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Perception by farmers of the determinants of irrigated rice yield in Mali

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Abstract

Recommendations for crop management are based on agronomic diagnoses of yield determinants at plot scale usually without the farmers being involved in the evaluation process. Farmers may consequently not apply the recommendations that do not account for their own perception of yield determination. We assumed that (i) farmers have their own perceptions of yield determination; (ii) it is possible to access these perceptions through individual discussions with farmers; (iii) subsequent group discussions allow knowledge to be exchanged between farmers and a common viewpoint to be reached; (iv) agronomists can use this common viewpoint as a basis for building improved solutions in collaboration with the farmers. In this study, we used participatory methods to identify and discuss the visual references the farmers consider the crop growth as indicators to forecast the yield of their plot and the drivers they think affect these indicators. The study was conducted in two sites in the Office du Niger irrigated rice scheme in Mali and comprised three steps: (i) individual discussions with rice producers about their perception of how yield is determined, (ii) group discussions to share their individual perceptions and reach a common viewpoint, (iii) analysis of these perceptions. Seven production indicators and 29 factors that may affect these indicators were identified. The three main indicators used by farmers were tiller abundance, hill density, and grain weight per panicle. Crop practices and constraints may prevent farmers from achieving high yields, such as a delay in the supply of fertilizers or in crop establishment. They had a complex perception of yield determination that was often close to agronomic knowledge. Here we demonstrate for the first time that farmers in the Office du Niger scheme have technical knowledge to which extension services could refer to provide relevant advice and tools for managing their constraints and improving yield.

Keywords Farmers' perceptions · Participatory approach · Yield indicators · West Africa · Rice · Office du Niger

1 Introduction

Crop yields are suboptimal and vary among fields and farmers in the same location. One role of agronomists is to identify constraints on yield and propose solutions for improvement, but farmers often do not use the proposed solutions (Bockstaller et al. 2009; Makowski et al. 2009).

According to Chatelin and Poussin (1991), this gap results from the failure to take the farmers' objectives and the conditions in which they make their decisions into consideration. Moreover, according to Toffolini et al. (2016), the farmers use their own references to assess the effects of their actions on their crop. Reducing the gap between the scientists' and the farmers' perceptions of the yield determinants should help build relevant solutions for improvement (Toffolini et al. 2016; Landais et al. 1988).

Several approaches have been developed to diagnose the variability of crop yield and performance in farming systems. These methods are either top-down farm assessments, or bottom-up, in which case they include stakeholder participation throughout the process. One method, yield component analysis, was developed and used as a diagnosis and guidance tool in irrigated rice systems in Japan (Matsushima 1966), Mali, and Senegal (Poussin et al.

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2003). Yegbemey et al. (2014) used participatory indicators of sustainability to diagnose maize cropping in Benin. Toffolini et al. (2016) examined how farmers use indicators in the choice and implementation of changes in their agricultural practices in response to the global challenges of food security, pollution, and climate change. However, a method for building applicable solutions for improving crop yield based on both agronomic knowledge and farmers' perceptions is lacking. Indeed, there are both consistencies and differences between farmers' perceptions and agronomic knowledge (produced by rice scientists). For instance, in Thailand, farmers identified poor land preparation and infestation by wild rice as major constraints, whereas scientists diagnosed plant losses at tillering due to rapid submersion and/or damage caused by rats and crabs (Crozat and Chitapong 1988). In contrast, in central Kenya, farmers' perceptions of the soil productivity was based on its color, texture and macrofauna, and the abundance of weed species, in line with agronomic knowledge (Mairura et al. 2007).

In the Office du Niger irrigation scheme (Mali), paddy yields have evolved under the influence of agronomic, socio-political, and economic drivers. Yields increased from less than 2 t.ha⁻¹ in the late 1980s to about 7 t.ha⁻¹ in the late 1990s (Coulibaly et al. 2006). This improvement was achieved through rehabilitation of the hydraulic network (allowing better control of irrigation water), general use of transplanting and of more productive varieties, and high rates of fertilization. However, the economic and social liberalization introduced by the Malian government in 1984 mainly explains why rice producers adopted innovative production techniques to intensify and diversify their production (Jamin et al. 1992). Despite this significant advance, the yields obtained today (6 t.ha⁻¹) are still below potential yields (8 to 10 t.ha⁻¹) and still vary among producers (Brondeau 2011). The aim of this study was to analyze farmers' perceptions of the determinants of rice yield, the visual references they use to assess the growth of rice in their plots, and which drivers (among climate, soil, practices, socio-economic environment) they think influence rice growth directly or indirectly. We used a participatory approach with rice producers to identify their perceptions. We analyzed the differences and convergences among producers and identified the points that were in accordance with—or differed from—agronomic knowledge, to explain how and why these differences emerged. We assumed that (i) farmers have their own perceptions of the determinants of yield; (ii) it is possible to access these perceptions through individual discussions with farmers; (iii) subsequent group discussions allow the exchange of knowledge between farmers and the construction of a common viewpoint; (iv) this common viewpoint provides the basis for agronomists to build solutions for yield improvement in collaboration with the farmers.

2 Materials and methods

2.1 Study sites

The Office du Niger scheme was created in the 1930s in the upstream inner delta of the Niger River in Mali. This region is located in the Sudano-Sahelian zone characterized by a semi-arid climate with three distinct seasons: a rainy season from June to October, with an average annual rainfall of about 400 to 500 mm and a daily average temperature of 28 °C; a cold dry season from November to February, with daily minimum temperature often lower than 16.6 °C; and a hot dry season from March to May, with daily maximum temperature often higher than 40 °C. These temperatures influence rice growth through delayed germination and slower vegetative growth in cold dry season and spikelet sterility during flowering in cold or hot dry seasons.

