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Management practices and rice grain yield of farmers after participation in a joint experimentation

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Low productivity of rice in Uganda is attributed to sub-optimal production practices related to soil nutrient, crop and weed management. Application of improved management practices could enhance productivity. Returning 1 year after a joint experimentation in which different components of recommended agronomic practices (RAP) for rice were tested, we assessed change in management practices and grain yield of participating farmers (participated in joint experimentation) and non-participating farmers (did not participate) with plots in the same irrigation scheme. Participating farmers belonging to the lower-yielding farmers under farmers' practice (FP) during joint experimentation improved their management practices, compared with the middle- and top-yielding farmers. Sixty-one, 24 and 7% of lower-, middle- and top-yielding farmers, respectively, weeded earlier after experimentation compared with weeding time under FP during joint experimentation. Seventy-nine percent of lower-yielding farmers used fertiliser after experimentation compared with 18% during experimentation, with a higher N rate increase than middle- and top-yielding farmers. Overall, participating farmers transplanted and weeded earlier, and applied slightly higher N rates compared with non-participating farmers. Top-yielding farmers had significantly ($p = 0.03$) higher grain yield, followed by middle- and lower-yielding farmers. However, lower-yielding farmers made significantly ($p < 0.001$) higher yield gain than middle- and top-yielding farmers. A paired t-test showed that average yield gain was 1,358 (1,027−1,689), 473 (252−695) and −91.7 (−397−213) kg ha^{-1}, respectively, for lower-, middle- and top-yielding farmers. Participating farmers had higher grain yield (4,125 kg ha^{-1}) than non-participating farmers (3,893 kg ha^{-1}). Three farm types were identified that differed in application of RAP, however, with small differences in household characteristics. The farm type with higher fertiliser use in nursery and field, line transplanting, timely weeding and higher N rate had the highest grain yield. We conclude that joint experimentation had a larger effect on raising yield of lower-yielding farmers, bringing farmers closer in their management and outputs. Lack of differences among farm households could indicate that wealth is not crucial in innovation adoption in this production system.

KEYWORDS

joint experimentation, participating farmers, non-participating farmers, recommended agronomic practices, *Oryza sativa*

Introduction

Rice (*Oryza sativa* L.) in Uganda has become an important food staple and cash crop, especially among smallholder farmers, making it the second most important cereal after maize [KilimoTrust, 2014; Uganda Bureau of Statistics (UBOS), 2021]. Yet, rice yield in Uganda averages only 2,800 kg ha^{-1} for both irrigated and rainfed rice compared with the global average yield of 4,700 kg ha^{-1} [Food and Agriculture Organisation of the United Nations (FAO), 2021], and a yield potential in sub-Saharan Africa of 9,200 and 7,000 kg ha^{-1} for irrigated and rainfed rice, respectively (Global Yield Gap Atlas, 2022). As a result, demand for rice surpasses production, which has resulted in an average net annual milled rice import of around 62,000 tonnes between 2015 and 2020, costing the country about USD 23.2 million each year [Food and Agriculture Organisation of the United Nations (FAO), 2022]. The low yield is attributed to, among other factors, soil-related constraints, poor management of rice fields, and use of low-yielding varieties.

Application of modern agricultural production technologies, such as improved weed management practices, appropriate use of inorganic fertilisers, and modern, high-yielding varieties could enhance rice crop productivity, hence reducing shortage and saving money spent on imports. This is in addition to increasing household food security, reducing poverty directly through increased household incomes and welfare, and indirectly through lower food prices and higher wages (Kassie et al., 2011, 2018; Manda et al., 2019; Wossen et al., 2019). Yet, even with the evident benefits of many of the new agricultural technologies, smallholder farmers either do not adopt them or it takes a long time for such technologies to start being adopted (Mottaleb, 2018). The lack of or slow adoption of improved agricultural technologies is attributed to high costs, uncertainties about proper application and success under local farmers' environmental conditions, and farmers' perceptions and expectations (Mottaleb, 2018; Sinyolo, 2020). Further studies show that variation in adoption of improved management practices that enhance crop yields is related to differences in socio-economic characteristics of farm households, including, for instance, family size, farm size and income, farmers' age and education, labour availability, availability of cash for investment, and risk perception (Danlami et al., 2016; Fosso and Nanfosso, 2016; Hassan et al., 2016; Tadesse et al., 2017; Takahashi et al., 2020; Urfels et al., 2021). Moreover, past participation in on-farm trials, training and awareness about the technology, and contact with extension agents are shown to influence adoption (Danlami et al., 2016, 2019; Hassan et al., 2016; Takahashi et al., 2020). Due to such constraints, improved agricultural technologies may not necessarily result in poverty reduction as some of these constraints make improved technologies inaccessible and less profitable for the poorer farmers (Wossen et al., 2019).

Increasing rice production for enhanced food and income security requires understanding the intricacy of smallholder rice farms in Uganda and their use of improved management practices (Giller et al., 2011; Priegnitz et al., 2019). Getting insights into the diverse and specific farm types necessitates evaluating the uptake of improved management practices in the rice production system together with the socio-economic characteristics and the associated variation in yield among rice farmers. Developing farm typologies i.e., collections of farms that are homogeneous in uptake of improved management practices (Priegnitz et al., 2019) is thus the first and crucial step in examining the adoption of improved management practices in smallholder farms. These typologies could help support more strong policy interventions as well as advisory programmes to improve the adoption of production technologies to increase rice yields (Banerjee et al., 2014). Typologies can also be used to help support the development, implementation and monitoring of agricultural development projects; and to develop more suitable agricultural technologies and policies for less-favoured regions and households. This is in addition to being a practical framework for designing differentiated approaches to addressing rural challenges (Kuivanen et al., 2016; Priegnitz et al., 2019).

This study assessed the change in management practices and grain yield of rice farmers 1 year after the end of a 1-year joint experimentation, conducted between January and December 2019 on-farm together with farmers, where different components of recommended agronomic practices (RAP) for lowland rice production were tested (Awio et al., 2022). Farm types were identified and characterised based on packages of RAP applied on-farm. Components of RAP that were used to form clusters of farms based on how these improved management practices were taken up by the farmers included field levelling, use of certified seed, use of fertiliser in the nursery bed, timely transplanting, line transplanting, gap-filling, use of fertiliser in the field, and timely weeding. For these farm clusters, differences in their socio-economic characteristics and additional rice farming practices were evaluated. The overall objective of the study was to evaluate how the joint experimentation with farmers translated 1 year later in changes in farmers' management practices and, hence, grain yield, and to identify factors that were related to uptake of improved management practices. Specific objectives of the study were (i) to assess change in management practices and the related change in grain yield of farmers 1 year after participation in joint experimentation, (ii) to compare management practices, grain yield and yield gap of farmers who participated and those who did not participate in the joint experimentation, and (iii) to identify and characterise farm types based on packages of RAP which farmers have adopted. Examining the impact of farmers' participation in a joint experimentation may be crucial in informing decisions on how yield enhancing technologies for rice could be delivered to farmers to ensure adoption and realisation of expected results.

