Tropentag 2010 ETH Zurich, September 14 - 16, 2010

Conference on International Research on Food Security, Natural Resource Management and Rural Development

On-farm Evaluation of Adaptive Rice Management Systems in the Middle Senegal River Valley

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Introduction

The System of Rice Intensification (SRI) has been widely proposed as an alternative rice production system to boost yields while reducing water, seed and agrochemical requirements. SRI has generated considerable controversy amongst researchers (e.g. Sheehy et al., 2004; Stoop and Kassam, 2005), though such debate has not impeded promotion of the system, which has now spread to over 40 countries. In Senegal, over 1,000 rice farmers have been exposed to SRI as a "special study" subject in local Farmer Field School curricula. However, information on the performance of the system outside field schools is lacking.

This study compares a locally adapted form of SRI (ASRI), substituting compost application with mineral fertilizers, to farmers' practice (FP) and recommended management practice (RMP) in the Middle Senegal River Valley (MSRV). Our objectives were to evaluate the agronomic and economic performance of each management system over multiple seasons and at multiple sites. We also investigated the ways in which farmers might further adapt both RMP and ASRI techniques to better respond to local agronomic and socioeconomic production constraints.

Material and Methods

Farmer managed experiments were initiated in the 2008 dry season (DS08). In FP, all crop management decisions were left to participating farmers. RMP made use of 23–25 day old seedlings transplanted at 20 × 20 cm with 3–4 plants hill^{-1}, flood irrigation, and herbicides (8 L Propanil + 1 L 2,4-D ha^{-1}) applied ~18 days after transplanting (DAT) followed by hand weeding as needed. Fertilizer DAP was applied basally at 18 kg-P and 20 kg-N ha^{-1}. Urea (115 kg-N ha^{-1}) was top-dressed in three splits. In ASRI, single, 11–14 day old seedlings were transplanted at 25 × 25 cm. The same fertilizer rate was used as in RMP. Irrigation was intermittent, with periods of 3–4 days with no standing water followed by similar durations of flooding until booting, after which a water layer was maintained. Weeds were controlled as recommended for SRI using a cono weeder, a hand operated mechanical tool with serrated teeth extending out from two opposing cones, which was pushed between rows to incorporate weeds into the soil. All farmers used the cultivar Sahel-108.

Three experimental sites were selected to represent the major types of irrigation schemes found in the MSRV, all within 15 km from Podor, in the far north of Senegal (16°39'N, 14°57'W). These included the Cuvette of Nianga West, the *périmètre irrigué villageois* of Guia-4 and the private "Oumar Younis" irrigation scheme. At each site, the experiment was laid out as a randomized complete block design (RCBD) with plot sizes ranging from 64–200 m^2, initially with four farmers site^{-1} (Table 1). Grain yields, corrected to 14% moisture content, were determined at physiological maturity from three randomly placed and then composited 4 m^2 quadrats.

At the conclusion of the DS08, farmers discussed their impressions of RMP and ASRI. Because each system offered unique advantages and disadvantages, they proposed testing an additional treatment employing what they considered to be each system's most useful components. This "Farmer Adapted System of Rice Intensification", or FASRI, was subsequently compared to FP, RMP and ASRI in the 2008 wet season (WS08) and 2009 dry season (DS09). Weed biomass was sampled during these seasons from two randomly placed 50 cm^2 quadrats $plot^{-1}$ at ~15, 30-35 DAT, and booting. Herbicide use was measured by noting their volume and dilution of in backpack sprayers before and after application. Farmers were equipped with stopwatches to collect real-time labor data, and price information was gathered from a database maintained by AfricaRice (see Demont *et al*. 2009). Yields were analyzed by ANVOA for a RCBD using JMP 8.0.2 (SAS Inst., San Francisco); weed data were subjected to repeated measures ANOVA.