The public Office du Niger operator was responsible for water management and made recommendations for rice cropping derived from local research. The Office du Niger scheme accounts for about 100,000 ha irrigated land, used by about 45,000 farmers mainly to cultivate rice (Adamczewski et al. 2015). Most of these farmers (or their fathers) have been growing rice since the creation of the irrigated scheme and have been engaged in an intensification process since the late 1980s, as described above. We thus assumed they had gained considerable experience in rice cropping using different systems (e.g., direct sowing and transplanting; single and double rice cropping systems; animal traction and mechanization). Two irrigation sectors, corresponding to two villages, Koyan (KO2; 14.248444° N and 5.974448° W) and Retail-IV (R-IV; 14.302614° N and 5.931578° W), with contrasted conditions, were selected for the surveys. KO2, located upstream in the irrigation network, has permanent access to irrigation water all year round, and currently, two crops of rice are cultivated a year, one in the dry season (from February to June) and one in the wet season (from June to November). R-IV, located downstream in the irrigation network, often lacks irrigation water during the dry season, and currently, only one crop is cultivated a year, in the wet season; moreover, many plots in R-IV have drainage and water control problems.

In both sites, transplanting is the usual method of crop establishment. However, some producers also use direct seeding with pre-germinated seeds, especially where water control is not good or in plots located on higher land. Average rice yield in 2015 was about 6.3 t.ha⁻¹ in the rainy season and about 5.4 t.ha⁻¹ in the dry season.

2.2 Indicators and factors

Farmers define indicators differently. For instance, in central Kenya, the criteria the farmers used to identify productive and non-productive plots were yield performance and

morphological soil characteristics (Mairura et al. 2007; Murage et al. 2000). In Latin America and Africa, Barrios et al. (2006) developed a participatory approach to identify indicators used by farmers to characterize soil quality, in order to build language that could be shared between farmers, extension workers and scientists, and to provide solutions for better management of soil resources; local indicators included both soil and plot characteristics, and criteria on crop performance. According to Toffolini et al. (2016), French farmers used indicators related to the impacts of their practices and used them as a decision tool for the choice of agricultural practices or strategies.

In this study, we define “indicators” as visual references in the rice crop used by farmers in Office du Niger to roughly evaluate the expected yield of their plot. According to Toffolini et al. (2016), this kind of indicator corresponds to quantitative, but not measured, information that refers to a relative reference: for instance, the farmers compare the distance between rice hills with the length of their hand to assess the density of hills in a plot. We define a “factor” as a driver (climate, soil, practice, or component of the socio-economic environment) that the farmers think has a direct or indirect impact on rice growth through one or several “indicators.” Some authors (e.g., Mairura et al. 2007) would consider some of our “factors” to be indicators. To prevent confusion, our farmers’ indicators and factors are written between simple quotes in the rest of the text.

2.3 Survey methodology

The survey was conducted in two stages. The first stage comprised individual interviews with 37 voluntary producers. Following a general meeting held in each village to explain the aim of the study, 18 farmers in KO2 (out of a total of 195 farmers in this sector) and 12 farmers in R-IV (out of a total of 163 farmers in this sector) were interviewed, without receiving any training beforehand. To understand how agricultural supervisors perceive the determinants of yield, the same interviews were held with seven research and development officers (R&D officers) with the Office du Niger development operator, and the Institut d’Economie Rurale, the Malian institute of agricultural research, all of whom had themselves been growing rice for many years.

Semi-open interviews were conducted in the field (next to the producer’s plot), using the local language (Bambara) with the person directly in charge of crop management (who is not necessarily the owner of the plot). The interview comprised a list of open questions, for instance: “Do you use any visual observations (“indicators”) to judge if your rice yield will be good or bad? What are these most important visual references (“indicators”)”? How and when do you observe each one? Are they linked, and if so, how? Do any drivers (“factors”) directly or indirectly influence these visual references (“indicators”)”? How?

The discussion guide was checked by senior scientists. These interviews enabled the drawing of 37 diagrams (30 by farmers, 7 by R&D agents), representing the different producers’ points of view on the determinants of irrigated rice yield. This small sample is not statically representative of all the local farmers, but these individual points of view were subsequently shared and discussed in general open meetings held in each village in order to reduce possible biases.

In the second stage, a farmers’ meeting was held in each village, with 25 participants in KO2 and 26 participants in R-IV, including some of the farmers who had been interviewed individually (Fig. 1). The aim of each meeting was to share and discuss the individual points of view with a larger panel of producers from the same village, in order to check if there was a common perception or not. All the “indicators” cited in the first step were written on the board and explained to participants. This list of “indicators” was then discussed and participants added any other “indicators” they thought were missing, and to explain how and when they observed them. Then, collectively, “indicators” were ranked based on their importance in determining yield and the “factors” that may influence them.

2.4 Data analysis

The interviews were transcribed and the meetings were recorded to collect information on the “indicators” and “factors” cited by the producers. First, “indicators” (or “factors”) corresponding to the same (or very close) visual reference (or driver) were pooled using the same word. Then, the number of times each “indicator” was cited by the producers was totaled (Table 1), and the same was done for each “factor” influencing each “indicator.” The total number of citations of each “factor”

Fig. 1 A farmer observing rice panicle length as yield indicator in his plot and a collective discussion on yield indicators



Table 1 “Indicators” cited by the 37 producers according to their origin (K02: Koyan village; R-IV: Retail-IV village; R&D: research and development officers) and ranked according to the number of times they were cited

“Indicator”	K02 farmers	R-IV farmers	R&D officers	Total
“Abundance of tillers per hill”	15	11	7	33
“Hill density”	15	7	5	27
“Grain weight per panicle”	13	7	2	22
“Panicle length”	11	6	2	19
“Abundance of grains per panicle”	8	3	3	14
“Panicle density”	1	2	2	5
“Abundance of empty grains per panicle”	2	1	0	3
Total citations	65	39	21	125

correspond to the sum of its citations for the seven indicators cited (Table 2). First, “indicators” and “factors” were ranked according to the number of times they were cited. Then, the similarities and differences among farmers’ perceptions and agronomic knowledge were analyzed.

