
# Comparative analysis of rice yield determinants in irrigated production system in West Africa: evidence from Classification and Regression Trees model in Mali and Senegal

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**Comparative analysis of rice yield determinants in irrigated production system in West Africa: evidence from Classification and Regression Trees model in Mali and Senegal ϒ**

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**Abstract**

Understanding the yield variability and its determinants is the first step to reduce the yield gap and increase production. This paper aimed to evaluate the socioeconomic and field management factors influencing rice yield variability among farmers in the dry and wet seasons. Data were collected from 2445 households in Mali and Senegal. Heckman selection and Classification and Regression Trees model were used to determine factors affecting rice yield variability. Results showed that, most rice farmers grew rice during the dry season in Senegal while in Mali, rice was mostly grown during the wet season. In Senegal, yields were higher in the dry season (6.3 to 6.6 t $ha^{-1}$) than in the wet season (4.9 and 5.3 t $ha^{-1}$). The season-to-season variation was less observed in Mali. Yield variability was determined by distance to market, rate and first application date of phosphorus and nitrogen fertilizers, number of nitrogen fertilizer applications after sowing, size of plot, amount of seed use and the use of quality seeds. We recommend the dissemination of seasonal good agricultural practices to enhance yields of the smallholder farmers to achieve rice self-sufficiency in the West Africa.

**Keywords**: determinants, classification and regression trees, yield variability, smallholder farmers, West Africa

**JEL codes: C14, D24, QI2**

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## 1. Introduction

Food insecurity remains a challenge in West Africa. At the global level, while the number of undernourished people decreased from 841.7 million to 821.6 million during the last decade (2009-2018), this number has increased in West Africa from 31.5 million to 56.1 million over the same period (FAO, 2019). The current pandemic inflicted by the corona virus disease (COVID-19) crisis is expected to increase the food insecurity due to different measures taking worldwide to contain the pandemic (Arouna et al., 2020).

In West Africa, rice is a strategic commodity for food security. Rice has gained high importance as a staple food and is currently one of the largest sources of food energy in West Africa, where annual per capita consumption levels rose five-fold in the last six decades and are currently the highest on the continent (Soullier et al., 2020; Tsujimoto et al., 2019). Production increased during the same period (USDA, 2019), but as a result of rapid demographic growth (2.7% annually) and diet changes, the region increasingly relies on rice imports (Mendez del Villar and Lançon, 2015). This renders West Africa very vulnerable to international trade disruptions such as the ones currently inflicted by the corona virus disease (COVID-19) crisis (Arouna et al, 2020). In face of uncertainty and disruption in the international market by the current unprecedent COVID-19 pandemic, increasing local rice production remains a critical issue for food security. Low productivity of rice production systems remains a main challenge for increasing rice production and achieving the objective of self-sufficiency and food security in West Africa (Mendez del Villar and Lançon, 2015; Haefele et al., 2013). The low productivity of local rice production is partly due to yields that are well below their potential. In SSA, actual yields in rainfed systems range from 1 to 3 t/ha, while actual yields in irrigated systems range from 2 to 6 t/ha; this represents only 38% of their potential (van Oort et al. 2015).

This study aimed to determine variations in yield in irrigation scheme in SSA and to identify socioeconomic and crop management determinants of rice yield variability among smallholder rice producers. The contribution of the study to the literature is threefold. First, we identified the determinants of yield variability both in the wet and dry seasons in irrigation schemes in West Africa. There are two growing seasons in the irrigated rice production in the West Africa. Most existing studies only focus one season (Tanaka et al., 2015, 2013; Niang, 2017). For instance, Tanaka et al. (2015) and Niang et al. (2017) considered only the wet season in their study. However, factors affecting the yield may varied largely between the growing season. Failing to disaggregate to the determinants per season may lead to biased policy and agronomic recommendations. Season-specific good agricultural practice may help to increase the yield in the two growing seasons and may affect greatly the annual production of paddy rice. Second, both socioeconomic and crop management factors were considered in this paper. This contributes to literature which is mainly focused on biophysical factors such soil fertility, poor agronomic practices (Senthilkumar et al., 2020; Tsujimoto et al., 2019; Ran et al., 2018; van Tanaka et al., 2017, 2015, 2013; Stuart et al., 2016; Niang et al., 2017) climatic conditions as determined by the length of the growing season, radiation, maximum and minimum temperatures and rainfall and biophysical (Tittonell and Giller, 2013). With the exception of van Oort et al., (2017), analysis of socioeconomic factors affecting the yield variability in both the wet and dry season in irrigation schemes are lacking. Finally, Heckman selection model and Classification and Regression Tree (CART) model were used to identify the main factors that explain the variability of yield within the farm. Heckman's two-step model was employed to resolve sample selection bias because not all farmers are producing in the wet and dry seasons. Decision trees are increasingly used in various fields for exploring non-linear relationships between independent and dependent variables (Ran et al., 2018; Tanaka et al., 2015; Delmotte et al., 2011; Banerjee et al., 2014; Sussy et al. 2019). CART is a typical decision tree algorithm for predicting continuous variable (regression) or categorical variable (classification) (Ran et al., 2018). It is a powerful method for categorizing variability in yield within groups of observations that are homogeneous and relate the variability to its underlying causes and driver variables.

## 2. Materials and methods

### *2.1.Description of study area*

This study was carried out in Mali and Senegal located in Sahel zone of Africa (Figure 1). In Mali, three major irrigation schemes were selected: Office du Niger (ON), Office of the irrigated scheme of Baguineda (OPIB) and Office of Rural Development of Selingue (ODRS). In Senegal, two major irrigation schemes of the Senegal River Valley (SRV) were selected: the Delta (Dagana) situated at the mouth of the Senegal River, and the Middle Valley (Podor). These five areas were selected because they represent more than 60% of rice production in the two countries. The survey areas belongs to the Sudano-Sahelian zone characterized by a semi-arid climate with three distinct seasons: a wet 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.