Materials and methods

Study area

The study was conducted in the Doho rice irrigation scheme, where components of recommended agronomic practices (RAP) for rice had been previously tested in researcher led on-farm field trials designed and managed together with farmers (Awio et al., 2022). The Doho rice irrigation scheme is located in Eastern Uganda in the Butaleja district[1] (34°02′ E, 0°56′ N). It is the largest public rice irrigation scheme in Uganda (Wanyama et al., 2017), covering an area of 1,000 ha, of which 952 ha is cultivated by over 4,000 smallholder farmers. It lies at an altitude of 1,100 m a.s.l. and belongs to the Lake Kyoga basin agroecological zone. It receives irrigation water from River Manafwa that originates from Mt. Elgon. The annual average rainfall in the area is 1,186 mm, distributed over two rainy seasons, from March to May and from August to October. The annual average temperature here is 22.7°C, with daily mean temperatures ranging from 15.4°C to 30.7°C (Namyenya, 2014). The scheme is divided into 11 blocks, each block sub-divided into 5–15 strips, and each strip having 20–30 farmers. Rice varieties commonly grown by farmers within the scheme are K 98 and K 85.

Data types and data collection

A semi-structured questionnaire was used to collect comprehensive information from smallholder rice farmers in the study area. Field observations were made at the time of field visits after individual farmer interviews to collect information on farmers' crop management practices and grain yield. Pre-testing of the semi-structured questionnaire was done at the beginning of January 2021 with 7 farmers within the scheme. The questionnaire was then refined and revised with closed and open-end questions to improve further discussion with respondents. In total, 146 rice farmers distributed across 6 sub-counties, 20 parishes and 41 villages of the Butaleja district were interviewed face-to-face in the local language (and only for the literate farmers upon indicating preference, English was used) by specifically trained enumerators from mid-January to the start of May 2021. Of these 146 farmers, 86 were part of the 114 farmers who participated in the joint experimentation of 2019 (herein referred to as participating farmers) and 60 had not taken part in the joint experimentation (herein denoted as non-participating farmers). These latter 60 farmers were purposively selected, as a control group to compare with the participating farmers, based on records from block leaders and willingness to take part in the study, to include farmers considered to be from poor,

medium and rich socio-economic backgrounds. All farmers who participated in this study were those who were in production and were to harvest their rice within the time frame of the study to make assessment of crop management practices and grain yield in farmers' fields possible. The study was conducted with informed oral consent by all respondents. Confidentiality of all information collected was guaranteed and research protocols ensured that it was impossible to link published, aggregated data to individual respondents. Applicable guidelines and regulations for survey ethics were diligently followed. No ethical approval prior to the study was obtained as this was not required in Uganda.

The collected information (Table 1) included characteristics of the farm household head and farmer (name, gender, age, education), household size, farm size (total household land area, total land area under rice production), herd size (total herd size, number of cattle, small ruminants and poultry), farmer's participation in the joint experimentation, information on family and hired labour for rice production, duration in rice growing, and on rice management practices including adoption of all specified RAP (cf. Table 1), seed source, grain yield, and market price for paddy and milled rice. Cropping area was recorded in acres and converted to hectares for reporting (1 ha being equal to 2.47 acres). All costs were recorded in Ugandan Shillings (UGX) and where it is converted to US Dollar for reporting the exchange rate of May 2021 was used (1 USD = 3,530 UGX). For grain yield estimation, a survey plot of 10 m × 10 m within each farmer's field was marked from the centre of the field during field observations and a net plot of 4 m × 4 m from within the 10 m × 10 m plot was defined for final yield assessment. At harvest all panicles from the net plot were cut using a sickle, threshed, sun-dried, and the grains winnowed to remove empty grains. Grain weight and moisture content were measured using a digital weighing scale (Mini Crane scale model MNCS-M) and moisture metre (SATAKE Moistex Model SS-7). Rice grain yield adjusted to 0% moisture content (dry weight) was expressed in kg ha^{-1}.

Data analysis

To assess differences in management practices and grain yield among all farmers, data were subjected to analysis of variance (ANOVA) using an unbalanced treatment structure in Genstat (19th edition) at 5% probability, taking the different farmers' fields as blocks. Where differences were significant, treatment means were separated using Fisher's least significant difference (LSD) test. A paired t-test was done for participating farmers to assess individual farmer's yield gain after participation in the joint experimentation. To quantify the effect of change in management practices of participating farmers after joint experimentation on grain yield, regression analysis using Generalised Linear Model was used. The exploitable yield gap

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1 A district in Uganda is the local government administrative unit, divided into counties, sub-counties, parishes and villages.

TABLE 1 Description of variables, units, and minimum and maximum values of variables used in the principal component analysis (PCA) and cluster analysis (CA), and the subsequent characterisation of farm types.

Name of variable	Description and units	Minimum	Maximum
Field levelling	= 1 if yes, 0 if no	0	1
Use of certified seed	= 1 if certified seed, 0 if farmer-saved seed	0	1
Use of fertiliser in the nursery bed	= 1 if yes, 0 if no	0	1
Transplanting time	= days of transplanting rice seedlings after sowing the nursery (DAS)	21	46
Timely transplanting	= 1 if transplanting is done up to 28 DAS, 0 if transplanting is done after 28 DAS	0	1
Line transplanting	= 1 if line transplanting, 0 if random transplanting	0	1
Gap-filling	= 1 if yes, 0 if no	0	1
Use of fertiliser in the field	= 1 if yes, 0 if no	0	1
Weeding time	= days of weeding after transplanting (DAT)	15	70
Timely weeding	= 1 if weeding is done up to 21 DAT, 0 if weeding done after 21 DAT	0	1
N rate	= amount of N applied in kg ha^{-1}	0	68.2
Timely fertilisation	= 1 if fertilisation is done up to 30 DAT, 0 if fertilisation is done after 30 DAT	0	1
Fertilisation time	= days fertiliser is applied after transplanting (DAT)	7	60
Organic (rice straw) input	= 1 if rice straw is incorporated in the soil during ploughing, 0 if not	0	1
Age of household head	= household head's age in years	22	82
Gender of household head	= 1 if male, 0 if female	0	1
Household head's education	= 1 if higher than primary school, 0 if no education or primary education	0	1
Age of farmer	= farmer's age in years	20	80
Gender of farmer	= 1 if male, 0 if female	0	1
Farmer's education	= 1 if higher than primary school, 0 if no education or only primary education	0	1
Farmer participated in joint experiment	= 1 if yes, 0 if no	0	1
Household size	= total number of household members	2	35
Family labour	= average number of household members ha^{-1} season^{-1}	1	128
Hired labour	= average number of people hired ha^{-1} season^{-1}	0	124
Cost of hired labour	= average amount of money spent on hired labour ha^{-1} season^{-1} in UGX $\times 10^6$	0	2.5
Herd size[a]	= total number of livestock in tropical livestock unit (TLU)	0	8.9
Small ruminant ratio	= share of small ruminants (goats and sheep) in total herd size	0	1
Poultry ratio	= share of poultry (chicken) in total herd size	0	1
Total value of livestock	= value of cattle, goats, chicken, sheep and pigs combined in UGX $\times 10^6$	0	16.8
Total household land area	= hectares of land owned by household	0	6.48
Total value of land	= value of land owned by household in UGX $\times 10^6$	0	64.0
Total land area for rice growing	= hectares of land used for rice growing	0.1	3.24
Land tenure for rice growing	= 1 if owned, 0 if rented or borrowed	0	1
Grain yield[b]	= rice grain yield in kg ha^{-1} dry weight	1,930	5,905
Price of paddy	= selling price of paddy in UGX kg^{-1}	600	1,100
Price of milled rice	= selling price of milled rice in UGX kg^{-1}	1,200	2,500
Total income from rice per year per farm[c]	= total cash income from selling all rice harvest in UGX year^{-1} ha^{-1} $\times 10^6$	2.96	25.7
Duration in rice growing	= number of years the farmer has been engaged in rice growing	2	38
Attended training/advise on rice farming	= 1 if yes, 0 if no	0	1
Other crops	= total annual household income from other crops in UGX $\times 10^6$	0	7.0
Livestock	= total annual household income from livestock in UGX $\times 10^6$	0	8.6
Employment	= total annual household income from formal employment in UGX $\times 10^6$	0	7.0
Causal labourer	= total annual household income from informal employment (UGX $\times 10^6$)	0	1.4
Business	= total annual household income from business (UGX $\times 10^6$)	0	5.87

(Continued)

TABLE 1 (Continued)

Name of variable	Description and units	Minimum	Maximum
Crop sale ratio	= share of income from sale of crops	0.36	1.00
Livestock sale ratio	= share of income from sale of livestock	0	0.33
Off-farm income ratio	= share of combined income from formal employment, casual labour and business	0	0.64

Variables in bold are the ones used in the PCA and clustering.