3 Results and discussion

3.1 “Indicators” of rice production in a plot

Producers (farmers and R&D officers) cited seven “indicators” of rice production in a plot (Table 1). Each producer cited between 2 and 5 “indicators” (average 3), resulting in a total of 125 statements of “indicators” cited. The most frequently cited were the “abundance of tillers per hill” (33/125) and “hill density” (27/125), closely followed by “grain weight per panicle” (22/125), “panicle length” (19/125), and “abundance of grains per panicle” (14/125). However, the “indicators” were not always seen and named in the same way by all producers.

Like agronomists (Matsushima 1966; Yoshida 1981), rice producers considered “abundance of tillers” per hill to be an important component of paddy production. Producers wanted to obtain at least 30 tillers per hill. They assessed “abundance of tillers per hill” at the end of tillering by visual observation: if irrigation water was visible between the hills, the “abundance of tillers per hill” was considered to be too low; if the “abundance of tillers per hill” was sufficient, no water should be visible. However, both “hill density” and “abundance of tillers per hill” occupy space. Through this “abundance of tillers per hill,” the producers were thus assessing both hill density and tillering and the capacity of the crop cover to intercept incident solar radiation. Producers evaluated “hill density” after transplanting by comparing the distance between two consecutive hills using hand length (around 20 cm); this corresponds to the locally recommended hill spacing $20 \times 20 \text{ cm}^2$ (PRI 2009). Despite the rough assessment, farmers had a good perception of hill density. Producers might use this evaluation of “hill density” to decide

on additional transplanting to replace dead plants or to correct too low transplanting density.

Unlike agronomists, who count the grains per panicle and measure the average grain weight, producers evaluated the “grain weight per panicle” at maturity or during harvest by observing the shape of the panicle, a curved shape indicating numerous well-filled grains. Farmers therefore used a visual reference that combined different yield variables: spikelet number per panicle, rate of filled spikelets and average single grain weight. The abundance of curve-shaped panicles was consequently an “indicator” of a good yield. Other producers observed “panicle length” to estimate the abundance of grains. “Grain weight per panicle,” “panicle length” and “abundance of grains per panicle” were therefore slightly different perceptions of the same information that can be termed “single panicle weight”. Together, these three “indicators” accounted for 55/125 citations, and “single panicle weight” was therefore the most important “indicator.”

Rice scientists consider panicle density to be a major yield component. For instance, Ottis and Talbert (2005) report a high correlation between yield and panicle density, and Gravois and Helms (1992) state that optimum rice yield cannot be achieved without optimum panicle density. In contrast to these scientists, “panicle density” was cited by only five producers. Yet producers may consider “panicle density” as a direct consequence of “hill density” and “abundance of tillers per hill,” which they consider to be major “indicators.” At heading or flowering, producers evaluated “panicle density” (or abundance) through tactile sensing: at harvesting, they put their hands in the rice to evaluate how often they were filled with panicles. As also observed by Dingkuhn and Le Gal (1996) in Senegal, the homogeneity of panicle maturity at harvest was not taken into consideration by our Malian producers, who waited for the maturity of the whole panicle to start harvesting, as did the Senegalese farmers.

Finally, three farmers cited the “abundance of empty grains per panicle.” They evaluated it by looking at the abundance of “white grains” (indicating unfilled spikelets) on the panicles compared to the abundance of “colored grains” (indicating fully ripened spikelets). They also observed the presence of whole or

Table 2 Factors that directly or indirectly influence indicators ranked according to the number of times they were cited (KO2: Koyan village; R-IV: Retail-IV village; R&D: research and development officers)

	KO2 farmers	R-IV farmers	R&D officers	Total
“Factor” with direct effect				
“Rate and mode of application of fertilizers”	32	16	7	55
“Management of floodwater in the plot”	9	7	6	22
“Distance between hills at transplanting”	13	3	5	21
“Age of seedling at transplanting”	10	5	4	19
“Land preparation”	5	3	4	12
“Weed management”	6	3	3	12
“Flooding of plot”	4	4	3	11
“Type of workers used for transplanting”	3	4	3	10
“Application of organic manure”	6	2	1	9
“Insects and diseases”	5	1	1	7
“Quality of seed used”	6	1	0	7
“Variety used”	1	4	1	6
“Replacement of missing hills”	4	0	2	6
“Abundance of weeds”	2	3	1	6
“Availability of seedlings at transplanting”	3	2	1	6
“Length of the soil drying period between two cropping seasons”	3	0	2	5
“Sowing date in nursery”	3	2	0	5
“Care of the nursery”	3	0	2	5
“Seed rate”	2	0	2	4
“Type of soil”	1	1	2	4
“Lack of leveling”	1	2	0	3
“Clearing of field borders”	2	0	0	2
“Air temperature too low”	0	1	0	1
Total citations	124	64	50	238
“Factor” with indirect effect				
“Financial resources”	4	3	1	8
“Drainage problems”	2	5	1	8
“Access to the plots”	0	5	0	5
“Date water was released in the irrigation canal”	0	5	0	5
“Ownership of equipment”	2	2	0	4
“Access to credit”	1	3	0	4
Total citations	9	23	2	34

partly empty panicles. For rice scientists, a high percentage of empty grains results from either spikelet sterility due to cold injury, i.e., when the daily temperature drops below 20 °C at flowering or bad grain filling during the maturation stage (Yoshida 1981). For farmers, favorable growing conditions (especially nursery sowing in early June) may help reduce the “abundance of empty grains per panicle” by avoiding the effect of later cold weather during flowering (encountered when nursery sowing is done in late July). Since the farmers had several years of experience in paddy cropping, they might have experience in managing their cropping calendar, unless some “factors” are beyond their control.

Most of the producers cited three “indicators,” the first two concerning the vegetative stage (“tiller abundance” and “hill

density”) and the third concerning the reproductive stage. Most of the producers thus considered both the vegetative and the reproductive stages, the vegetative stage being the most important in their opinion, based on the “indicators” cited (number and citation). The farmers’ first three “indicators” were “abundance of tillers per hill,” “hill density” and “grain weight per panicle,” whereas the R&D officers considered “panicle length” as the third “indicator”; but both “indicators” are close to “single panicle weight”. Farmers and R&D officers therefore had similar perceptions of the rice yield of a plot. Both evaluated the stem density resulting from the vegetative stage, and the “grain weight per panicle” resulting from the reproductive stage. Indeed, yield results roughly from multiplying these two components.