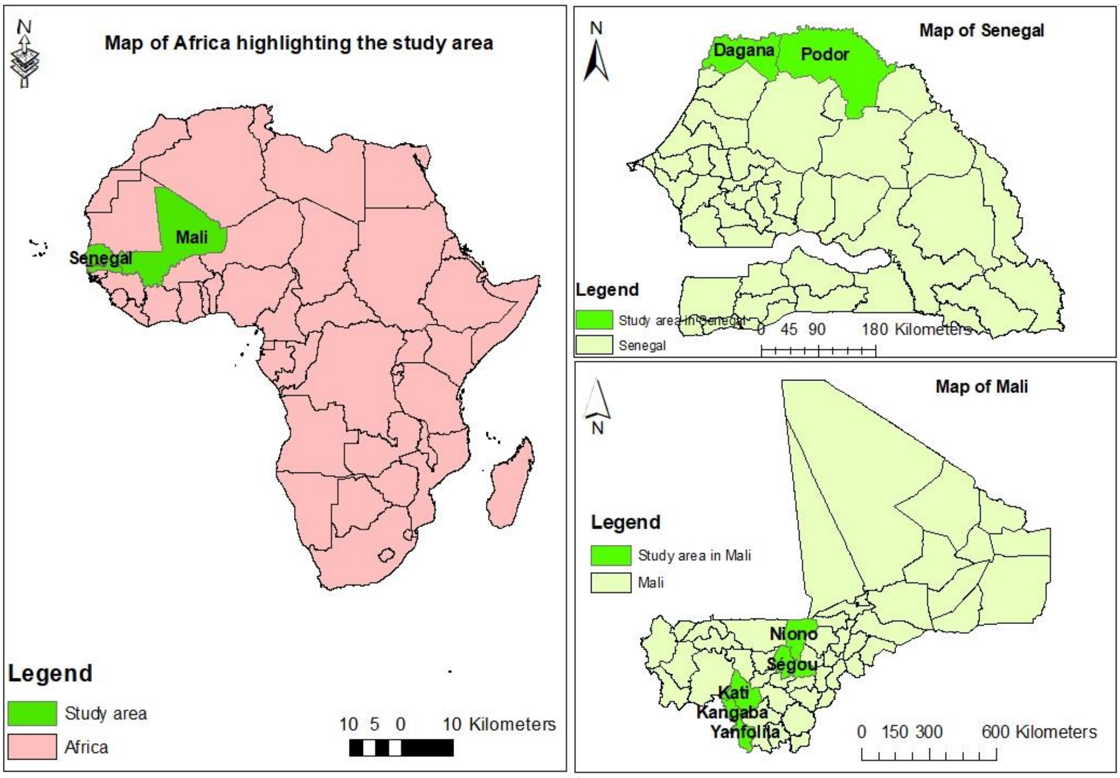



***Fig. 1:*** *Study area in Mali and Senegal*

### *2.2.Description of dataset*

Primary data were collected in May 2019 in both Mali and Senegal. Survey was conducted in three irrigation schemes in Mali (ON, OPIB and ODRS) and two irrigation schemes in Senegal (Podor and Dagana). Two stages sampling was used for data collection in each scheme. In the first stage, villages were randomly selected in each scheme. The number of villages per scheme was proportional to the total number of villages (Table 1). In total, 122 (60 in Mali and 62 in Senegal) villages were selected. In the second stage, farmers were randomly selected in each village. On average, 20 households were selected from each village. A total of 2445 rice farmer households were surveyed, comprising 1218 households in Mali and 1227 households in Senegal (Table 1).

For data collection, 41 enumerators (20 enumerators in Mali and 21 enumerators in Senegal) were recruited and trained on the questionnaire and the use of tablets. Data collection lasted from May 05th – 25th, 2019. Data collection were conducted using questionnaire automated on tablet computers and a web-based application and the android terminals through the Open Data Kit (ODK) Collect application. Farmers were interviewed using a structured questionnaire to gather information on household socioeconomic characteristics and agricultural practices including production seasons, land preparation, rice varieties, crop establishment, fertilizer management, water management, weed control and pest management. The quantity of harvested paddy (unhusked rice) was collected by asking the number of bags with harvested paddy and typical weight of one bag with the paddy.

**Table 1:** Number of rice farmers surveyed per irrigation scheme

| Country | Irrigation schemes | Number of villages | Number of farmers |
|---|---|---|---|
| Mali | Office du Niger (ON) | 40 | 807 |
| | Baguineda (OPIB) | 10 | 203 |
| | Selingue (ODRS) | 10 | 208 |
| Senegal | Podor | 42 | 842 |
| | Dagana | 20 | 385 |
| Total | | 120 | 2445 |

*2.3.Data analysis*

Descriptive statistics (i.e. average, minimum, maximum, median and standard deviation) were calculated for socioeconomic characteristics of rice producer households, characteristics of rice production systems and postharvest. To estimate the yield gaps, farmers were categorized into three classes based on grain yield: the top decile (top 10%), middle decile (middle 80%) and bottom decile (bottom 10%). Following Stuart et al. (2016), the exploitable yield gap was computed as the difference between the grain yield of the top decile (attainable yield) and the mean grain yield of all farmers, and the yield gap percentage was estimated by dividing this difference by the yield of the top decile. Data analysis was disaggregated per irrigation scheme, growing season and country.

In the study area, the decision to participate in the wet or dry season rice production depends on the farmers. Therefore, there were farmers who did not produce rice in one of the seasons. To address the problem of selection bias and attempt to obtain a robust estimator, the Heckman two-stage regression model was used. In the first stage, the participation to rice cropping in a season (wet or dry) is modelled with a probit model. In the second step, we added an inverse Mill's ratio, derived from the probit estimation, to the explanatory variables in yield regression equations.

Defining $D_i^*$ as a latent variable for $D_i$ as the variable for decision to produce in a given season, we have the following equation:

$$D_i^* = z_i'\alpha + \varepsilon_{0i} \tag{1}$$

where the subscript $i$ indicates the household, $D_i$ is the dummy variable for decision to produce, $\alpha$ is the parameter vector, and $\varepsilon_{0i}$ is the error term. $z_i$; is the vector of socioeconomic variables that affect the farmer's decision to produce in the wet or dry season, including crop management practices such as the fertilizer application rate, the seed rate, transplanting sowing, credit, distance to the market, etc.