Results and Discussion

In the DS08, all farmers chose transplanting for FP crop establishment using three to eight 32–40 day old seedlings $hill^{-1}$. Mean FP fertilizer dose was slightly lower (-9 kg-N and -4 kg-P ha^{-1}) than in RMP and ASRI. Only one farmer used three rather than two N top dressings, and fields tended to be deep flooded (up to 25 cm water depth). Farmers applied between 3–7 L of Propanil + 1 L 2,4-D ha^{-1}. Three of Guia-4's and one of Nianga's farmers did not hand weed after herbicide application, despite post-spraying survival weeds, most notably *Oryza longistaminata* A. Chev. & Roehr and *Echinochloa colona* (L.) Link. At Oumar Younis, farmers uniformly applied 1.5 L ha^{-1} of oxadiazon (Ronstar) pre-emergent herbicide in DS08, though in subsequent seasons they used Propanil + 2,4-D. They always hand weeded near panicle initiation.

Across seasons and sites, there were no statistical differences between RMP and ASRI yields, although they were always significantly higher (P<0.05) than FP (Table 1). These data support McDonald *et al.* (2006) who showed SRI yields to be commensurate with "Best Management Practices", though in the present study, each far out yielded FP. But while farmers appreciated the potential for high yields and water savings with ASRI, they described labor demands for multiple mechanical weedings as onerous. Weedings also fell at a time labor was already constrained by horticultural crop requirements. Similarly, farmers described the elevated herbicide dose used in RMPs as potentially costly, and indicated that because of poorly functioning agrochemical markets, larger volumes of herbicides might be difficult to reliably source. Farmers consequently proposed testing FASRI as a fourth treatment that borrowed from both ASRI and RMP. FASRI included transplanting two 11–14 day old seedlings $hill^{-1}$ at 20 × 20 cm, intermittent irrigation and recommended fertilizer rates. Weeds were mechanically controlled once with a cono weeder around 18 DAT. Herbicides (6:1 Propanil to 2,4-D ratio) were applied 12–18 days later, but only at locations in the field were weed presence warranted action.

Yields in the WS08 followed the same pattern as the previous season. While no significant differences were found between ASRI, RMP or FASRI, they all significantly increased yields (P<0.05) over FP (Table 1). Using FASRI, farmers reduced herbicide use by 40% and 11% compared to RMP and FP. Weed biomass was significantly lower in FASRI than FP plots (P<0.05), but not different than ASRI or RMP. Higher weed biomass in FP plots was probably caused by a combination of poor land leveling, the late application of low concentrations of herbicides on fields that were incompletely drained, and insufficient hand weeding.

Comparing economic performance, mean profits over FP were greatest with FASRI at all locations. ASRI yielded benefits similar to RMP at Nianga and Guia-4, but at Oumar Younis, they were slightly lower (Table 2). In 2008, the NGO Africare compared SRI to FP and in a similar environment near Timbuktu, Mali. High SRI yields and profits were also observed, though they did not further compare SRI to other, alternative crop management practices.

Table 1. Rice yields (t ha^{-1}) of FP, ASRI, RMP and FASRI for three cropping seasons in the MSRV[a].

	DS08	WS08	DS09
Cuvette Nianga West			
FP	5.54 ***a***	4.22 a	4.80 ***a***
ASRI	7.19 ***b***	5.66 b	6.72 ***b***
RMP	6.55 ***b***	5.45 b	6.50 ***b***
FASRI	--	5.59 b	6.73 ***b***
PIV Guia-4			
FP	4.73 ***a***	4.66 a	4.50 a
ASRI	7.50 ***b***	5.33 b	8.25 b
RMP	6.84 ***b***	5.23 b	8.25 b
FASRI	--	5.63 b	8.36 b
Oumar Younis			
FP	5.28 a	4.53 a	--
ASRI	8.61 b	5.68 b	--
RMP	9.02 b	5.86 b	--
FASRI	--	6.49 b	--
Analysis of variance			
Location	**	NS	***
Management	***	***	***
Location × Management	NS	NS	NS

[a] N=4 farmers site^{-1} in DS08. N=4 (Nianga), 6 (Guia-4) and 5 (Oumar Younis) in WS08. In DS09, N=6 (Guia-4) and 4 (Nianga) farmers site^{-1}. In fitting our ANOVA models, we utilized type III sum of squares, which is robust to small differences in sample size (Quinn and Keough, 2002).
*Indicates significance: ** P<0.01, *** P<0.001. In columns, means followed by a common letter or sharing bold, italic text are not significantly different using Tukey's HSD test (α=0.05), which controls against Type I errors.