3.2 Contributions of the group discussions

During the village meetings, the list of “indicators” remained the same and how they ranked was partly or completely confirmed. This result shows that our small sample did not introduce a major bias. For instance, the farmers’ perception of the importance of the vegetative growth stage (“hill density” and “abundance of tillers per hill”) did not change from the individual to the group discussion. In the village of KO2, “indicators” were collectively ranked as follows: “hill density,” “abundance of tillers per hill,” “panicle density,” “panicle length,” “abundance of grains per panicle,” “grain weight per panicle,” and “abundance of empty grains per panicle.” In R-IV, they were ranked as follows: “hill density,” “abundance of tillers per hill,” “abundance of grains per panicle,” “panicle density,” “grain weight per panicle,” and “abundance of empty grains per panicle.” The rank of “panicle density” was greatly improved during the collective discussion in both villages (ranked 3rd at KO2, and 4th at R-IV). This underlines the effect of group dynamics: exchanges between farmers led to a common perception that was closer to agronomic knowledge, as stated by Matsushima (1966) and Yoshida (1981).

3.3 “Factors” influencing the “indicators”

Producers cited many “factors” that influence rice yield in their plot. They distinguished direct factors that affect “indicators,” such as the impact of the “rate and mode of application of fertilizers” on the “abundance of tillers per hill” for instance, and indirect “factors” impacting direct “factors,” such as the “financial resources” that make it possible to buy fertilizers (sufficiently early and in the right quantity), which affects the “rate and application mode of fertilizers,” which, in turn influences the “abundance of tillers per hill.”

3.3.1 Direct “factors”

Twenty-three direct “factors” (Table 2) were cited, 18 of which were related to crop practices. The application of fertilizers was the most frequently cited direct “factor” (55/238) by all three groups of producers (farmers from KO2 and R-IV, and R&D officers). The producers therefore perceived the importance of nutrient supply in determining yield. Conversely, the type of soil was one of the least cited “factors,” because the producers considered that the soil is what it is, and that they are not able to do anything about it, although in fact, they can improve soil fertility by applying fertilizers. The next most frequently cited “factors” were the “management of floodwater in the plot” (22/238), the “distance between hills at transplanting” (21/238), and the “age of seedlings at transplanting” (19/238). “Management of floodwater” in the plot was ranked higher in R-IV, where access to water is more difficult than in KO2. These three direct “factors”

influence the transplanting conditions and confirm the importance of “indicators” relating to “hill density” and “abundance of tillers per hill.” Other direct “factors” also concern transplanting: the “type of worker used for transplanting,” because family workers transplant more hills per m² than piecework employees; the “availability of seedlings at transplanting” and the “replacement of missing hills,” which influence “hill density”; and finally, “flooding of the plot,” which prevents the use of young seedlings at transplanting (because they are too short) and also influences the “abundance of tillers per hill.” “Care of the nursery” and the “seed rate” also influence the “availability” and “quality of seedlings,” and consequently “hill density” and the “abundance of tillers per hill.” Other “factors,” such as the “type of soil,” “lack of leveling,” and too “low air temperature” (14/238), were less frequently cited, even if, in the scientists’ opinion, they have a notable influence on paddy yield. Like temperature or the type of soil, producers consider these “factors” as out of their control or do not want to undertake the work required to correct leveling and bunding. For instance, in R-IV, tertiary construction (irrigation and drainage channels, leveling of plots, and bunding) was left to farmers. This task was often beyond the farmers’ capacity nor they did not have the necessary equipment, resulting in poor leveling and bunding, and hence in irrigation and drainage problems. The length of the soil drying period between two cropping seasons was not taken into consideration by farmers in R-IV because they did not have sufficient water to cultivate two rice crops a year. Indeed, cumulative delays in the first cropping season (from February to May) affect the start of the following cropping season (from June to November), which is the main season in terms of cultivated area. Moreover, the use of medium duration varieties (115–125 days) instead of early duration ones (90 to 110 days) in the first season, accentuated the delay at the beginning of the second season.

3.3.2 Indirect “factors”

Six indirect “factors” (Table 2) were cited. “Financial resources” and “access to credit” allow the producers to buy certified seeds and fertilizers, and to hire workers for transplanting at the right time, or buy/rent the equipment needed for land preparation. The “date water is released into the irrigation canal” influences sowing date and irrigation calendar, which in turn influences the whole growing season and the starting date of the following cropping season. Drainage problems affect water management in the plot, which influences the “abundance of tillers per hill,” weed management and fertilizer losses. Bélières et al. (2011) showed that farmers’ difficulties in accessing inputs, credit, and equipment, and constraints related to water management contribute to the drop in productivity in the Office du Niger area.

3.3.3 “Factors” influencing the “abundance of tillers per hill”

KO2 farmers cited 15 “factors” that affect the “abundance of tillers per hill,” farmers in R-IV cited 14 “factors,” and R&D officers cited 15 “factors.” The “rate and mode of application of fertilizers,” the “age of seedlings at transplanting” and “management of floodwater in the plot” were by far the most frequently cited direct “factors”; “weed management” came in the fourth position. To promote “abundance of tillers per hill,” producers applied fertilizers, maintained a shallow layer of water in the field and weeded by hand or used chemical herbicides. In addition, they used seedlings younger than 35 days. Farmers’ perception of suitable plant age at transplanting is older than the recommended 21 days. Farmers use older seedlings because of the delay in land preparation (they often do not have enough equipment to prepare the land earlier) or a delay in the delivery of irrigation water. Moreover, as reported by Poussin et al. (2003) in Senegal, many farmers use older, and therefore taller, seedlings as they are less sensitive to a deep layer of water in plots with poor leveling or located in lowland areas. They also transplant more seedlings per hill (more than 4 seedlings per hill) than the recommended 2 or 3 seedlings per hill, because they know that old seedlings have less tillering capacity (Dingkuhn et al. 1990). Our producers’ perceptions of “factors” influencing “tiller abundance” are the same as those reported in Matsushima (1966) and Tanaka et al. (2013).