RAP, recommended agronomic practices.

[a]Tropical livestock unit (TLU) is taken to be an animal of 250 kg live weight (Jahnke et al., 1987).

[b]Estimated from the 4 m × 4 m net plot.

[c]Income estimate reported by the farmer, not calculated from estimated grain yield; number of observations (n) = 146.

(i.e., the difference between attainable farm yield and actual farm yield) was estimated using the top decile approach (Stuart et al., 2016). Attainable farm yield was defined as the mean yield of the top 10-percentile of yields from all farmers' fields after joint experimentation, and actual farm yield was taken as the mean yield of participating and non-participating farmers. To evaluate the differences in management practices and grain yield of participating farmers, these farmers were grouped based on grain yield in (i) farmers' practice (FP) plot and (ii) recommended agronomic practice (RAP) plot during the joint experimentation. Based on FP plot yield, farmers were categorised as lower-yielding (with grain yields between 1,364 and 3,037 kg ha^{-1} dry weight, $n = 28$), middle-yielding (with grain yields varying from 3,048–4,050 kg ha^{-1} dry weight, $n = 29$) and top-yielding (with grain yields ranging from 4,065–5,545 kg ha^{-1} dry weight, $n = 29$) third during the joint experimentation. Based on RAP plot yield, farmers were grouped as those who had higher yield in RAP plot compared with FP plot (i.e., RAP yield > FP yield: RAP and FP yield ranged from 2,210 to 5,753 and 1,364 to 5,545 kg ha^{-1} dry weight, respectively, $n = 69$) and those who had higher FP plot yield compared with RAP plot yield (i.e., FP yield > RAP yield: FP and RAP yield ranged from 3,048 to 4,825 and 2,875 to 4,255 kg ha^{-1} dry weight, respectively, $n = 17$) during the joint experimentation.
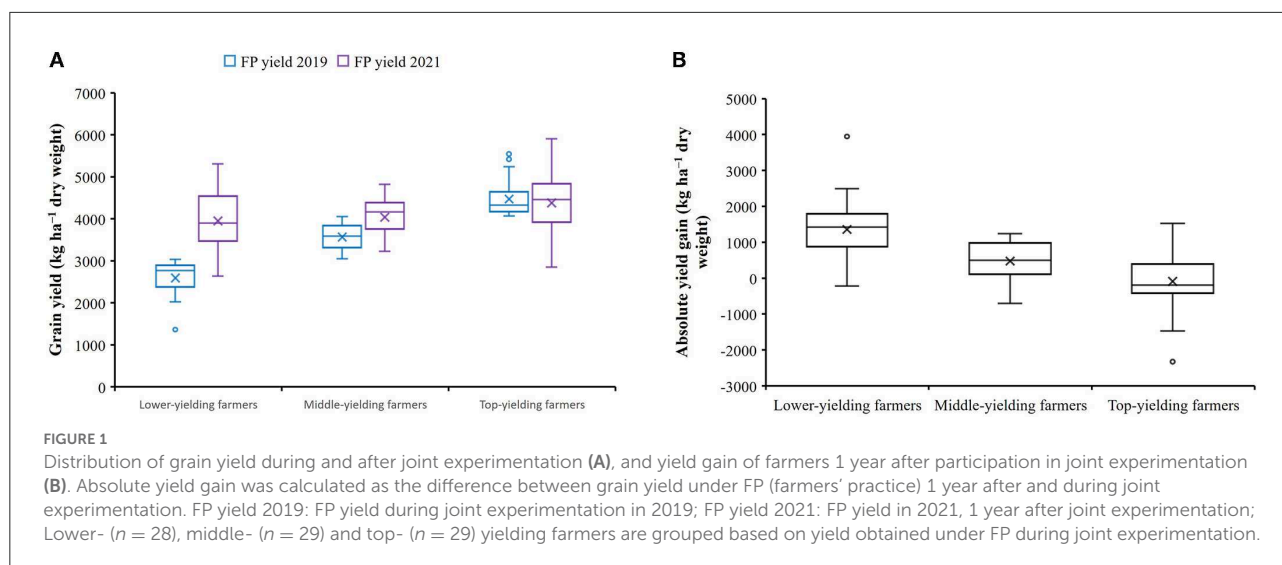
To construct farm typologies, where combined data for participating and non-participating farm households were used, SPSS (Statistical Package for the Social Sciences), version 25.0 was used to analyse the data following a multivariate method. A principal component analysis (PCA) was first used to reduce the number of variables into a new set of components. Eight variables related to components of RAP (i.e., field levelling, use of certified seed, use of fertiliser in the nursery bed, timely transplanting, line transplanting, gap-filling, use of fertiliser in the field, and timely weeding) were chosen for the PCA. Three principal components exceeding an eigenvalue of 1.00, according to Kaiser's criterion, were retained accounting together for 50.1% of the total variance (Supplementary Table S1). Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy indicated the sample was adequate (value of 0.56) and Bartlett's test of sphericity ($p = 0.008$) showed

that the analysis would be valid. Evaluating the correlations between the variables and the three components, a loading of >0.50 was considered. With the identified components, a hierarchical, agglomerative cluster analysis (CA) was done using Ward's method to minimise the variance within a cluster and squared Euclidean distance to measure the distances. After clustering farms based on the components of RAP applied, one-way ANOVA was used to test for significant differences between clusters for variables in the categories: RAP components adopted, socio-economic characteristics, rice production and farming knowledge, and other sources of income (Table 1). Differences in means between the clusters were separated using Fisher's LSD test. The proportion of participating and non-participating farm households in each identified cluster or farm type was determined. Analysis of household characteristics for participating and non-participating farmers in each cluster was made where results indicated households under a given cluster, whether participating or non-participating farm households, were identical (Supplementary Table S2).

