practicing mulching. Costs and benefits for both were derived from the responses to a household survey of all eleven rice farmers who grow rice in the upland area where the experiment was located.

Finally, we organised a field trip for rice farmers from each of the three communities who were not involved in the experiments, so they could visit the experimental field and also learn from this activity. The experiment was concluded by means of an assessment workshop that included 27 farmers from the three areas, four extension agents and a representative of AfricaRice. The participants were asked to review the evidence and judge the effectiveness of each tested option. They then discussed the extent to which the two logics (scientists' and farmers') contributed to an adapted water management practice appropriate to farmers' conditions.

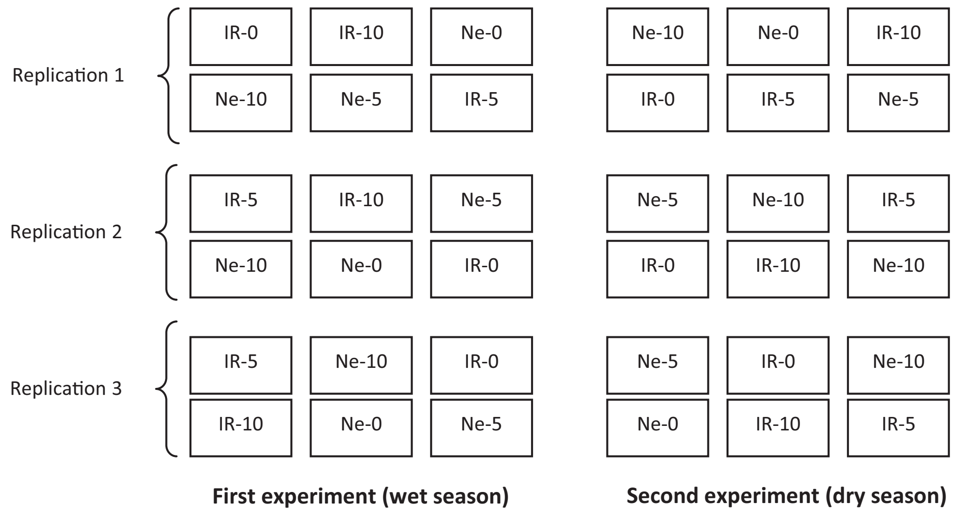

Fig. 3. Experimental layout in Bamè (Benin) during wet then dry seasons of 2011–2012. IR and Ne for IR-841 and Nerica-4 which are lowland and upland rice varieties, respectively. The number (0–5–10) corresponds to the quantity of mulch (rice straw) in Mg per ha.

3. Results

3.1. Effect of mulching on rice production

The results of the six treatments showed that the rice yield during the first experiment (the wet season) was higher than the yield of the second experiment (the dry season). For each rice variety, there was significant variation in the yields obtained with different doses of mulch ($p \leq 0.05$), except between Ne-0 and Ne-5 for the first period (Fig. 4).

The differences in IR-841 yield between the two experiment periods were greater than the differences for Nerica-4. This suggests that IR-841 is more affected by the seasonal variation in moisture availability. In addition, the analysis showed that irrespective of the period and the rice variety used, the yields were significantly lower in the un-mulched plots ($p \leq 0.05$). In all treatments, the yields increased as the dose of mulch applied increased. The highest yield was obtained with IR-841 in the treatments that received 10 Mg ha^{-1} of mulch and the lowest with Nerica-4 in the un-mulched plots. Overall, the yield of IR-841 was higher than the yield of Nerica-4.

Fig. 5 shows that weed infestation in the mulched Nerica plots was lower than in the un-mulched plots. The weed prevalence decreased as the dose of mulch increased. These differences were significant ($p < 0.05$). The weed infestation in all IR-841 plots was quite low and there were no significant variations of the weed infestation in the IR-841 plots whatever the dose of mulch applied ($p > 0.05$).

3.2. Effect of mulching on water variation in rice plots

In the first experimental period (wet season) the plots were irrigated once, just before transplanting the rice nursery. During the rest of this period, rain was the only source of water and was sufficient (Fig. 6). Visual observation of the soil by the members of the platform indicated that the soil moisture in the top layer was higher in the mulched plots. For the second experiment there were no rains; the plots were irrigated each week. During the vegetative phase, there was no visual difference in the soil moisture for any of the 6 treatments. In the reproductive and ripening stages (with limited irrigation), soil moisture of the top layer was higher in the mulched plots than in the un-mulched plots.