3.3.4 “Factors” influencing “hill density”

KO2 farmers cited 10 “factors” and both farmers in R-IV and R&D officers cited six “factors” influencing “hill density.” The most frequently cited “factors” were “distance between hills at transplanting,” “type of workers used for transplanting,” “availability of seedlings at transplanting,” and “land preparation.”

Farmers in KO2 cited the “distance between hills at transplanting” as the main “factor,” whereas farmers and R&D officers in R-IV cited the “type of worker used for transplanting.” The interviewed farmers said that the distance between two hills should be less than or equal to a man’s hand (about 20 cm), which is in line with local research results and recommendations. When not enough seedlings are available, workers increase the space between the hills in order to transplant the whole field, even though they know the “hill density” will not be optimal and old seedlings reduce tillering capacity. Adequate care of the nursery, the use of a sufficient number of healthy seeds for pre-germination before sowing (seed rate and quality of seed used) help obtain sufficient seedlings. The high price of certified seeds ($0.58 \text{ €} \cdot \text{kg}^{-1}$ compared to $0.23 \text{ €} \cdot \text{kg}^{-1}$ for paddy) limits their use, even if farmers know the important role they play in the potential yield of their plot. To meet their seed needs, farmers use paddy from previous seasons as seed or exchange seeds with other farmers.

Farmers believe the quality of work affects “hill density.” Non-family workers, who are paid per hectare planted, try to finish transplanting as quickly as possible. This often leads to lower hill density than transplanting done by family members. In addition, farmers perceive that a shallow layer of water in the plot at transplanting (flooding of plot and lack of leveling prevents the right management of floodwater in the plot), contributes to suitable “hill density.” This perception is in line with the works of Anbumozhi et al. (1998) who explained that a water depth exceeding 15 cm damages the roots and is responsible for 20% to 37% of plant mortality after transplanting.

3.3.5 “Factors” influencing “panicle length”

The main “factors” cited as influencing “panicle length” were the rate and “mode of application of fertilizers”, the “variety used,” and a “deep layer of water in the plot” due to flooding of the plot or bad management of floodwater in the plot. The “factor” most frequently cited by farmers was the “rate and mode of application of fertilizers,” whereas R&D officers cited the “distance between hills at transplanting” and the “flooding of the plot.” Farmers also considered the variety of cultivated rice (“variety used”) to be an important “factor.” For example, they say that Kogoni 91-1 (the variety the most frequently cultivated in the wet season today) has longer panicles than IR 32 307-107-3-2-2 (the short duration variety most cultivated in the dry season). This farmers’ perception is in agreement with the researchers’ opinion that potential “panicle length” is a varietal characteristic, but that the use of manure or fertilizers and good growing conditions can help achieve this potential (Matsushima 1966).

3.4 Diagrams of yield determination

Farmers’ perception of yield determinants varied from one farmer to another, especially the number of “indicators” they use. Two contrasted cases are presented and discussed here: the first one (Fig. 2) comes from a farmer who considered only two “indicators” influenced by four direct “factors”; the second one (Fig. 3) from a farmer who considered five “indicators” influenced by seven direct and indirect “factors.” In both cases, “indicators” from both vegetative and reproductive stages were considered.

In the first case, the farmer from R-IV had a simple perception of yield determination based on the “abundance of tillers per hill” observed during the vegetative stage, and the “abundance of grains per panicle” observed at the end of the reproductive stage, and four direct “factors” influencing them. He focused on good land preparation and three applications of fertilizer (N and P) (only 15 days apart, which is very close because a period of at least 21 days is recommended between consecutive fertilizer applications) at the total rates of 120N and 30P (the recommendations are 120N and 20P), and also