Results

Grain yield and management practices of participating farmers

Participating farmers that had lower (lower-yielding third), moderate (middle-yielding third) and higher (top-yielding third) yields under FP during joint experimentation likewise observed significantly different yields after experimentation ($p = 0.03$, SED = 169). Top-yielding farmers during joint experimentation also had the highest mean yield 1 year later (4,379 kg ha^{-1}), followed by middle (4,039 kg ha^{-1}) and lower (3,951 kg ha^{-1}) yielding farmers who had similar yields (Figure 1A). Average yields during experimentation had been 4,471, 3,566 and 2,593 kg ha^{-1}, respectively, for the top-, middle- and lower-yielding farmers ($p < 0.001$, SED = 98.5). Median yields after experimentation were 4,458, 4,161 and 3,895 kg ha^{-1}, against 4,323, 3,589 and 2,772 kg ha^{-1} during experimentation, respectively, for the top-, middle- and lower-yielding farmers (Figure 1A). Despite having lower grain yield,

FIGURE 1
Distribution of grain yield during and after joint experimentation **(A)**, and yield gain of farmers 1 year after participation in joint experimentation **(B)**. Absolute yield gain was calculated as the difference between grain yield under FP (farmers' practice) 1 year after and during joint experimentation. FP yield 2019: FP yield during joint experimentation in 2019; FP yield 2021: FP yield in 2021, 1 year after joint experimentation; Lower- ($n = 28$), middle- ($n = 29$) and top- ($n = 29$) yielding farmers are grouped based on yield obtained under FP during joint experimentation.

lower-yielding farmers observed a significantly ($p < 0.001$, SED = 199) higher yield gain compared with the middle- and top-yielding farmers (Figure 1B; Supplementary Table S3). A paired t-test indicated that at individual farmer's field, average yield gain was 1,358 kg ha^{-1}, ranging between 1,027 and 1,689 kg ha^{-1} for the lower-yielding farmers ($p < 0.001$). This gain was on average 473 kg ha^{-1} for the middle-yielding farmers, ranging between 252 and 695 kg ha^{-1} ($p < 0.001$). Top-yielding farmers had on average -91.7 kg ha^{-1} yield gain, ranging from -397 to 213 kg ha^{-1} ($p = 0.54$) (Supplementary Table S3).

A multiple linear regression showed that change in grain yield after joint experimentation was influenced by change in weeding time and the combined effect of change in fertilisation timing and N rate, accounting for overall 41% of the yield gain observed (Table 2). Weeding and fertilisation by 1 day earlier on average increased grain yield by 40.9 and 11.6 kg ha^{-1} day^{-1}, respectively. Increasing N amount by 1 kg ha^{-1} resulted in 16.6 kg ha^{-1} increase in grain yield (Table 2). There was a significant difference ($p < 0.001$, SED = 3.20) in change of weeding time among the farmers, explaining the observed differences in yield gain. Lower-yielding farmers improved their weeding time by weeding on average 2 days earlier (ranging from 2 days later to 6 days earlier) after experimentation compared with weeding time in the FP plot during experimentation. Middle- and top-yielding farmers weeded on average 8 (range: 3–12) and 14 (range: 9–19) days later, respectively, after experimentation compared with weeding time in the FP plot during joint experimentation (Table 3). Overall, the majority (61%) of lower-yielding farmers weeded earlier than their weeding time in the FP plot during joint experimentation, compared with 24 and 7% of middle- and top-yielding farmers, respectively (Figure 2). In all, weeding time delay compared with recommended weeding time, after experimentation, was not different among farmers ($p > 0.05$, SED = 2.76), with

average weeding delay of 14, 15 and 15 days, respectively, for the lower-, middle- and top-yielding farmers (Figure 3). During experimentation, this weeding delay was significantly different among farmers ($p < 0.001$, SED = 1.76), where lower-, middle- and top-yielding farmers had an average weeding delay of 16, 8 and 3 days, respectively. Lower-yielding farmers also had a slightly larger N rate increase of 19.7 kg ha^{-1} compared with 16.0 and 12.2 kg ha^{-1} increase in N rate for the middle- and top-yielding farmers, after experimentation, respectively (Table 3).

Analysis of household socio-economic characteristics of lower-, middle- and top-yielding farmers showed no major difference among households that could explain differences in yield or yield gain among farmers. Even though lower-yielding farm households had significantly smaller household size, fewer small ruminants and less income from other crops compared with middle- and top-yielding farm households (Table 4), these differences were small and populations overlapped. Likewise lower-yielding farm households had smaller herd size, land size, area under rice production and a larger income from off-farm activities, however, these differences were not significant among groups. The lack of clear differences among farm households could indicate that all these farmers have the potential to achieve the higher yield levels attained by top producers under their current production system.

To test if farmers who had, during the joint experimentation, a higher yield in their FP plots than their RAP plots would differ in yield and practices from farmers who had a lower yield in their FP plots than their RAP plots, these two groups were analysed separately. Farmers who had higher yield on their FP plot compared with their RAP plot during joint experimentation also had on average higher yields after experimentation (4,385 kg ha^{-1}, median 4,401 kg ha^{-1}) than farmers who had lower yield under FP plot compared with RAP plot during joint experimentation (4,061 kg ha^{-1}, median

TABLE 2 Slopes of linear regression lines relating change in grain yield on farmers' fields and change in management practices of farmers after participation in joint experimentation, Doho rice irrigation scheme, Butaleja District, Uganda, 2021.

Management practice	Slope estimate	Unit of slope estimate	Standard error	p-value	Lower 95% confidence limit	Upper 95% confidence limit	Adjusted R^2
Weeding time (DAT)	40.9	kg ha^{-1} day^{-1}	6.23	<0.001	28.6	53.3	0.33
N (kg ha^{-1})	16.6	$\frac{\text{kg grain ha}^{-1}}{\text{kg N ha}^{-1}}$	5.83	0.01	5.03	28.2	0.08
Fertilisation timing (DAT)	11.6	kg ha^{-1} day^{-1}	5.51	0.04	0.63	22.5	0.04
Transplanting time (DAS)	8.7	kg ha^{-1} day^{-1}	20.3	0.67	−31.7	49.1	0.00
+ Weeding time (DAT)	39.6	kg ha^{-1} day^{-1}	5.86	<0.001	27.9	51.3	0.41
+ Fertilisation timing × N rate	0.51	$\frac{\text{kg ha}^{-1}\,\text{day}^{-1}}{\text{kg N ha}^{-1}}$	0.15	<0.001	0.22	0.80	

DAT, days after transplanting; DAS, days after sowing; number of observations (n) = 86.

TABLE 3 Grain yield and management practices during (2019) and after (2021) joint experimentation separately for the same farmers with lower, middle and higher yields during joint experimentation in 2019.