Estimated form of equation (1) is expressed as follows: $D_i = \begin{cases} 1 & if\ D_i^* = z_i^*\alpha + \varepsilon_{0i} > 0 \\ 0 & if\ D_i^* = z_i^*\alpha + \varepsilon_{0i} \leq 0 \end{cases}$

(2)

The probit model gives the following inverse Mill's ratio, $\lambda_i$.

$$\lambda_i = \frac{\phi(z_i'\hat{\alpha})}{\Phi(z_i'\hat{\alpha})} \tag{2}$$

Where $\phi(.)$ and $\Phi(.)$ are the probability density function and cumulattive distribution function of the normal distribution, respectively. $\hat{\alpha}$ is the predicted value of $\alpha$.

The rice yield ($Y$) can only be observed when producers have produced in a season. Therefore, the following relationship is established:

$$Y_i = \begin{cases} Y_i & if\ D_i = 1 \\ unobservable & if\ D_i = 0 \end{cases} \qquad (3)$$

This relation makes sample selection a problem and justify the use of the Heckman selection model.

CART model, a nonparametric modelling approach, was also used to identify the main factors that explain the variability of yield between smallholder farmers and classification of farmers per group. Effectiveness of this analysis at farm scale was demonstrated for several crop production systems including rice systems (Tanaka et al., 2015; Ran et al., 2018; Delmotte et al., 2011), maize production systems (Banerjee et al., 2014; Sussy et al., 2019; Tittonell and Giller, 2013) and sugarcane production systems (Ferraro et al., 2009). CART uses a binary recursive partitioning technique to split the dataset into groups based on the values of explanatory variables. The optimum splits are determined by the negative log of the P-value associated with the sum of squares due to the difference in means. The model is developed in hierarchy consisting of splitting nodes (determining factors) and clusters of data points (terminal nodes). All calculations and diagrams in the CART model in this paper were built using STATA 16. The rice yield (treated as the dependent variable in the CART analysis) was expressed as grain yield in tons per hectare for a field. Rice yield was calculated by dividing total weight of harvested paddy (the product of number of bags and typical weight of the bag with the paddy) by farm size.

## 3. Results

### *3.1.Characteristics of rice farming households*

Household sociodemographic data are summarized in Table 2. Results showed male dominance in rice production in irrigation schemes. The percentage of male farmers in the five irrigation schemes ranged from 87% (Podor, in Senegal) to 95% (ON, in Mali). In general, the mean age of rice farmers was 52 years indicating that rice farmers were not young. The majority of rice farmers (about 90%) were married and on average eight members per household in the different irrigation schemes. About 22% of farmers in Mali had access to credit and financial services while it was higher in Senegal (57%). The lowest percentage of farmers received credit was found in OPIB (3%), followed by ODRS (10%), and the highest percentages were in Dagana (78%) and Podor (48%). In general, rice farmers did not attend formal education, but they had attended agricultural training (73% in Mali and 78% in Senegal). This high percentages may be related to the fact that most producers have crop production as their main activity (from 76% in ORDS to 92% in OPIB). However, although the percentage of farmers who have received agricultural training was high in Mali, only 38% of OPIB's farmers have received training. The percentage of producers with information on new rice varieties ranged from 81% in Podor (Senegal) to 99% in ODRS (Mali). In addition, most farmers were aware of the price of paddy rice on the market. Although most farmers in the five irrigation schemes were engaged in agricultural production as their main activity, had information on new rice varieties and knew the market price of paddy rice, very few were in contact with extension except at the ODRS, where there was more than 84% of rice farmers in contact with extension agents. In the other irrigated schemes, the highest percentage of rice farmers in contact with extension agents was found in ON (33%), followed by OPIB (31%), and the lowest percentages were in Dagana (8%) and Podor (17%). In general, a distance of 8-9 km on average exists between villages and local market. The rice production periods are different for the two countries. In Mali, most rice farmers grow rice in the wet season (90%) while in Senegal, rice is mostly grown in the dry season (81%).

**Table 2:** Socio-demographics and institutional characteristics of rice farming households

| **Variables** | **Overall (n=2445)** | **Mali** | | | | **Senegal** | | |
|---|---|---|---|---|---|---|---|---|
| | | **ON (n=807)** | **OPIB (n=203)** | **ORDS (n=208)** | **Overall (n=1218)** | **Podor (n=842)** | **Dagana (n=385)** | **Overall (n=1227)** |
| Household characteristics | | | | | | | | |
| Age (year) | 51.72 | 51.46 | 54.06 | 53.71 | 52.28 | 52.35 | 48.57 | 51.17 |
| | (13.21) | (13.39) | (13.63) | (14.45) | (13.65) | (12.62) | (12.65) | (12.75) |
| Household size | 7.80 | 8.93 | 8.27 | 8.19 | 8.69 | 7.14 | 6.42 | 6.91 |
| | (4.34) | (4.41) | (5.50) | (3.67) | (4.51) | (4.18) | (3.44) | (3.97) |
| Household members working age (n) | 4.88 | 5.31 | 5.11 | 4.41 | 5.13 | 4.64 | 4.60 | 4.63 |
| | (2.69) | (2.65) | (3.25) | (1.95) | (2.68) | (2.69) | (2.64) | (2.68) |
| Distance to market (km) | 8.79 | 9.45 | 7.61 | 6.46 | 8.63 | 7.41 | 13.25 | 9.24 |
| | (9.92) | (8.19) | (4.52) | (11.84) | (8.55) | (6.92) | (13.95) | (10.06) |
| =1 if male (%) | 91.40 | 94.76 | 93.20 | 90.60 | 93.72 | 87.17 | 91.67 | 88.62 |
| =1 if married (%) | 92.90 | 95.79 | 96.12 | 91.22 | 94.92 | 89.27 | 93.06 | 90.49 |
| =1 if formal education (%) | 16.66 | 15.54 | 21.36 | 25.71 | 18.33 | 6.75 | 31.25 | 14.67 |
| =1 if household head is rice farmer (%) | 96.72 | 96.72 | 100.00 | 89.66 | 95.73 | 98.67 | 96.30 | 97.90 |
| Institutional characteristics | | | | | | | | |
| =1 if access to credit (%) | 38.68 | 30.52 | 2.91 | 10.03 | 22.85 | 47.68 | 78.24 | 57.56 |
| =1 if household head attended agricultural training (%) | 75.69 | 72.94 | 37.38 | 96.55 | 73.07 | 76.66 | 83.33 | 78.82 |
| =1 if contact with extension (%) | 29.98 | 33.15 | 31.07 | 84.01 | 43.06 | 17.26 | 8.33 | 14.37 |
| =1 if main activity is crop production (%) | 85.80 | 86.24 | 92.23 | 75.86 | 84.93 | 86.28 | 87.96 | 86.83 |
| =1 if get information | 86.07 | 86.80 | 93.20 | 98.75 | 90.02 | 80.86 | 82.41 | 81.36 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| on new rice varieties (%) | | | | | | | | |
| =1 if get information on the price of paddy on the market (%) | 87.27 | 79.78 | 72.33 | 97.81 | 82.42 | 90.27 | 98.84 | 93.04 |
| =1 if members of association (%) | 68.66 | 65.45 | 36.41 | 86.52 | 65.91 | 66.81 | 82.64 | 71.93 |
| =1 if growing only in dry season (%) | 44.38 | 18.07 | 9.22 | 2.19 | 13.75 | 75.11 | 93.06 | 80.91 |
| =1 if growing in only wet season (%) | 66.78 | 87.83 | 100.00 | 100.00 | 91.84 | 41.92 | 26.39 | 36.90 |
| =1 if growing in both seasons (%) | 13.35 | 10.39 | 9.22 | 2.19 | 8.60 | 18.36 | 20.37 | 19.01 |