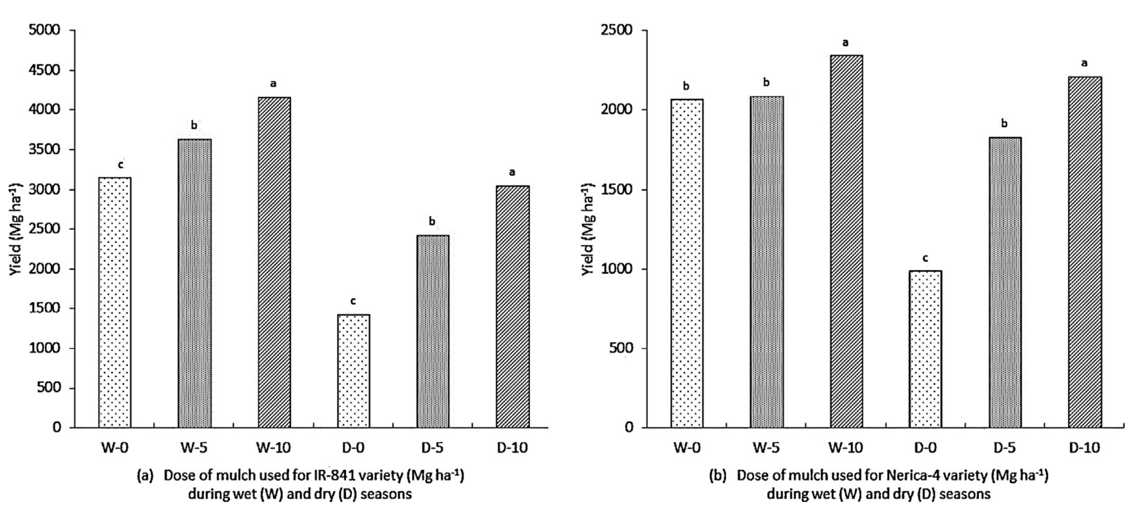

Fig. 4. Paddy yields during wet (W) and dry (D) seasons for lowland and upland rice varieties with 0, 5 and 10 Mg mulch ha^{-1}. Graphics followed by the same letter for the same season are not significantly different as established by the Student Newman and Keuls test ($p < 0.05$).

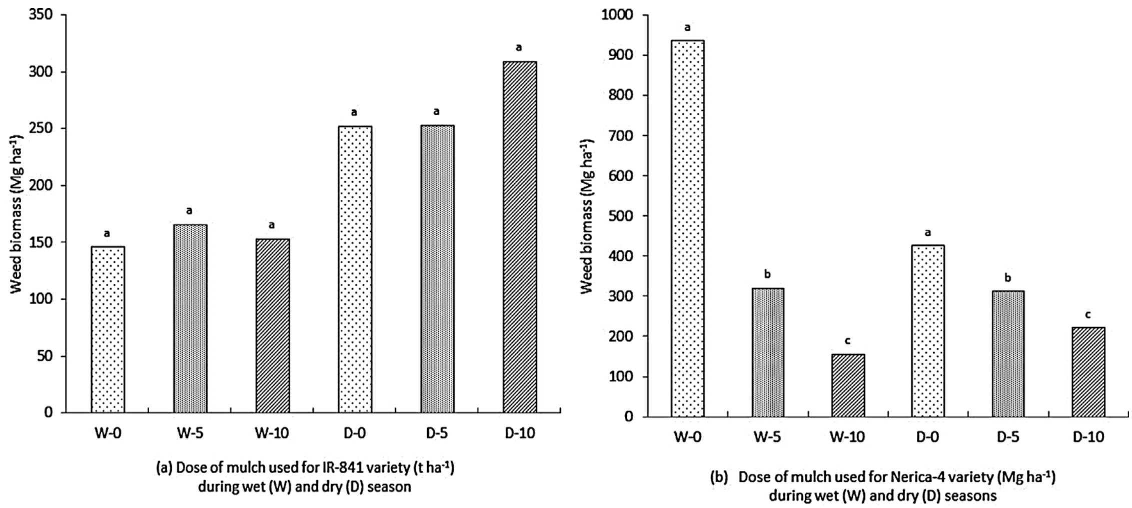

Fig. 5. Weed biomass during wet (W) and dry (D) seasons for lowland (IR-841) and upland (Nerica-4) rice varieties with 0, 5 and 10 Mg mulch ha^{-1}. Graphics followed by the same letter for the same season are not significantly different as established by the Student Newman and Keuls test ($p < 0.05$).