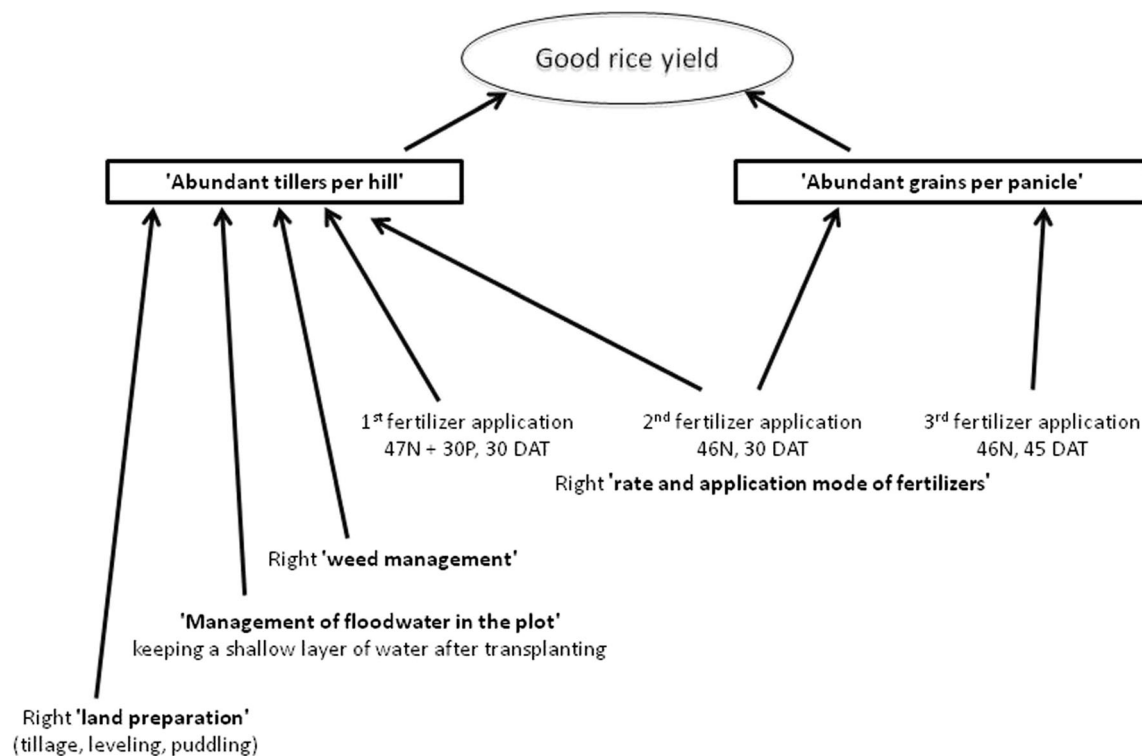


Fig. 2 Sample diagram of yield determinants produced by Madou (farmer in the village of Retail-IV), who used two “indicators” (“abundance of tillers per hill” and “abundance of grains per panicle”). Farmer’s objective is written inside an oval; each “indicator” is written

inside a rectangle; impact of “direct factor” is represented with a solid line; impact of “indirect indicator” is represented with a dotted line; xN and xP signify N and P rates (kg.ha⁻¹); DAT signifies “days after transplanting”

recommends weeding and maintaining a shallow layer of water (5 cm) after transplanting. In his opinion, good land preparation and water management favor “abundance of tillers per hill,” as described by Wopereis et al. (1999). However, his first fertilizer application was later than recommended (first fertilizer application at transplanting). This farmer, like other farmers in the Office du Niger, focuses on his major irrigation and drainage constraints, due to poor soil leveling, which affect hill density and tillering, rather than trying to manage and achieve all the crop variables. However, during the farmers’ meetings, this type of producer benefits from exchanges with other producers who focus on other constraints and “indicators,” or have a more detailed perception of yield determination.

The second farmer, from KO2, considered five “indicators” (“hill density,” “abundance of tillers per hill,” “panicle length,” “abundance of grains per panicle,” and “abundance of empty grains per panicle”), influenced by six direct “factors” (“distance between hills at transplanting,” “age of seedling at transplanting,” “weed management,” “management of floodwater in the plot,” “rate and mode of application of fertilizers,” “insects and diseases”) and one indirect “factor” (“ownership of equipment”), and therefore had a more detailed perception of the determinants of yield. He first focused on transplanting (30-day old seedlings, 3 or 4 seedlings per hill, and with spaces between hills no wider than 30 cm) and

second on fertilization, with two applications of N and P completed with K and trace elements, S and Zn. The aim of the first fertilizer application was to promote the “abundance of tillers per hill,” the second to promote “panicle length,” the “abundance of grains per panicle.” This farmer also recommended maintaining a shallow layer of water (5 cm) in the plot after transplanting and manual weeding or the use of herbicides to promote the “abundance of tillers per hill,” and taking care to control “insects and diseases,” which could increase the “abundance of empty grains per panicle.” This farmer’s perception of the determinants of yield using five “indicators” referring to both the vegetative and reproductive growth stages and clearly defined “factors,” was very close to the rice scientists’ perception. However, like the first farmer, this second one did not apply the recommendations: the first fertilizer (15 DAT) was later than recommended (at transplanting or 3 to 4 DAT).

In both cases (as in almost all of the 37 cases), the farmers focused first on the quality of rice at planting to obtain high “abundance of tillers per hill,” and second on fertilizer applications to promote high vegetative growth and to achieve high “abundance of grains per panicle.” However, the first farmer could not achieve high “abundance of tillers per hill” without high “hill density” (and young seedlings) at transplanting; his N and P fertilizer rates were in line with those recommended,