*() Standard deviation*

### *3.2.Crop management practices*

The mean farm size was 1.2 and 1.3 ha in the dry and wet seasons, respectively. Not only farmers were mostly grown rice in the wet season in Mali and in the dry season but also the rice cropping areas were higher in these seasons as well. The highest difference was observed in the irrigation scheme of ON (0.62 ha) followed by the scheme of ODRS (0.37 ha) in Mali (Table 3). Mechanical ploughing and harrowing were the dominant methods (on at least 56% and 63% of the plots, respectively) in the different zones in both seasons except in OPIB where the percentage is less than 5%. Mean amount seed varied across sites, ranging from 66 to 118 kg ha$^{-1}$ in the dry season, and 61 to 111 kg ha$^{-1}$ in the wet season. The largest amounts of seed were used in Senegal during both seasons. This was explained by the fact that most rice farmers in the Podor and Dagana in Senegal did direct sowing. Indeed, only 9.5% and 22.5% of rice growers used transplantation respectively during the dry and wet seasons in the two schemes of Senegal. In contrast, transplanting was the dominant sowing method of rice farmers at the three sites in Mali. On average the percentages were 99% and 92% over all three sites in Mali during the dry and wet seasons, respectively.

In the dry season, the mean total amount of N, P and K application after sowing ranged from 92 to 117 kg N $ha^{-1}$, 7 to 11 kg P $ha^{-1}$ and 14 to 27 kg K $ha^{-1}$, respectively. The trends were similar during the wet season. The results also showed that in Mali, the frequency of urea applications on the plots varies between one and two times (49% and 47%, respectively) while, in Senegal, it was between two and three times (75% and 23%, respectively). In contrast, rice farmers used only one NPK application on the plots. The first application date of urea averaged 20 to 31 days and 19 to 28 days after sowing during the dry and wet season, respectively. On the other hand, the application of NPK often took place a little earlier after sowing. On average, the first dates of application of NPK were between 7 and 22 days and 6 and 18 days after sowing during the dry and wet seasons, respectively.

Weed control was carried out in all plots once (86%) or twice (13%) during the dry season; and once (73%) or twice (8%) during the wet season (Table 3). In general, weed control activity is accomplished by hand and / or the application of herbicide. Moreover, bird control is also an activity carried out by producers at the plot level especially during the dry season (28% to 98%) when birds cause more damage in the fields.