3.3. Economic value of mulch in rice production

A comparative analysis of the estimated returns when applying mulch in the experimental plots for each of the two rice varieties indicated that the returns are generally higher for IR-841 (Table 4). This implies that, farmers can earn more by producing IR-841 with a dose of 10 Mg ha^{-1} of mulch (under Bamè agro-ecological conditions). Farmers could earn five-fold their current returns in the wet period, and seven-fold during the dry period, if they applied 10 Mg ha^{-1} of mulch in IR-841 plots. Although in the dry period the Nerica-4 returns were higher than the income generated for this variety during the wet period, overall Nerica-4 was shown to be not profitable for farmers under the ecological conditions of Bamè because of its low yields.

4. Discussion

We took the approach of identifying efficient water management options jointly through a multi-stakeholder process because, despite massive expansion over the past three decades, success of earlier participatory approaches has remained limited (Ojha et al., 2013) and the term 'participatory' is often used as a mere label without substance (Douthwaite et al., 2001; Pijnenburg and Nhantumbo, 2002; Pain and Francis, 2003; Leeuwis, 2004). Through involving rice farmers as well as an extension agent in all stages of the experiment, we hoped to overcome this bias and have more chances to put research findings into use. We agree with others who believe that conclusions drawn by people themselves, on the basis of their experiences, may have a greater impact on adoption than insights formulated by others (Kolb, 1984; Leeuwis and Aarts, 2011). Since the evaluation methods of farmers (qualitative) and researcher (quantitative) were somewhat different, the overall assessment and evaluation were also done in a mixed method that others have found successful (Janssen and van Ittersum, 2007; Ton, 2012).

4.1. Scientific assessment

The effect of mulch is clear: when the dose of mulch increased, the yields also increased for both rice varieties. Yields in the first (wet) period were higher for both rice varieties than the yields recorded in the dry period. A significant contributor to this yield difference is the improved water availability (Araya et al., 2011). But the variation could probably also be explained in part by a fertilising effect of the mulch. By the end of the first experimental period, the mulch was almost completely decomposed and remnants incorporated into the soil. We think that it may have contributed to soil fertilisation, as Ramakrishna et al. (2006) and Adeniyan et al. (2008) also found.

During the second experiment, there was no rain. Observations by all stakeholders indicated that plants of both varieties suffered from water stress; however the visual symptoms of water stress

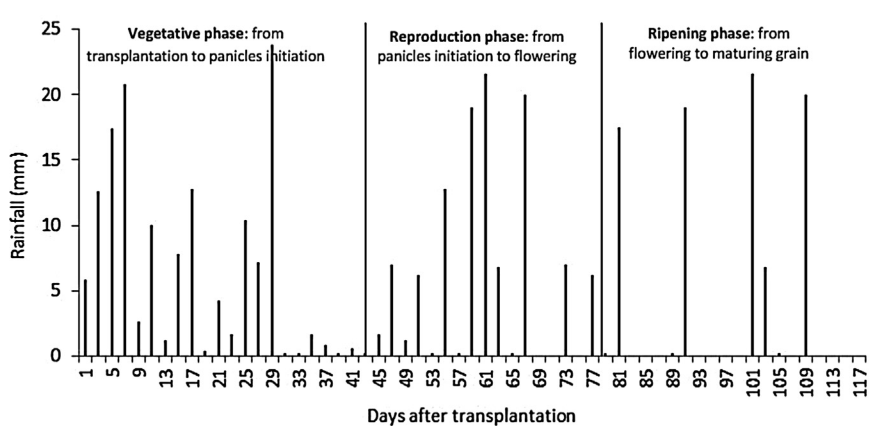

Fig. 6. Rainfall distribution during the first experimental period (wet season).

Table 4
Comparison of the average revenue per hectare from eleven farmers' fields with calculated revenue from mulch experiment (2011–2012 data).