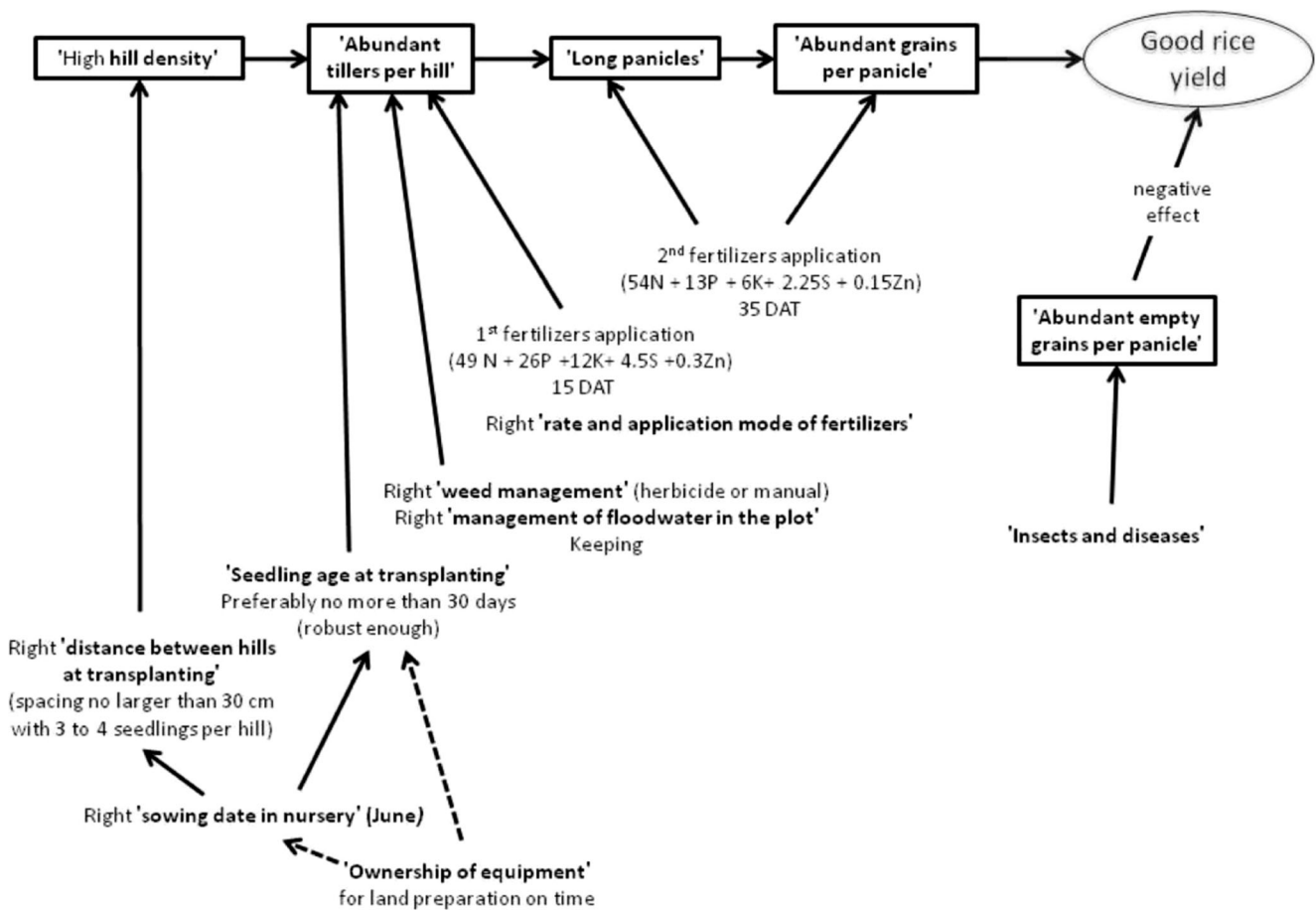


Fig. 3 Sample diagram of yield determinants produced by Issa (farmer in the village of Koyan) who used five “indicators” (“hill density,” “abundance of tillers per hill,” “panicle length,” “abundance of grain per panicle,” “abundance of empty grains”). Farmer’s objective is

written inside an oval; each “indicator” is written inside a rectangle; impact of “direct factor” is represented with a solid line; impact of “indirect indicator” is represented with a dotted line; xN and xP signify N and P rates (kg.ha⁻¹); DAT signifies “days after transplanting”

but the first application was late and the three split applications of fertilizer were too close. In contrast, the second farmer applied fertilizer twice (20 days apart) but also applied K, S, and Zn, which are not recommended (but perhaps the soil in his plot lacked these elements because of the two crops grown per year). However, the N fertilizer rate was low and the first application was too late to reach his objective of numerous grains per panicle.

In the Office du Niger, fertilizers, based on a recommended rate of 120N + 20P, are subsidized and sold at the uniform price of 0.33 €.kg⁻¹ for urea (66% N) and diammonium phosphate (18% N and 20% P). Applying more than the recommended rates or another type of fertilizer, requires purchasing it on the market at a non-subsidized price (0.42 €.kg⁻¹ for urea and 0.53 €.kg⁻¹ for diammonium phosphate). Farmers’ financial resources therefore explain the differences in fertilizers (type and rate) between them. The first fertilizer application is often late, as seen in these both cases. This delay is generally due to a delay in access to subsidized fertilizers, which involves obtaining the subsidy voucher established and delivered by the Office du Niger operator.

4 Conclusion

Farmers do have perceptions of the determinants of rice yield: they cite “indicators” that refer to the potential yield of their plots and “factors” with a direct or an indirect influence on yield through these “indicators.” Variations in their perceptions convey the different constraints they face. For instance, farmers in R-IV focus on low rice tillering in accordance with poor leveling or drainage problems, while farmers in KO2 explain their need for equipment to reduce the delay in rice planting in the first cropping season and its consequence for the success of the following cropping season. In the individual surveys, “indicators” related to the vegetative stage were considered to be more important than “indicators” related to the reproductive stage. While “panicle density” was not considered as a main “indicator” by most of the farmers in the individual surveys, subsequent group discussions greatly changed its importance. Thus, the perceptions cited by the farmers may vary depending on the study approach (individual or collective) or on the period when the interview takes place (the vegetative or reproductive stage). However, each farmer uses

between 2 and 5 “indicators,” generally referring to both the vegetative and reproductive stages, showing that they include the whole rice growing period in their perception of the determinants of yield. They cite many “factors” that have a direct or indirect influence on yield, most related to their crop practices, evidence for the different constraints they face and that are not the same at the two sites. Farmers therefore adapt their strategies to the resources available and to the constrained environment and include these adaptations in their perceptions of the determinants of yield.

The dynamic effect of group discussion enabled exchanges between farmers and brought their perceptions closer to agronomic knowledge. It allowed farmers to discuss the “indicators,” and the “factors” that may influence them, and compare simpler and more complex points of views. What is more, the farmers established links between the determinants of rice yield and technical details (planting of young seedlings, proper land preparation), organizational “factors” (cropping calendar), policy “factors” (the availability of subsidized fertilizers), and economic “factors” (ownership of the necessary equipment), evidence that farmers have knowledge to which extension services should refer before selecting the most appropriate advisory tools.

The differences between the farmers’ perception and the agronomic knowledge are mainly related to a difference in the way of apprehending reality and acting. On the one hand, agronomists use yield components to identify constraints on yield: they split yield up into measured density or growth of rice organs (grain density, average grain weight) influenced by biotic or abiotic conditions. Based on this diagnosis, they test different practices in order to design optimal crop management, but without taking socio-economic constraints into account. On the other hand, farmers use visual references in the crop as “indicators” of the potential yield of their plot or in order to decide on an action. In addition, from the farmers’ point of view, these “indicators” are influenced by “factors” that may or may not be within their control. The farmers’ perception of the determinants of yield gives more importance to the “indicators” and “factors” that are affected by their main constraints. Thus, the gaps between the recommendations the farmers receive and their practices are not due to ignorance, but to their adaptation to the constraints that prevent them from applying the recommendations. This knowledge of farmers’ perception will therefore allow the scientists (not only rice scientists) and the agents in charge of the recommendations to focus on these constraints and to build appropriate solutions in collaboration with the farmers. Participatory research with the farmers in order to build these solutions should therefore also involve these agents in charge of the recommendations.

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Compliance with ethical standards

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Conflict of interest The authors declare that they have no conflict of interest.