**Table 3:** Farm characteristics of rice production inputs

| | **Mali** | | | | | | **Senegal** | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Dry season (n=219)** | | | **Wet season (n=1463)** | | | **Dry season (n=1081)** | | **Wet season (n=494)** | |
| | **ON** | **OPIB** | **ODRS** | **ON** | **OPIB** | **ODRS** | **Podor** | **Dagana** | **Podor** | **Dagana** |
| ***Continuous variable*** | | | | | | | | | | |
| Rice area (ha) | 1.08 | 1.28 | 0.36 | 1.70 | 1.47 | 0.73 | 0.77 | 2.03 | 0.58 | 1.98 |
| | (0.96) | (1.69) | (0.13) | (1.65) | (1.55) | (1.00) | (3.48) | (3.97) | (0.88) | (2.86) |
| Seeding rate (kg/ha) | 65.52 | 71.80 | 66.29 | 61.32 | 73.87 | 75.03 | 101.46 | 118.37 | 94.19 | 110.90 |
| | (22.53) | (17.36) | (18.27) | (18.17) | (20.02) | (19.04) | (30.07) | (16.20) | (31.19) | (18.95) |
| N application rate (kg/ha) | 91.56 | 101.26 | 116.06 | 93.60 | 106.21 | 81.79 | 117.15 | 101.00 | 144.04 | 138.53 |
| | (29.24) | (24.92) | (27.99) | (28.10) | (35.88) | (35.02) | (31.80) | (33.59) | (41.40) | (53.97) |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| P application rate (kg/ha) | 7.24 | 10.02 | 11.13 | 6.58 | 8.18 | 9.94 | 10.90 | 10.32 | 10.40 | 8.64 |
| | (4.10) | (3.41) | (2.95) | (3.02) | (3.41) | (3.89) | (6.52) | (3.79) | (4.62) | (4.21) |
| K application rate (kg/ha) | 13.76 | 19.02 | 21.14 | 12.49 | 15.54 | 18.89 | 26.99 | 25.55 | 25.77 | 21.40 |
| | (7.78) | (6.47) | (5.61) | (5.74) | (6.47) | (7.39) | (16.16) | (9.38) | (11.45) | (10.43) |
| 1st application urea date | 30.80 | 19.11 | 25.86 | 23.15 | 20.83 | 18.07 | 21.84 | 28.02 | 25.61 | 27.49 |
| | (18.54) | (9.72) | (17.37) | (13.15) | (8.33) | (14.29) | (6.38) | (8.50) | (11.29) | (10.01) |
| 1st application NPK date | 20.27 | 7.37 | 9.57 | 14.09 | 5.75 | 7.41 | 8.57 | 21.97 | 11.50 | 17.24 |
| | (15.90) | (3.82) | (4.20) | (10.48) | (3.31) | (3.94) | (9.78) | (8.54) | (10.04) | (10.90) |
| 1st application herbicide date | 24.42 | 23.21 | 13.00 | 12.91 | 20.30 | 12.36 | 18.17 | 24.67 | 15.06 | 21.74 |
| | (16.87) | (12.08) | (8.39) | (15.46) | (12.66) | (9.33) | (7.24) | (6.78) | (9.78) | (7.88) |
| Number of man day for weeding | 2.98 | 3.04 | 3.51 | 3.16 | 4.10 | 3.56 | 3.33 | 2.65 | 3.73 | 2.66 |
| | (1.28) | (1.34) | (1.26) | (1.44) | (1.24) | (1.22) | (1.22) | (1.28) | (1.17) | (1.42) |
| **Frequency of urea application after sowing** | | | | | | | | | | |
| No urea application (%) | 0.52 | 0.00 | 0.00 | 0.96 | 0.49 | 5.96 | 0.29 | 0.00 | 0.00 | 4.39 |
| Single urea application (%) | 50.78 | 21.05 | 85.71 | 23.77 | 40.78 | 88.40 | 0.74 | 3.23 | 2.37 | 0.00 |
| Two-split urea application (%) | 45.60 | 78.95 | 14.29 | 70.79 | 58.25 | 5.64 | 71.13 | 81.34 | 72.82 | 81.58 |
| Three-split urea application (%) | 3.11 | 0.00 | 0.00 | 4.48 | 0.49 | 0.00 | 27.84 | 15.42 | 24.80 | 14.04 |
| **Frequency of NPK application after sowing** | | | | | | | | | | |
| No NPK application (%) | 10.88 | 0.00 | 0.00 | 7.78 | 1.94 | 4.08 | 10.01 | 0.50 | 7.12 | 7.02 |
| Single NPK application (%) | 74.61 | 94.74 | 85.71 | 79.96 | 96.12 | 95.30 | 87.19 | 98.01 | 90.77 | 92.11 |
| Two-split NPK application (%) | 13.47 | 5.26 | 14.29 | 11.51 | 1.94 | 0.63 | 2.65 | 1.49 | 2.11 | 0.88 |
| Three-split NPK application (%) | 1.04 | 0.00 | 0.00 | 0.75 | 0.00 | 0.00 | 0.15 | 0.00 | 0.00 | 0.00 |
| **Frequency of herbicide application after sowing** | | | | | | | | | | |
| None | 0.00 | 0.00 | 0.00 | 28.78 | 8.74 | 9.09 | 0.00 | 1.00 | 13.19 | 5.26 |
| Once | 96.89 | 94.74 | 71.43 | 67.80 | 89.32 | 85.89 | 81.30 | 89.30 | 62.01 | 86.84 |
| Twice | 3.11 | 5.26 | 28.57 | 3.41 | 1.94 | 5.02 | 18.70 | 9.70 | 24.80 | 7.89 |
| =1 if Smart valley technology | 82.90 | 31.58 | 0.00 | 78.04 | 52.91 | 17.24 | 0.44 | 0.00 | 0.26 | 0.00 |
| =1 if Improved variety | 70.98 | 94.74 | 100.00 | 27.19 | 89.81 | 89.97 | 95.14 | 95.27 | 83.64 | 92.11 |
| =1 if Transplanting | 98.96 | 100.00 | 100.00 | 92.43 | 100.00 | 86.83 | 15.17 | 0.00 | 28.50 | 2.63 |
| =1 if Herbicide application | 68.39 | 78.95 | 85.71 | 71.22 | 91.26 | 90.91 | 81.44 | 98.01 | 86.81 | 94.74 |
| =1 if Insecticide application | 28.50 | 94.74 | 85.71 | 27.29 | 86.41 | 78.06 | 0.59 | 0.25 | 0.26 | 5.26 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| =1 if Bird control | 64.77 | 73.68 | 28.57 | 43.07 | 36.89 | 7.84 | 67.30 | 98.01 | 90.24 | 94.74 |
| =1 if Tillage method | 46.63 | 26.32 | 42.86 | 22.39 | 33.98 | 16.30 | 15.91 | 3.73 | 24.54 | 1.75 |
| =1 if Land mechanical harrowing | 62.69 | 5.26 | 85.71 | 68.12 | 2.91 | 68.65 | 95.43 | 100.00 | 91.56 | 99.13 |
| =1 if Mechanical ploughing method | 56.48 | 0.00 | 71.43 | 55.76 | 0.49 | 65.83 | 94.55 | 85.82 | 93.67 | 85.09 |
| =1 if Alternative wet and dry irrigation | 62.18 | 26.32 | 0.00 | 46.06 | 3.88 | 34.48 | 0.44 | 9.95 | 0.00 | 3.51 |

*() Standard deviation*

### *3.3.Rice yield and the attainable yield*

The average rice grain yield in the surveyed schemes ranged from 4.2 to 6.6 t ha$^{-1}$ and 3.6 to 5.3 t ha$^{-1}$ in the dry and wet seasons, respectively (Table 4; Fig. 2). However, yield varied between growing seasons, irrigation schemes and countries. In Senegal, the yields ranged between 6.3 and 6.6 t ha$^{-1}$ during the dry season in Podor and Dagana, respectively, and between 4.9 and 5.3 t ha$^{-1}$ during the wet season Podor and Dagana, respectively. The highest and lowest yield gap in rice was observed for Dagana in the dry season (32%) and the wet season (52%), respectively. In addition, these results showed that the yields during the dry season were higher than in the wet season in Senegal. This is in contrast of Mali. In Mali, the season-to-season variation in yields was less pronounced. In Mali, the yield during the wet season is higher than during the dry season but not in the ODRS scheme where the reverse is observed (4.3 in the dry season to 3.6 t ha$^{-1}$ in the wet season). Mean rice yields were 4.2 to 4.4 t ha$^{-1}$ in ON and 4.3 to 4.8 t ha$^{-1}$ and OPIB during the dry and wet seasons, respectively. On average, the yields ranged between 3.6 and 4.8 t ha$^{-1}$ during the dry season and between 4.15 and 4.3 t ha$^{-1}$ during the wet season in Mali. The highest yield gap in rice was determined for OPIB (75%) in dry season, followed by ODRS (69%) in wet season, and the lowest were observed in ODRS (41%) in dry season followed by ON (51%) and OPIB (51%) in wet season, respectively.