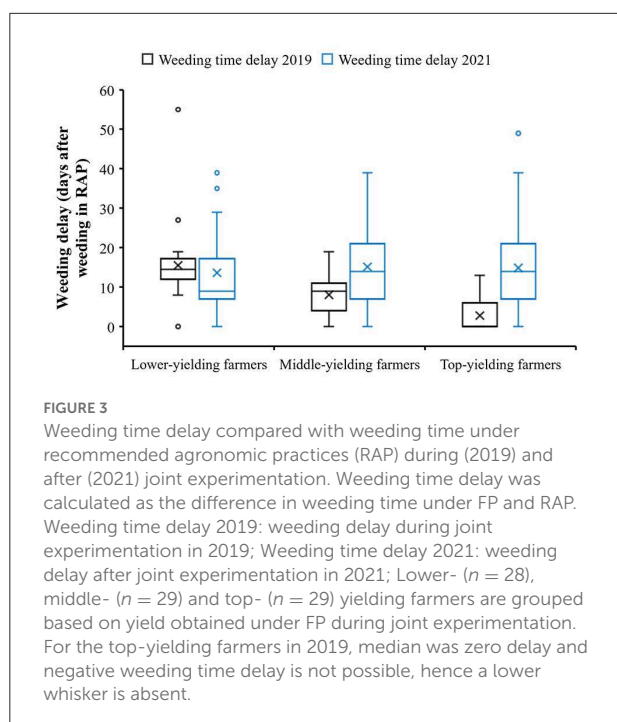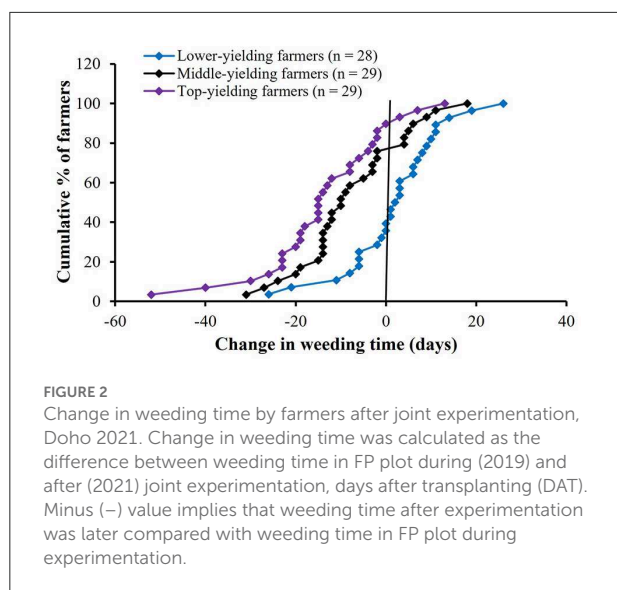| Parameter		During experimentation (2019)			After experimentation (2021)		
		Lower	Middle	Top	Lower	Middle	Top
Grain yield (kg ha^{-1})		2593[a]	3566[b]	4471[c]	3951[a]	4039[a]	4379[b]
Weeding time	14–21 DAT (%)	3.6	17.2	65.5	3.6	13.8	13.8
	22–28 DAT (%)	0	24.2	20.7	25.0	13.8	24.1
	≥29 DAT (%)	96.4	58.6	13.8	71.4	72.4	62.1
Average weeding time (DAT)		36.5[c]	28.4[b]	22.0[a]	34.6	36.1	35.8
Fertiliser use	Yes (%)	17.9[a]	27.6[a]	55.2[b]	78.6	75.9	79.3
	No (%)	82.1	72.4	44.8	21.4	24.1	20.7
Average N amount (kg ha^{-1})		4.44[a]	6.84[a]	14.7[b]	24.1	22.9	26.9
Fertilisation time	14–21 DAT (%)	0	0	6.2	9.1	27.3	21.7
	22–28 DAT (%)	0	12.5	25.0	27.3	9.1	17.4
	≥29 DAT (%)	100	87.5	68.8	63.6	63.6	60.9
Average fertilisation time (DAT)		40.2[ab]	44.6[b]	32.9[a]	30.0	33.6	32.4
Crop establishment method	Line transplanting (%)	21.4	20.7	34.5	39.3	44.8	41.4
	Random transplanting (%)	78.6	79.3	65.5	60.7	55.2	58.6
Transplanting time	21–28 DAS (%)	25	27.6	20.7	25	20.7	41.4
	29–35 DAS (%)	75	69.0	72.4	50	62.1	44.8
	≥36 DAS (%)	0	3.4	6.9	25	17.2	13.8
Average transplanting time (DAS)		29.6	29.7	30.7	31.9	31.8	30.9

DAT, days after transplanting; DAS, days after sowing.

Values within a row and experiment timing followed by a same letter are statistically the same according to Fisher's *post-hoc* test; when no letters are provided differences were not significantly different.

For the lower-, middle- and top-yielding farmers, numbers of observations (n) were 28, 29 and 29, respectively, during and after joint experimentation.

4,153 kg ha^{-1}), (Figure 4A). However, this yield difference was statistically marginal ($p = 0.07$, SED = 176). During the joint experimentation the average FP yields of these two groups was 3,922 (median 3,854) and 3,464 (median 3,313) kg ha^{-1}, respectively ($p = 0.05$, SED = 227). Overall, average yield gain by farmers after joint experimentation was 571 kg ha^{-1}, varying between 366 and 776 kg ha^{-1} (Supplementary Table S3). The yield gains were not different

($p = 0.61$, SED = 260) between these two groups of farmers (Figure 4B; Supplementary Table S3). At individual farmer's field, a paired *t*-test showed an average yield gain of 597 (median 630, value ranging between 348 and 846) and 463 (median 420, values ranging 200–727) kg ha^{-1}, respectively, for farmers who had lower and higher yields under FP plot compared with RAP plot during the joint experimentation (Figure 4B; Supplementary Table S3). All management practices a year after

FIGURE 2
Change in weeding time by farmers after joint experimentation, Doho 2021. Change in weeding time was calculated as the difference between weeding time in FP plot during (2019) and after (2021) joint experimentation, days after transplanting (DAT). Minus (−) value implies that weeding time after experimentation was later compared with weeding time in FP plot during experimentation.

FIGURE 3
Weeding time delay compared with weeding time under recommended agronomic practices (RAP) during (2019) and after (2021) joint experimentation. Weeding time delay was calculated as the difference in weeding time under FP and RAP. Weeding time delay 2019: weeding delay during joint experimentation in 2019; Weeding time delay 2021: weeding delay after joint experimentation in 2021; Lower- ($n = 28$), middle- ($n = 29$) and top- ($n = 29$) yielding farmers are grouped based on yield obtained under FP during joint experimentation. For the top-yielding farmers in 2019, median was zero delay and negative weeding time delay is not possible, hence a lower whisker is absent.

the joint experimentation were similar among these two groups except weeding time, where 35% of farmers who had higher yield under FP plot compared with RAP plot weeded within 21 DAT, with an average weeding time of 30 DAT ($p < 0.001$, SED = 0.08). This was only 4% for farmers who had lower yield under FP plot compared with RAP plot, with an average weeding time of 37 DAT.

Grain yield and management practices of participating and non-participating farmers

Grain yield varied significantly among farmers who participated (participating farmers) and those who did not participate (non-participating farmers) in the joint experimentation ($p = 0.05$). Participating farmers had a higher grain yield, averaging 4,125 kg ha^{-1} compared with 3,893 kg ha^{-1} average grain yield for non-participating farmers (SED = 117). Median yield was 4,184 kg ha^{-1} for participating farmers, with grain yield ranging between 2,636 and 5,905 kg ha^{-1}. Median yield was 3,971 kg ha^{-1} for non-participating farmers, and grain yield varied from 1,930 to 5,423 kg ha^{-1} (Figure 5). The exploitable yield gap was 20.0 and 24.5%, respectively, for participating and non-participating farmers, when the average of top-decile yield from all farmers' fields after joint experimentation (5,158 kg ha^{-1}) was taken as attainable farm yield.

We observed differences in some management practices between participating and non-participating farmers. Sixteen percent of participating farmers used certified seed, and 28% transplanted timely, with average transplanting time of 32 DAS, compared with 3 and 13% for non-participating farmers, respectively (Table 5). Differences in weeding time (36 vs. 39 DAT) and N amount (24.3 vs. 19.8 kg ha^{-1}) were statistically marginal ($p = 0.07$), between participating and non-participating farmers. Analysis of household data showed no difference among participating and non-participating farm households, except for training on rice farming which was significantly different ($p < 0.001$). More participating farmers (93%) had attended training related to rice production than non-participating farmers (50%) (Table 5). Participating farmers had also spent slightly more years in rice growing than non-participating farmers.