	Farmers' fields		Experimental field			
	Wet	Dry	Ne-10 wet	IR-10 wet	Ne-10 dry	IR-10 dry
Inputs cost (€)	*116*	*106.9*	*103.9*	*103.9*	*103.9*	*103.9*
Seed	27.5	27.5	27.5	27.5	27.5	27.5
Fertilizer	76.5	76.4	76.4	76.4	76.4	76.4
Herbicide	12.0	3.0	0.0	0.0	0.0	0.0
Labour (€)	*394*	*335.9*	*458*	*458*	*412.2*	*412.2*
Field cleaning	45.8	30.5	45.8	45.8	30.5	30.5
Construction internal bunds	30.5	12.2	30.5	30.5	15.3	15.3
Land preparation	84.0	59.5	84.0	84.0	68.7	68.7
Mulching	0.00	0.00	61.1	61.1	61.1	61.1
Nursery transplantation	53.5	53.5	53.5	53.5	53.5	53.5
Weeding	18.3	18.3	21.3	21.3	21.3	21.3
Bird scaring	48.9	48.9	48.9	48.9	48.9	48.9
Harvest	36.7	36.6	36.6	36.6	36.6	36.6
Post-harvest activities	76.3	76.3	76.3	76.3	76.3	76.3
Irrigation cost (€)	*18.3*	*53.5*	*5.3*	*13.7*	*13.7*	*22.9*
Yield (mg ha^{-1})	*2600*	*2040*	*2341*	*4155*	*2208*	*3041*
Selling price (€/kg)	*0.2*	*0.3*	*0.2*	*0.2*	*0.3*	*0.3*
Total average returns (€/ha)	67.2	33.3	−31	376	43.4	250.4

Note. (a) Input costs comprise seed, fertilizer and herbicides. On the experiment plots, herbicide was not applied, in order to observe the effect of the use of the mulch on weed control. (b) Labour was estimated by assuming that farmers used only hired labour, even for the activities that they themselves usually would undertake. (c) The irrigation cost is the money that farmers spend directly (fuel, pump maintenance) for irrigating the plots. Depreciation of motor-pump was not considered.

were noticed mainly in the un-mulched plots (Araya et al., 2011). Despite the water stress, yields nonetheless increased with the dose of mulch applied. The variation in the yields for each of the two periods showed that Nerica-4 tolerated the moisture stress better than IR-841. This is in accordance with Koné et al. (2008) who demonstrated Nerica-4's drought tolerance. However, when yields for the two experimental periods are combined, IR-841 had much higher total yield. This variety thus appears to be economically more profitable and a secure choice for farmers. This likely explains why, although IR-841 has been recommended as a lowland variety, farmers also use it in upland areas.

Generally, weed infestation in the first experiment was less than during the second period. Two factors could explain this observation. During the first experimental period, the rainwater remained on the surface in most of the plots which may affect weed growth. A significant variation in weed infestation was observed between the Nerica-4 mulched and Nerica-4 un-mulched plots. However, there was no significant variation observed in the IR-841 treatments where weed infestation was quite low even in the un-mulch plots. Numerous studies show that mulch serves as a physical barrier that can reduce weed growth (e.g. Rosemeyer et al., 2000; Freeman and Gnayem, 2004; Ramakrishna et al., 2006; Isaac et al., 2007) and this seemed to be the main effect at work in the Nerica-4 plots. The growth characteristics of IR-841 plants may help to explain the low weed infestation and lack of variation observed for this variety across the two periods. IR-841 has drooping leaves that shade the soil surface and limit weed emergence compared to Nerica-4, which has erect leaves.

The field observations indicated that the mulch kept the soil wetter. The mulch acted as vapour barrier that decreased evaporation of soil water (Araya and Stroosnijder, 2010; Stroosnijder et al., 2012). If the use of mulch helps to retain soil moisture, it can provide room for farmers to reduce the frequency and amount of irrigation. As a result, there would be no need for each farmer to have an individual motor-pump. Rather, a more limited number of pumps could be cooperatively owned, lowering overall costs. We estimate that up to 5 farmers could share one pump.

4.2. Assessment by farmers

The yields recorded showed that Nerica-4 had the lowest yield. It is reasonable to expect that, because of its potential to withstand soil moisture stress, farmers would cultivate Nerica-4 during the dry season. However, the farmers usually do not cultivate it in their own plots because of its lower yield, which implies lower economic return. While the income that Nerica-4 generated during the second experimental period increased (Table 4), this was mainly because of an increase in the rice price in the dry period. Although IR-841 is a long cycle variety and is water demanding, the farmers thought that they could make better profits in uplands because of its high yield. This is illustrated by the farmers' responses: "in the same plot size, we harvested 3 bags of IR-841 for 1 bag of Nerica-4", or "Although Nerica-4 is a three-month cycle, it is more profitable for us to produce IR-841 (a four-month cycle) to get more rice". The intensification of rice production and the higher demand for rice contributed to farmers' decision.