**Table 4:** Sample mean, attainable (top decile) mean and gaps in grain yield

| | | Dry season | | | | | Wet season | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Mean yield | Attainable yield (Top decile) | Yield gap | Gap (%) | Number of plots | Mean yield | Attainable yield (Top decile) | Yield gap | Gap (%) | Number of plots |
| **Mali** | **ON** | 4.15[a] | 6.82 | 2.67 | 64.34 | 193 | 4.39[b] | 6.62 | 2.23 | 50.80 | 938 |
| | **OPIB** | 4.28[a] | 7.50 | 3.22 | 75.23 | 19 | 4.81[a] | 7.26 | 2.45 | 50.94 | 206 |
| | **ODRS** | 4.31[a] | 6.08 | 1.77 | 41.07 | 7 | 3.60[a] | 6.07 | 2.47 | 68.61 | 319 |
| **Senegal** | **Podor** | 6.34[a] | 9.09 | 2.75 | 43.38 | 679 | 5.33[b] | 7.90 | 2.57 | 48.22 | 379 |
| | **Dagana** | 6.60[a] | 8.68 | 2.08 | 31.52 | 402 | 4.92[b] | 7.48 | 2.56 | 52.03 | 115 |

*The same letter indicates no significant different according to Tukey's protected TK- test (α = 0.05).*
*Yield gap = attainable yield − mean yield.*

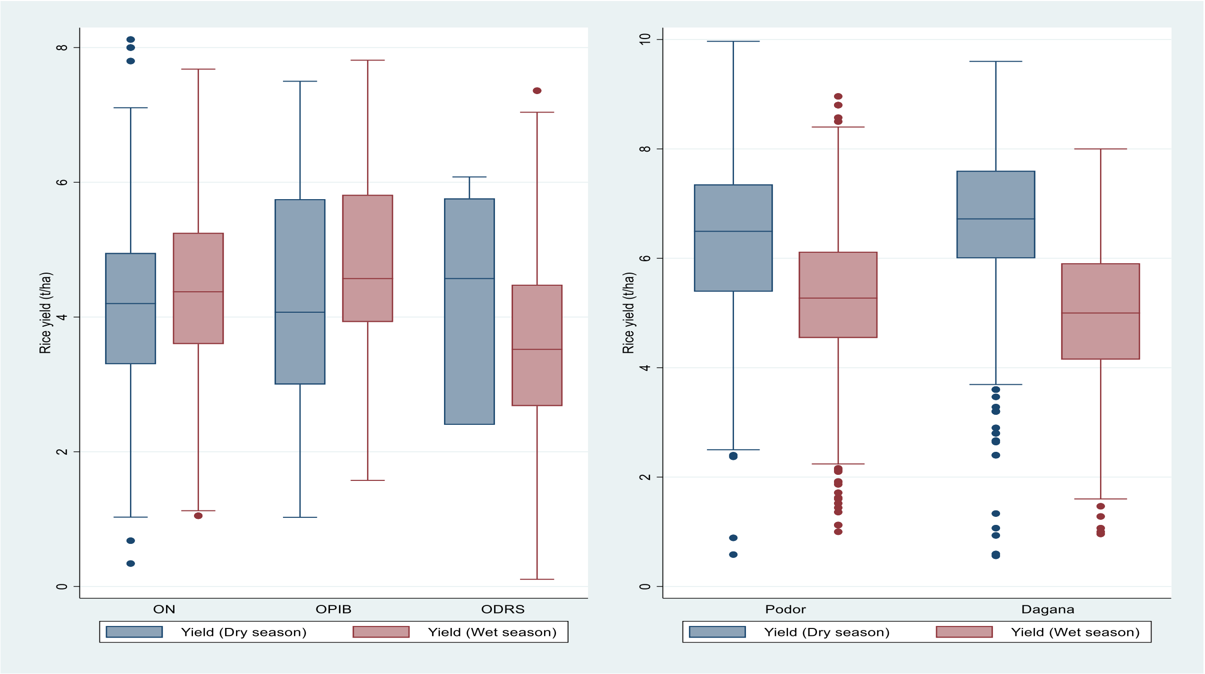



***Figure 2:*** *Rice yield per scheme and growing season*

### *3.4.Factors affecting rice yield*

Table 5 shows the factors affecting rice yield using the Heckman selection model. The results showed that the determinants of yield vary by season and country. In both seasons, the amount nitrogen application rate (N) influenced yield in both countries. Area determined yield during the rainy season in Mali and both seasons in Senegal. On the other hand, the quantity of seed was a determinant during both seasons in Mali but only in dry season in Senegal. The phosphorus application rate (P) and the distance to the market influenced the yield during the dry season only in the two countries. In contrast, transplanting was a determinant only during the wet season in both countries. The use of improved varieties was also a determinant of yield in the wet season in Mali and in the dry season in Senegal. In addition to these variables, mechanical levelling influenced yield in both seasons in Senegal. In addition, herbicide application and bird hunting influenced yield in the dry season in Senegal and the wet season in Mali, respectively.