Farm households characteristics, farm types and characterisation from clusters
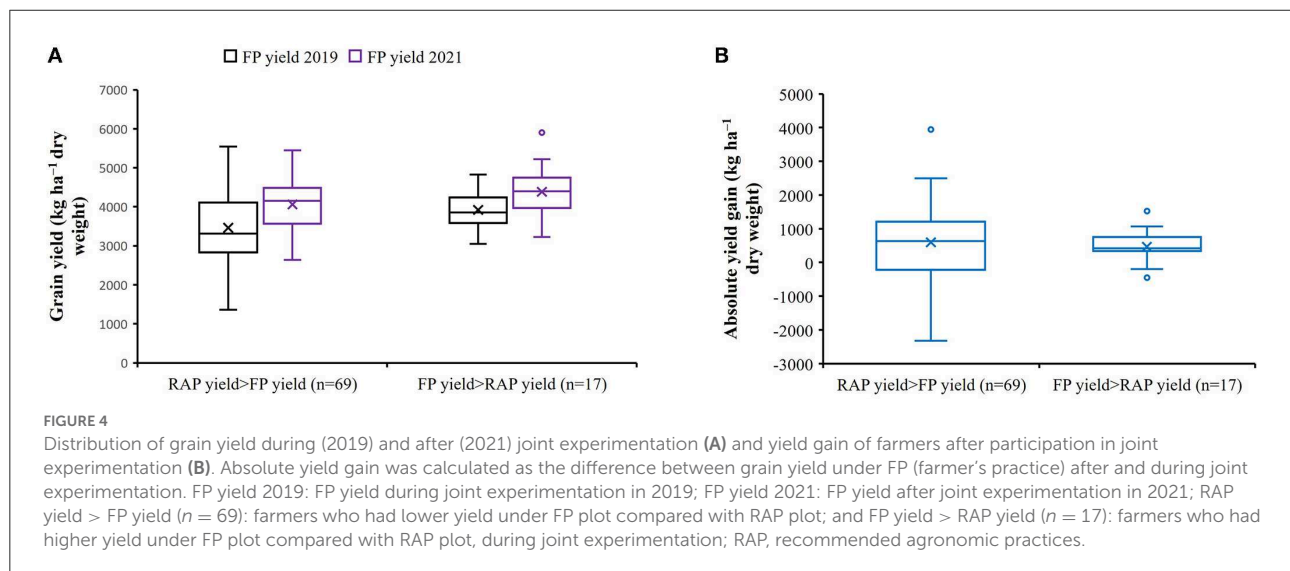
Analysis of household socio-economic data indicated that 86% of the farm households were male headed, with 40% of household heads having attained education higher than primary level (Table 6). The average farmer's age was 40 years and 42% of the farmers had attained education higher than primary school. Total household size was on average 10.2 persons. Farmers had on average 1.20 ha of farmland, of which 0.47 ha was under rice production. In terms of labour input in rice production, family and hired labour per rice growing season per ha was on average 22 persons. Regarding application of recommended agronomic practices for rice, 73% of farmers used fertiliser in the nursery bed, 22% transplanted timely (within 28 DAS rice seeds in the

TABLE 4 Household socio-economic characteristics of lower-, middle- and top-yielding farmers, Doho rice irrigation scheme, Butaleja District, Uganda, 2021.

Characteristic	Lower (n = 28)	Middle (n = 29)	Top (n = 29)	SED	p-value
Household characteristics					
Household head's education	0.36	0.48	0.41	0.13	0.64
Farmer's education	0.46	0.48	0.34	0.13	0.53
Duration in rice growing (years)	17.6	17.8	17.8	3.01	0.99
Attended training on rice farming	0.96	0.90	0.93	0.07	0.61
Household size	8.75[a]	12.6[b]	10.2[ab]	1.55	0.05
Herd size (TLU)	0.87	1.81	1.71	0.46	0.09
Number of small ruminants (TLU)	0.13[a]	0.32[b]	0.22[ab]	0.08	0.05
Total livestock value ($\times 10^6$ UGX)	1.15	2.56	2.44	0.86	0.20
Total household land area (ha)	0.96	1.38	1.32	0.29	0.30
Total value of household land ($\times 10^6$ UGX)	9.45	13.4	12.3	3.05	0.43
Land area under rice growing (ha)	0.43	0.57	0.48	0.12	0.48
Labour in rice production					
Family labour ha^{-1} $season^{-1}$	17.7	25.5	18.5	5.30	0.28
Hired labour ha^{-1} $season^{-1}$	25.2	24.8	19.3	7.04	0.65
Cost of hired labour ha^{-1} $season^{-1}$ ($\times 10^6$ UGX)	0.62	0.85	0.66	0.14	0.24
Sources of income $year^{-1}$ ($\times 10^6$ UGX)					
Rice (net)	5.48	5.38	5.82	0.84	0.89
Other crops	0.24[a]	0.67[ab]	0.92[b]	0.33	0.02
Livestock	0.28	0.54	0.53	0.29	0.60
Off-farm	1.47	0.99	0.90	0.50	0.48

Values within a row followed by a same letter are statistically the same according to Fisher's *post-hoc* test; when no letters are provided differences were not statistically significant; TLU, tropical livestock unit; n, number of farm households in each group.

FIGURE 4
Distribution of grain yield during (2019) and after (2021) joint experimentation **(A)** and yield gain of farmers after participation in joint experimentation **(B)**. Absolute yield gain was calculated as the difference between grain yield under FP (farmer's practice) after and during joint experimentation. FP yield 2019: FP yield during joint experimentation in 2019; FP yield 2021: FP yield after joint experimentation in 2021; RAP yield > FP yield (n = 69): farmers who had lower yield under FP plot compared with RAP plot; and FP yield > RAP yield (n = 17): farmers who had higher yield under FP plot compared with RAP plot, during joint experimentation; RAP, recommended agronomic practices.

nursery), 36% used line transplanting, 76% applied fertiliser in the field, with an average N rate of 22.4 kg ha^{-1} and 12% weeded timely (within 21 DAT rice seedlings, Table 6). Only 11% of the farmers used certified rice seeds, while 98% did field levelling

and 95% incorporated rice straw from the previous season into the soil.

Principal component analysis (PCA) and cluster analysis (CA) resulted in identification of three different clusters defined
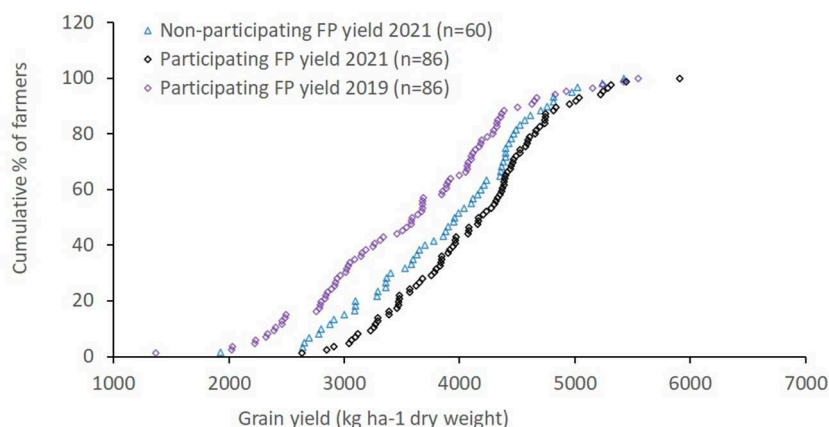
FIGURE 5
Cumulative distribution of grain yield of farmers after joint experimentation in 2021. Participating farmers are those who participated and non-participating farmers did not participate in the joint experimentation.