We were unable to measure irrigation use in these experiments, although observations of floodwater depths suggested greater water use in RMP and FP than ASRI and FASRI. In simultaneous on-station experiments on similar soil types and geomorphic positions, Krupnik *et al.* (2010) demonstrated that water savings of up to 30% were possible with ASRI compared to RMP without significant differences in grain yield. Assuming a 30% reduction in water use over FP, which tended to have even deeper water layers than RMP, we estimate that profits over FP could increase by another 14–29% and 11-20% under ASRI and FASRI, respectively.

Table 2. Increases in mean profits (€ ha^{-1}) of RMP, MP and FASRI over FP (WS08 and DS09).

	Cuvette Nianga West			PIV Guia-4			Oumar Younis		
	RMP	ASRI	FASRI	RMP	ASRI	FASRI	RMP	ASRI	FASRI
WS08	194	198	270	73	86	144	182	152	258
DS09	473	396	504	295	249	341	--	--	--

656 FCFA= 1 €

Prior to the initiation of the 2009 DS, the Senegalese state reduced urea subsidies by 50%. Herbicide and DAP subsidies were eliminated altogether. Farmers at Guia-4 responded by applying an average of 11 kg-N ha^{-1} less than other systems. They applied no P at all. At Nianga, farmers applied an average of 8 kg-P ha^{-1}, while N doses were nearly identical to other systems. Across sites, Propanil and 2,4-D application ranged from 3-9 L and 0-0.5 L ha^{-1}. Resulting FP yields were low (Table 1). Because of severe crop damage by granivorious birds (*Quelea quelea* L.), data from Oumar Younis are not reported. But across the remaining sites, ASRI, RMP and FASRI, all of which maintained recommended fertilizer rates, increased yields by 2.8, 2.7 and 2.9 t ha^{-1} over FP. Herbicide load was reduced by 58% and 37% under FASRI compared to RMP and FP. Weed biomass was also significantly lower than FP, but higher than RMP and equal to ASRI (P<0.05). While higher weed biomass in FASRI did not reduce yield compared to RMP (Table 1), less than ideal weed control occurred because two farmers applied herbicides before fields were totally drained, thus reducing herbicide application efficacy and necessitating some additional hand weeding. Nonetheless, profits over FP were again greatest with FASRI (Table 2), and estimation of the potential economic value of water savings suggested that farmers could realize a further 6–9% (ASRI) and 5–7% (FASRI) increase in profits using intermittent irrigation.

Our results support Häefele *et al.* (2000), who demonstrated that improved crop management can help bridge yield gaps in the Sahel. But while Häefele *et al.* tested only increased fertilizer and herbicide rates, this study provides evidence that it is possible to reduce the latter without sacrificing yield or profitability. Propanil + 2,4-D mixtures are also the most widely used weed management tool in the region (Demont *et al.* 2010), although evidence of *Echinochloa colona* (L.) Link resistance to Propanil has been acknowledged for over a decade (Häefele *et al.* 2000). The integration of mechanical weeding provides a possible way to slow the development of Propanil-resistant ecotypes, although, as observed in this study, farmers will still opt for the limited integration of chemical control techniques. There is currently no sign that agrochemical subsidies will resume; management options that reduce herbicide requirements may consequently be attractive, especially for poorer farmers lacking capital, access to sufficient credit, or in situations where herbicide supply chains are poorly functioning. But for farmers with capital and access to agrochemicals, RMP will probably remain attractive. Conversely, adoption of the “full” ASRI system is unlikely due to heavy demands for multiple weedings and labor bottlenecks.

Conclusions and Outlook

In this study, we investigated the potential of two crop management systems, RMP and ASRI, to increase rice yields and profitability over FP. But in contrast to most SRI assessments that focus on strict FP and/or RMP comparisons, and that treat farmers as passive participants rather than active agents, we encouraged farmer ownership of these experiments by testing a fourth crop management system designed by farmers themselves. The advantages incorporating farmers’ suggestions to modify and adapt management systems were clear, as FASRI demonstrated consistently high yields and had the greatest profits in all seasons and sites studied. We conclude by suggesting that such an action research approach to on-farm experimentation could yield similar benefits elsewhere, and should consequently be encouraged.

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