**Table 5:** Determinant of yield with Heckman selection model

| | Mali | | Senegal | |
|---|---|---|---|---|
| | **Dry season** | **Wet season** | **Dry season** | **Wet season** |
| ***Rice yield (kg/ha)*** | | | | |
| Rice area (ha) | 0.042 | 0.074*** | -0.052*** | -0.172*** |
| | (0.09) | (0.02) | (0.01) | (0.04) |
| Seeding rate (kg/ha) | 0.011*** | 0.008*** | 0.005** | 0.002 |
| | (0.00) | (0.00) | (0.00) | (0.00) |
| N application rate (kg/ha) | 0.013*** | 0.009*** | -0.003* | 0.004** |
| | (0.00) | (0.00) | (0.00) | (0.00) |
| P application rate (kg/ha) | 0.042* | -0.014 | 0.028*** | 0.020 |
| | (0.02) | (0.01) | (0.01) | (0.02) |
| 1st application urea date | 0.002 | 0.003 | -0.001 | 0.004 |
| | (0.01) | (0.00) | (0.01) | (0.01) |
| Number of man day for weeding | 0.027 | 0.009 | 0.004 | 0.044 |
| | (0.07) | (0.02) | (0.03) | (0.05) |
| Distance to inputs market (km) | -0.035*** | 0.003 | -0.018*** | -0.003 |
| | (0.01) | (0.00) | (0.00) | (0.01) |
| =1 if Improved variety | 0.197 | -0.155** | 0.563*** | 0.043 |
| | (0.21) | (0.07) | (0.21) | (0.20) |
| =1 if Transplanting | 1.435 | 0.916*** | -0.230 | -0.547** |
| | (0.89) | (0.13) | (0.18) | (0.24) |
| =1 if Herbicide application | -0.202 | -0.063 | -0.460*** | 0.146 |
| | (0.20) | (0.08) | (0.18) | (0.23) |
| =1 if Bird control | 0.209 | 0.324*** | 0.060 | -0.374 |
| | (0.19) | (0.07) | (0.13) | (0.24) |
| =1 if Land mechanical harrowing/levelling | -0.156 | -0.086 | 1.311*** | 1.265*** |
| | (0.19) | (0.07) | (0.27) | (0.29) |
| Constance | -0.432 | 2.159*** | 5.204*** | 3.373*** |
| | (1.20) | (0.25) | (0.52) | (0.61) |
| ***Determinant of decision to production (selection model)*** | | | | |
| Age (year) | 0.472** | -0.544** | -0.012 | -0.026 |
| | (0.22) | (0.27) | (0.13) | (0.12) |
| Household size | -0.002 | 0.004 | -0.006* | 0.001 |
| | (0.00) | (0.00) | (0.00) | (0.00) |
| =1 if male | -0.057 | 0.138 | 0.041 | 0.166 |
| | (0.12) | (0.14) | (0.12) | (0.11) |
| =1 if access to credit | 0.026*** | -0.024*** | -0.018* | 0.031*** |
| | (0.01) | (0.01) | (0.01) | (0.01) |
| =1 if household head attended agricultural training | -0.485*** | 0.520*** | -0.660*** | 0.442*** |
| | (0.10) | (0.12) | (0.11) | (0.10) |
| =1 if contact with extension | 0.118 | -0.197* | 0.455*** | -0.604*** |
| | (0.10) | (0.11) | (0.10) | (0.09) |
| =1 if main activity is crop production | 0.501*** | -0.345*** | 0.246*** | -0.143* |
| | (0.09) | (0.11) | (0.08) | (0.07) |
| Constance | -1.679*** | 1.875*** | 0.920*** | -0.231 |
| | (0.28) | (0.34) | (0.23) | (0.21) |
| *Lambda* | 0.621** | -0.951** | -1.451*** | -0.041 |
| | (0.30) | (0.42) | (0.38) | (0.34) |
| *N* | 1593 | 1593 | 1336 | 1336 |
| *N_selected* | 219 | 1463 | 1081 | 493 |
| *N_nonselected* | 1374 | 130 | 255 | 843 |
| *Wald chi2(12)* | 71.307*** | 179.787*** | 108.047*** | 109.824*** |

### *3.5.Factors affecting variation in rice yield*

The CART analysis for the rice yield as a function of socioeconomic and crop management characteristics were employed separately for each of the cinq selected regions for this study and the two growing seasons. Results showed twenty-nine terminal nodes with ten splitting nodes in the ON scheme (r = 0.42, P < 0.000, n = 99) (Fig. 3a); seventeen terminal nodes with six splitting nodes in the Podor (r = 0.22, P < 0.000, n = 334) (Fig. 3b) and nineteen terminal nodes with four splitting nodes in the Dagana (r = 0.19, P < 0.000, n = 189) (Fig. 3c) during the dry season[1]. During the wet season, the CART analysis showed thirty-one terminal nodes with ten splitting nodes in the ON scheme (r = 0.14, P < 0.000, n = 459) (Fig. 4a); three terminal nodes with two splitting nodes in the OPIB (r = 0.12, P < 0.000, n = 92) (Fig. 4b); eleven terminal nodes with four splitting nodes in the ODRS (r = 0.22, P < 0.000, n = 163) (Fig. 4c); eleven terminal nodes with five splitting nodes in the Podor (r = 0.34, P < 0.000, n = 196) (Fig. 4d) and five terminal nodes with three splitting nodes in the Dagana (r = 0.34, P < 0.000, n = 57) (Fig. 4e).

In the dry season, phosphorus application rates were the most important factor affecting in yield variation in ON (Fig. 3a) and average yields were 3.5 t $ha^{-1}$. Plots fertilized with a low dose of phosphorus (up to 3.9 kg $ha^{-1}$, node 2), compared with those fertilized with phosphorus in a slightly higher dose (3.9-19.7 kg $ha^{-1}$, node 3), gave lower yields on average by 39% (1.7 t $ha^{-1}$). On farms with phosphorus in higher dose, short distance to input and output market was an important determinant of the level of yield. Indeed, farms with short distance to market (1-11 km, node 6), yields were higher on average by 0.4 t $ha^{-1}$ than on farms where the distance to the market was greater than 11 km (node 7). In addition, in farms with short distance to market, the use of improved varieties (node 11) increased the yield by 27% (1.1 t $ha^{-1}$) compared to farms that did not use improved varieties (4.1 t $ha^{-1}$, node 10). However, in farms where the distance to the market is greater than 11 km (12-40 km), a use of phosphorus application rate between 8.7-19.7 kg $ha^{-1}$ (node 13) allowed to obtain a yield of 5.1 t $ha^{-1}$, i.e. an increase of

[1] Due to insufficient sample size, the CART analysis could not be run for ODRS and OPIB during the dry season.