as farm types with their characteristics (Table 6). Cluster 1 (farms with less application of RAP) constituted the second largest cluster with 28% (n = 41) of the farms. Of the farmers in this group, 32% used fertiliser in the nursery, 15% transplanted timely, 5% transplanted in line, and 27% applied fertiliser in the field, with the lowest N amount of 7.8 kg ha^{-1}. In comparison to the other two clusters, these farmers had moderate land area under rice production (0.45 ha) and expended less cost. Average grain yield was the lowest for them at 3,761 kg ha^{-1}. However, net income from rice growing in these farms was slightly higher at 5,510,000 UGX (ca. 1,560 USD) year^{-1}; in addition to more income from off-farm activities at 1,060,000 UGX (ca. 300 USD). This cluster constituted 26 and 32%, respectively, of participating and non-participating farm households (Supplementary Table S2). Cluster 2 (farms with highest level of application of RAP) was the smallest cluster with 24% (n = 35) of the farms. In this group, 71% of the farmers used fertiliser in the nursery, 63% transplanted timely, 69% transplanted in line, and 94% applied fertiliser in the field, with the highest N application rate of 32.5 kg ha^{-1}. These farmers also had the largest land area under rice production (0.60 ha) and the highest production cost. Average grain yield was the highest at 4,342 kg ha^{-1}, however, with the lowest net income from rice production at 5,030,000 UGX (ca. 1,425 USD) year^{-1}, but the highest income from other crops. The lower income from rice production could be attributed to the higher expenditure on labour. Overall, these farms have more diversified sources of income compared with the other clusters. Thirty percent of participating and 15% of non-participating farm households made up this cluster. Cluster 3 (farms with moderate application of RAP) was the largest cluster with 48% (n = 70) of the total farms studied. Of the farmers in this cluster, 98% used fertiliser in the nursery, 6% transplanted timely, 39% used line transplanting, and 96% applied fertiliser in the field, with

average N amount of 26.0 kg ha^{-1}. These farmers had slightly smaller land area under rice production (0.42 ha), with higher production cost. Grain yield was moderate in this cluster at 4,031 kg ha^{-1}, and leading to a net income from rice production of 5,500,000 UGX (ca. 1,560 USD) year^{-1}. Participating and non-participating farm households that made up the cluster were 44 and 53%, respectively (Supplementary Table S2).

Discussion

This study showed that top-yielding farmers during experimentation still had the highest average yield after experimentation compared with the lower- and middle-yielding farmers during experimentation. Yet, the lower-yielding farmers made the highest yield gains (Figure 1). The higher yield gains by the lower-yielding farmers could be attributed to a significant improvement in management practices after experimentation. Generally lower-yielding farmers improved their weed management, and fertiliser use, amount and timing (Table 3; Figure 2). Even though lower-yielding farmers made larger yield gains, the overall yields recorded by farmers are still low, for the rice variety grown, when compared with yields observed under researcher-managed on-farm trials in the same study area (Awio et al., 2021). Grain yields recorded in this study are, however, higher than yields earlier reported under farmers' practice in the study area (Senthilkumar et al., 2020; Awio et al., 2022). The lack of yield gain by the top-yielding farmers might imply that at their current management level these farmers could not further raise their grain yields beyond the level observed during joint experimentation, probably because the observed current N input could be too low (which was up to a maximum of 68 kg N ha^{-1} after experimentation from 46 kg N ha^{-1} maximum rate during experimentation), in

TABLE 5 Management practices and household socio-economic characteristics of participating and non-participating farmers, Doho rice irrigation scheme, Butaleja District, Uganda, 2021.

Characteristic	Participating farmers (*n* = 86)	Non-participating farmers (*n* = 60)	SED	*p*-value
Management practice				
Field levelling	0.98	0.98	0.02	0.78
Use of certified seed	0.16	0.03	0.05	0.01
Use of fertiliser in the nursery bed	0.73	0.73	0.07	0.99
Timely transplanting	0.28	0.13	0.07	0.04
Average transplanting time (DAS)	31.5	33.5	0.84	0.02
Line transplanting	0.42	0.28	0.08	0.10
Gap-filling	0.71	0.65	0.08	0.45
Use of fertiliser in the field	0.78	0.73	0.07	0.53
Timely fertilisation	0.66	0.70	0.09	0.60
Average fertilisation time (DAT)	32.0	30.8	2.03	0.56
Average N amount (kg ha^{-1})	24.3	19.8	2.54	0.07
Timely weeding	0.10	0.13	0.05	0.60
Average weeding time (DAT)	35.5	39.1	1.96	0.07
Household characteristics				
Farmer's education level	0.43	0.40	0.08	0.72
Attended training on rice farming	0.93	0.50	0.06	<0.001
Duration in rice growing (years)	17.7	14.4	1.82	0.07
Household size	10.6	9.58	0.97	0.32
Herd size (TLU)	1.47	1.02	0.27	0.10
Total household land area (ha)	1.22	1.16	0.19	0.72
Land area under rice growing (ha)	0.49	0.44	0.08	0.45
Family labour ha^{-1} season^{-1}	20.6	24.9	3.74	0.25
Hired labour ha^{-1} season^{-1}	23.1	19.9	3.96	0.42
Cost of hired labour ha^{-1} season^{-1} (×10^6 UGX)	0.71	0.71	0.10	0.99
Income year^{-1} (×10^6 UGX)				
Rice (net)	5.56	5.32	0.54	0.66
Other crops	0.61	0.33	0.18	0.12
Livestock	0.45	0.34	0.17	0.48
Off-farm	1.11	0.83	0.30	0.34

DAS, days after sowing; DAT, days after transplanting; TLU, tropical livestock unit; n, number of observations.

combination with lack of P and K application. It may therefore be necessary that farmers in this production system increase N rates, and P and K application be emphasised based on field inherent fertility to further raise grain yields as current farmers' fertilisation strategies do not put into consideration P and K application (Awio et al., 2022). This should be in addition to improved crop management practices, like proper timing of weeding and fertiliser application. Large yield gains have been reported in the same location under researcher management when N, P and K rates were increased from 80-40-40 to 100-50-50 kg ha^{-1} N, P and K, respectively (Awio et al., 2021). The results of our study are consistent with the findings of Ogada and Nyangena (2015) who observed higher yield gains, due to adoption of improved management practices, by farm

households that had lower to medium grain yield than farm households at the upper end of the yield distribution. Shaibu et al. (2021) reported that the highest benefits from scaling up and adoption of improved management practices would be derived by low resource-endowed farm households. Similarly, Ainembabazi et al. (2018) showed that adoption of improved crop varieties would benefit poor farm households more than better-off households. However, in our present study there was no clear difference in resource endowment of lower, middle and top yielding farm households. Farmers who observed higher grain yield in their recommended agronomic practices (RAP) plot compared with their FP plot during experimentation realised larger yield gains than farmers who had lower yield under RAP compared with FP plot, an indication that the former

TABLE 6 Characteristics of farm households and the identified clusters including the *p*-value of one-way analysis of variance of differences between farm types.