However, IR-841 is not reliable in the upland area if there is not enough water to meet its high water demand. Farmers act strategically to build on the economic potential of their resources by producing IR-841 in uplands even though there is no guarantee that they could have enough water for irrigation (Henrich and McElreath, 2002; Stroosnijder, 2012). With the increasing uncertainty in the seasonal regularity of rainfall, as a direct manifestation of climate change, the sustainability of the farmers' choices might be questioned. In years of poor rainfall, they know that they can lose their entire harvest if there is no water available for irrigation. Their choice to nevertheless use IR-841 might be risky but, because of the related economic gain and the facilities that are now given to rice farmers in the context of local rice promotion, they all chose to continue producing IR-841. According to our interviews and informal discussions, the production of IR-841 is viewed by the farmers as an important strategy for profit maximisation. Even if it is a seemingly illogical practice to adapt a lowland variety for use in the upland area, our results (Table 4) show that the yield and economic returns that IR-841 generates in upland areas is sufficiently high, especially with mulching, that the farmers choose this option because of what they expect to gain.

4.3. Benefits of the platform: lessons learnt

All actors involved in the experiment noted that their participation in the platform allowed them to discover and discuss things they did not know before (e.g. weed control and soil moisture capacity of mulch). The platform was a space where the participants exchange and discuss their experiences with each other. Through this process, they together generated knowledge through a hybridisation of farmers' understanding inherited from their everyday farming practices and the scientists' experiences (Darré, 1999). The process also provided the participating farmers with more confidence in collaboration with the other stakeholders such as the extension agent and the researcher. In addition, the platform facilitated cross exchange of experiences among farmers from the three areas (Nederlof et al., 2007).

The participants' feedback on the outcomes of the experiment indicated that all of them gained better understanding of the growth stages of the rice plant, soil moisture management, and the skills of interacting with the other stakeholders. Initially, the farmers were not aware of the potential of mulch to affect soil moisture during the growing stages of the rice plant. They usually burned the biomass waste at the end of the growing season. As a result of the experiment, they have decided to keep the rice straw in their fields after the harvest for use as mulch during the following season. 2 from 3 farmers recognised during the interviews that the mulch use is beneficial in rice production (better yields, less weed infestation and low production cost), but its application required a lot of work. Based on that, they explained that they will prioritise its application in the plots where rice plants suffered the most from water stress.

According to the participants, another important outcome was the linkage that the farmers made with another research project that was on-going in the same area, about the use of urea deep placement (UDP) technology (Gaudin, 2012). The two farmers from Koussin-Lélé involved in the platform had also participated in the UDP experiment. They came to the conclusion that by combining the mulching and the UDP technologies, they can improve the efficient use of urea in rice farming and soil moisture as well. Moreover, the farmers deduced that by using mulch in their rice plots, they could control weed infestation more effectively. The additional labour cost of mulching could be recovered by the reduction of weeding costs and the yield increase. The joint experiment also validated the farmers' adoption of IR-841 for upland areas.

The researcher and the extension agent gained an understanding of farmers' practices and demonstrated that farmers are not passive adopters of others' recommendations but, rather, adapt technologies to their own needs and conditions (Long, 2001). The extension agent said that following this experience he would look at farmers' practices with a different perception. The researcher and extension agent became convinced, like Janssen and van Ittersum (2007), that even though farmers are not developing technologies by means of scientific criteria, they are continuously involved in daily experimentation so as to adapt to their environment, and changing production and market conditions.

5. Conclusions

We can conclude that the process used to select a viable option for more efficient water management in rice farming, involving a mixed group of stakeholders, facilitated the interaction between the members of the platform, the co-generation of knowledge for efficient water use by integration farmers' understanding and scientific inputs. Evaluating the resulting technical field experiment with multiple methods provided sufficient evidence for a clear result: the long-term lowland variety IR-841 with 'rice-straw' mulch at 10 Mg ha^{-1} allows farmers to better use available water and increase yields in their upland plots. Beyond its technical value, the joint experiment created room for the participants to share their knowledge and perspectives and to learn from each other. This is an important achievement since the same farmers had earlier shown little willingness to act collectively in their lowland command area. Although the adoption rate was not directly studied, the participants in the platform and final workshop considered that the adaptive collaborative research approach that was used would improve adoption rates of new practices considerably.

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