References

- Adamczewski A, Hertzog T, Jamin JY, Tonneau JP (2015) Competition for irrigated land: inequitable land management in the Office du Niger (Mali). *Int J Sustain Dev* 18(3):161–179. <https://doi.org/10.1504/IJSD.2015.070237>
- Anbumozhi V, Yamaji E, Tabuchi T (1998) Rice crop growth and yield as influenced by changes in ponding water depth, water regime and fertilization level. *Agric Water Manag* 37:241–253. [https://doi.org/10.1016/S0378-3774\(98\)00041-9](https://doi.org/10.1016/S0378-3774(98)00041-9)
- Barrios E, Delve RJ, Bekunda M, Mowo J, Agunda J, Ramisch J, Trejo MT, Thomas RJ (2006) Indicators of soil quality: a South–South development of a methodological guide for linking local and technical knowledge. *Geoderma* 135:248–259
- Bélières J-F, Hilhorst T, Kébé D et al (2011) Irrigation et pauvreté: le cas de l’Office du Niger au Mali. *Cah Agric* 20:144–149
- Bockstaller C, Guichard L, Makowski D et al (2009) Agri-environmental indicators to assess cropping and farming systems: a review. In: Lichtfouse E, Navarrete M, Debaeke P, Véronique S, Alberola C (eds) *Sustainable Agriculture*. Springer, Dordrecht, pp 725–738
- Brondeau F (2011) L’agro-business à l’assaut des terres irriguées de l’Office du Niger (Mali). *Cah Agric* 20:136–143
- Chatelin M-H, Poussin J-C (1991) Diagnostic d’exploitation agricole: apport de la simulation. *Économie Rurale* 206:77–80
- Coulibaly YM, Bélières J-F, Koné Y (2006) Les exploitations agricoles familiales du périmètre irrigué de l’Office du Niger au Mali: évolutions et perspectives. *Cah Agric* 15:562–569
- Crozat Y, Chitapong P (1988) The on-farm agronomical survey: a tool for grading limiting factors of a crop and designing new technologies. In: Trébuil G (ed) *Farming systems research and development in Thailand. Illustrated methodological considerations and recent advances*. GRET/Prince of Songkla University, France/Thailand, pp 87–110
- Dingkuhn M, Le Gal P-Y (1996) Effect of drainage date on yield and dry matter partitioning in irrigated rice. *Field Crops Res* 46:117–126
- Dingkuhn M, Schnier HF, De Datta SK et al (1990) Nitrogen fertilization of direct-seeded flooded vs. transplanted rice: II. Interactions among canopy properties. *Crop Sci* 30:1284–1292. <https://doi.org/10.2135/cropsci1990.0011183X003000060025x>
- Gravois KA, Helms RS (1992) Path analysis of rice yield and yield components as affected by seeding rate. *Agron J* 84:1–4. <https://doi.org/10.2134/agronj1992.00021962008400010001x>
- Jamin J-Y, Berete O, Sanogo MK (1992) Intensification de la riziculture à Niono au Mali. In: Bosc PM, Dollé V, Garin P, Yung JM (eds) *Le développement agricole au Sahel. Tome III : Terrains et innovations*. Cirad, Montpellier, pp 153–185
- Landais É, Deffontaines J-P, Benoit M (1988) Les pratiques des agriculteurs point de vue sur un courant nouveau de la recherche agronomique. *Etudes Rurales* 109:125–158

- Mairura FS, Mugendi DN, Mwanje JI, Ramisch JJ, Mbugua PK, Chianu JN (2007) Integrating scientific and farmers' evaluation of soil quality indicators in Central Kenya. *Geoderma* 139:134–143. <https://doi.org/10.1016/j.geoderma.2007.01.019>
- Makowski D, Tichit M, Guichard L, van Keulen H, Beaudoin N (2009) Measuring the accuracy of agro-environmental indicators. *J Environ Manag* 90:S139–S146
- Matsushima S (1966) Crop science in rice. Theory of yield determination and its application. Fuji Publishing Co, Tokyo
- Murage EW, Karanja NK, Smithson PC, Woomer PL (2000) Diagnostic indicators of soil quality in productive and non-productive smallholders' fields of Kenya's Central Highlands. *Agric Ecosyst Environ* 79:1–8
- Ottis BV, Talbert RE (2005) Rice yield components as affected by cultivar and seeding rate. *Agron J* 97:1622–1625. <https://doi.org/10.2134/agronj2005.0123>
- Poussin J-C, Wopereis MCS, Debouzie D, Maeght J-L (2003) Determinants of irrigated rice yield in the Senegal River valley. *Eur J Agron* 19:341–356. [https://doi.org/10.1016/S1161-0301\(02\)00078-3](https://doi.org/10.1016/S1161-0301(02)00078-3)
- Tanaka A, Saito K, Azoma K, Kobayashi K (2013) Factors affecting variation in farm yields of irrigated lowland rice in southern-central Benin. *Eur J Agron* 44:46–53. <https://doi.org/10.1016/j.eja.2012.08.002>
- Toffolini Q, Jeuffroy M-H, Prost L (2016) Indicators used by farmers to design agricultural systems: a survey. *Agron Sustain Dev* 36:1–14. <https://doi.org/10.1007/s13593-015-0340-z>
- Wopereis MCS, Donovan C, Nebie B et al (1999) Soil fertility management in irrigated rice systems in the Sahel and Savanna regions of West Africa: Part I Agronomic analysis. *Field Crops Res* 61:125–145. [https://doi.org/10.1016/S0378-4290\(98\)00154-3](https://doi.org/10.1016/S0378-4290(98)00154-3)
- Yegbemey RN, Yabi JA, Dossa CSG, Bauer S (2014) Novel participatory indicators of sustainability reveal weaknesses of maize cropping in Benin. *Agron Sustain Dev* 34:909–920. <https://doi.org/10.1007/s13593-014-0214-9>
- Yoshida S (1981) Fundamentals of rice crop science. Int. Rice Res. Inst, Los Banos