Characteristic	Cluster 1 ($n = 41$)	Cluster 2 ($n = 35$)	Cluster 3 ($n = 70$)	Mean ($n = 146$)	*p*-value
Components of RAP adopted					
Field levelling	1.00[b]	0.91[a]	1.00[b]	0.98	0.01
Use of certified seed	0.02[a]	0.43[b]	0.00[a]	0.11	<0.001
Use of fertiliser in the nursery bed	0.32[a]	0.71[b]	0.98[c]	0.73	<0.001
Timely transplanting	0.15[a]	0.63[b]	0.06[a]	0.22	<0.001
Line transplanting	0.05[a]	0.69[c]	0.39[b]	0.36	<0.001
Gap-filling	0.68[a]	0.94[b]	0.56[a]	0.68	<0.001
Use of fertiliser in the field	0.27[a]	0.94[b]	0.96[b]	0.76	<0.001
Timely weeding	0.12	0.14	0.10	0.12	0.81
Timely fertilisation	0.55[a]	0.82[b]	0.63[a]	0.65	0.04
Average N amount (kg ha^{-1})	7.76[a]	32.5[c]	26.0[b]	22.4	<0.001
Organic input	0.93	0.97	0.94	0.95	0.70
Average transplanting time (DAS)	32.8[b]	28.9[a]	33.8[b]	32.3	<0.001
Average weeding time (DAT)	40.5[b]	32.0[a]	37.4[b]	37.0	0.01
Average fertilisation time (DAT)	35.8[b]	26.9[a]	33.1[b]	32.4	<0.001
Rice production and farming knowledge					
Grain yield (kg ha^{-1} dry weight)[1]	3,761[a]	4,342[c]	4,031[b]	4,030	0.001
Duration in rice growing (years)	15.8	17.6	16.1	16.4	0.75
Attended training in rice farming	0.63	0.86	0.77	0.75	0.07
Socio-economic characteristics					
Age of household head	45.4	47.2	44.3	45.3	0.64
Gender of household head	0.88	0.94	0.81	0.86	0.19
Household head's education	0.32	0.49	0.41	0.40	0.32
Age of farmer	41.9	40.9	38.7	40.1	0.50
Gender of farmer	0.63[ab]	0.83[b]	0.56[a]	0.64	0.02
Farmer's education	0.29	0.51	0.44	0.42	0.13
Farmer participated in OFT[2]	0.54	0.74	0.54	0.59	0.11
Household size	10.2	10.1	10.2	10.2	0.99
Family labour ha^{-1} season^{-1}	22.6	23.5	21.7	22.4	0.92
Hired labourer ha^{-1} season^{-1}	22.8	21.0	21.6	21.8	0.94
Total labour cost ha^{-1} year^{-1} ($\times 10^6$ UGX)	2.48[a]	3.13[b]	3.03[b]	2.90	<0.001
Total household land area (ha)	1.17	1.49	1.06	1.20	0.17
Land area under rice growing (ha)	0.45	0.60	0.42	0.47	0.12
Herd size (TLU)	1.45	1.37	1.14	1.28	0.58
Cattle (TLU)	1.14	1.02	0.91	1.00	0.72
Small ruminants (TLU)	0.21	0.23	0.19	0.21	0.71
Poultry (TLU)	0.09[b]	0.11[b]	0.04[a]	0.07	<0.001
Income year^{-1} ($\times 10^6$ UGX)					
Rice (net)	5.51	5.03	5.50	5.39	0.75
Other crops	0.25[a]	0.91[b]	0.43[a]	0.50	0.02
Livestock	0.42	0.62	0.30	0.41	0.27
Off-farm	1.06	1.05	0.93	1.00	0.91

[1] Estimated based on harvest from 16 m^2 within individual farmer's field.

[2] Joint experiment conducted on-farm in 2019.

Values within a row followed by a same letter are not statistically different according to Fisher's *post-hoc* test; when no letters are provided there were no statistical differences.

n, number of farm households in each cluster.

farmers learnt something from the joint experimentation which they were able to apply in their fields and make some gains in grain yields. Franke et al. (2010) in on-farm trials found that farmers copied management practices from experimental treatments, in some cases competing in terms of yield with the researcher-managed plots. This observation could point to the broader influence on-farm experimentation can have on farmer's yield improvements the subsequent seasons, something we observe in the present study.

Participating farmers had a slightly but significantly higher grain yield and application of some of the improved rice management practices compared with non-participating farmers (Figure 5; Table 5). This shows the potential benefit of exposing farmers to RAP, through participatory learning, on boosting rice yields in Uganda and similar rice production systems in sub-Saharan Africa. The findings further underscore the point that participating farmers learnt something from the joint experimentation and were able to apply that in their fields during the subsequent seasons, resulting in higher grain yields. Similar observation was made by Senthilkumar et al. (2018) who showed improvements in the implementation of RAP for rice by farmers and subsequently increased grain yields after participatory on-farm trials with farmers. Krupnik et al. (2012) and Senthilkumar et al. (2018) noted that farmers learnt by doing to better implement the components of RAP during the course of time the participatory trials were conducted. Kondylis et al. (2017) observed that directly training farmers resulted in a large increase in adoption of sustainable land management practices among farmers. Joint experimentation with farmers can therefore be an interesting way of directly training farmers where learning by doing is facilitated. This farmer training combined with farmers' own experiences with recommended agronomic practices can be used as a tool in rice farming extension efforts to transform rice production, triggering a positive change in the participating farmers' crop management practices, grain yield and livelihoods (Senthilkumar et al., 2018). This, however, requires an enabling environment for rice farmers to increase their production through the adoption of RAP components, for instance, improved access to certified seeds of high-yielding varieties and fertilisers at affordable prices, access to locally adapted simple weeding tools, and fair access to rice markets among others. Joint experimentation can also provide better feedback to research and extension on innovations or innovation components that will not work under local farmers' conditions.

The results of our study indicate that distinguished farm types varied in adoption of improved management practices for rice and grain yield, but not in resource endowment or socio-economic characteristics (Table 6). This may imply that farmers in this production system have the capacity of reaching a higher yield level when improved management practices are applied. The lack of difference in resource

endowment among farm types could suggest that wealth is not an important factor in adopting improved management practices for rice in the current production system and rice scheme. Our study finding, however, contrasts with previous studies which reported household wealth and other socio-economic parameters to be key in adoption of innovations. For instance, a study of Urfels et al. (2021) in tropical Asia showed that household resource endowment determined timing of rice planting, in addition to ecosystem and climatic factors. In SSA, Chekene and Chancellor (2015), Nakano et al. (2018) and Nonvide (2021) noted that farmers' education, age, farming experience and training on improved rice production practices were important in the adoption of improved rice production technologies among rice farmers. Similarly, Fosso and Nanfosso (2016), Hassan et al. (2016) and Lulseged et al. (2016) showed household wealth, off-farm employment, farm size, participation in on-farm trials, and farmers' education to be associated with adoption of improved management practices for maize, e.g., improved weed management, improved seeds, and use of fertiliser. Likewise, Derssch et al. (2016), Tadesse et al. (2017), and Tadesse et al. (2019) observed that adoption of improved potato varieties and production practices was related to household wealth and educational levels. In the present study, however, these variables were not significantly different among the identified farm types, except farmer's gender. Difference among farm types in attending trainings related to rice farming would be significant at 0.10% probability.

Conclusion

This study indicates that joint experimentation had a larger effect on raising yields of originally lower-yielding farmers and narrowed the yield gap between lower- and higher-yielding farmers, thus bringing farmers closer in their management and outputs. Lower-yielding farmers made more gains compared with higher-yielding farmers, an indication that lower-yielding farmers had more room to raise their yields, as it seemed difficult for higher-yielding farmers to further increase their yields. Despite the larger yield gains by lower-yielding farmers, the overall yields observed by farmers in the study area are still rather limited when compared with researcher-managed yields previously reported on-farm in the same rice scheme. No difference in household resource endowment was observed amongst farm types which could imply that wealth is not a crucial element of adoption of available innovation in this production system, unless all households were limited in further innovating. Further studies aimed at understanding the limitations to why some farmers do not apply packages of RAP despite not being socio-economically different from those farmers who apply, may be relevant to identify appropriate

solutions to such bottlenecks hence boosting also these farmers' rice productivity.

Data availability statement

The data for this study are available upon reasonable request to the corresponding authors and under the condition that the identity of farmers involved can be protected.

Author contributions

Conceptualisation, methodology, and validation: TA and TJS. Data collection, formal analysis, and writing—original draft preparation: TA. Writing—reviewing and editing: TA, PCS, and TJS. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2022.1009469/full#supplementary-material

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