55% (1.8 t ha$^{-1}$) compared to those that use an amount between 3.9-8.7 kg ha$^{-1}$ (node 12). The highest yields were obtained in farms who use of improved varieties. Indeed, in these farms, the highest yields (6.2 t ha$^{-1}$) were obtained with a seed rate between 57-118 kg ha$^{-1}$ (node 19) and contact with extension agent (node 29). However, the lowest yields (4.3 t ha$^{-1}$) were observed in plot with a low dose of phosphorus (up to 3.9 kg ha$^{-1}$, node 2) and a seed rate between 20-41 kg ha$^{-1}$ (node 19).

In the Podor scheme, farm size was the primary splitting node of differentiation (Fig. 3b). Smaller farms (up to 1 ha) achieved higher yields on average by 5.9 t ha$^{-1}$ (node 2) than farms above 1 ha (4.7 t ha$^{-1}$, node 3). Farms with more than 1 ha were divided into two according to the amount of phosphorus application rate. Plots where less than 9.7 kg ha$^{-1}$ phosphorus was used yielded average 3.8 t ha$^{-1}$ (node 6), whereas an average yield of 5.64 t/ha was achieved when phosphorus application rate ranged between 9.7-50.3 kg ha$^{-1}$ (node 7). The results show also that distance to market is also an important factor in the level of yields. Similar to ON, farms located at most 16 km from the market obtained higher yields (6.1t ha$^{-1}$, node 4) than in farms located more than 16 km (5.7 t ha$^{-1}$, node 5) i.e. an increase of 6% (0.4 t/ha). The highest yield (7.2 t ha$^{-1}$, node 17) was obtained in smaller farms located at most 16 km from the market, when the first date of application of the urea occurred 25 days after sowing (node 8) and the amount of phosphorus used was between 10.9-55.8 kg ha$^{-1}$ (node 17).

Farm size also was the primary splitting node of differentiation during the dry season in Dagana scheme (Fig. 3c). In this zone, the highest yield (6.8 t ha$^{-1}$, node 8) was obtained when cultivated rice area was between 0.2-5 ha (node 2), frequency of urea application after sowing was 1 or 2 (node 4) and first date of application of the NPK occurred 22 days after sowing (node 8). However, lowest yields (4.3 t ha$^{-1}$) were observed in plot with farm size more than 6 ha (node 3).

**Fig. 3a. Dry season in ON (Mali)**

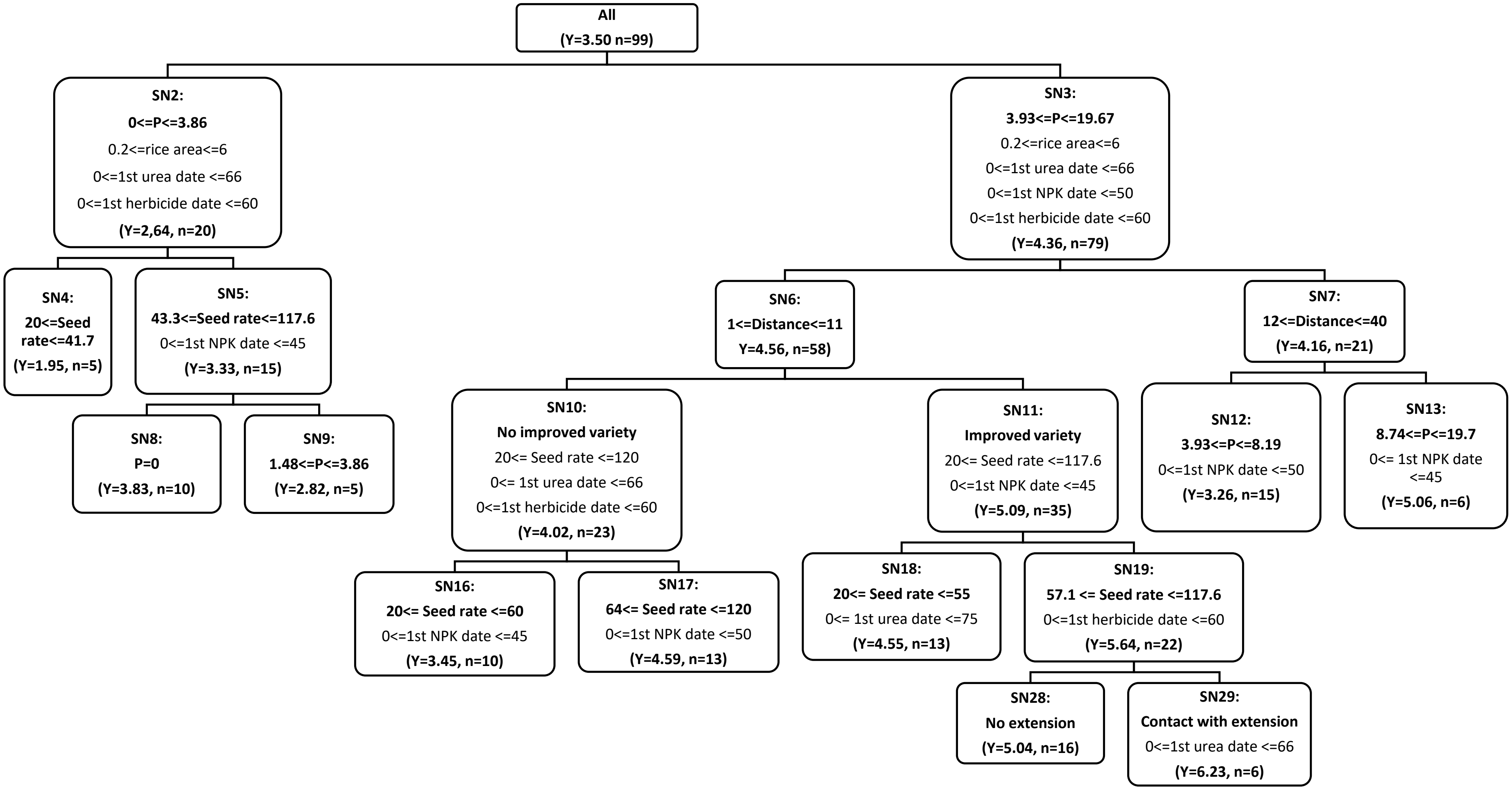


**Fig. 3b. Dry season in Podor (Senegal)**

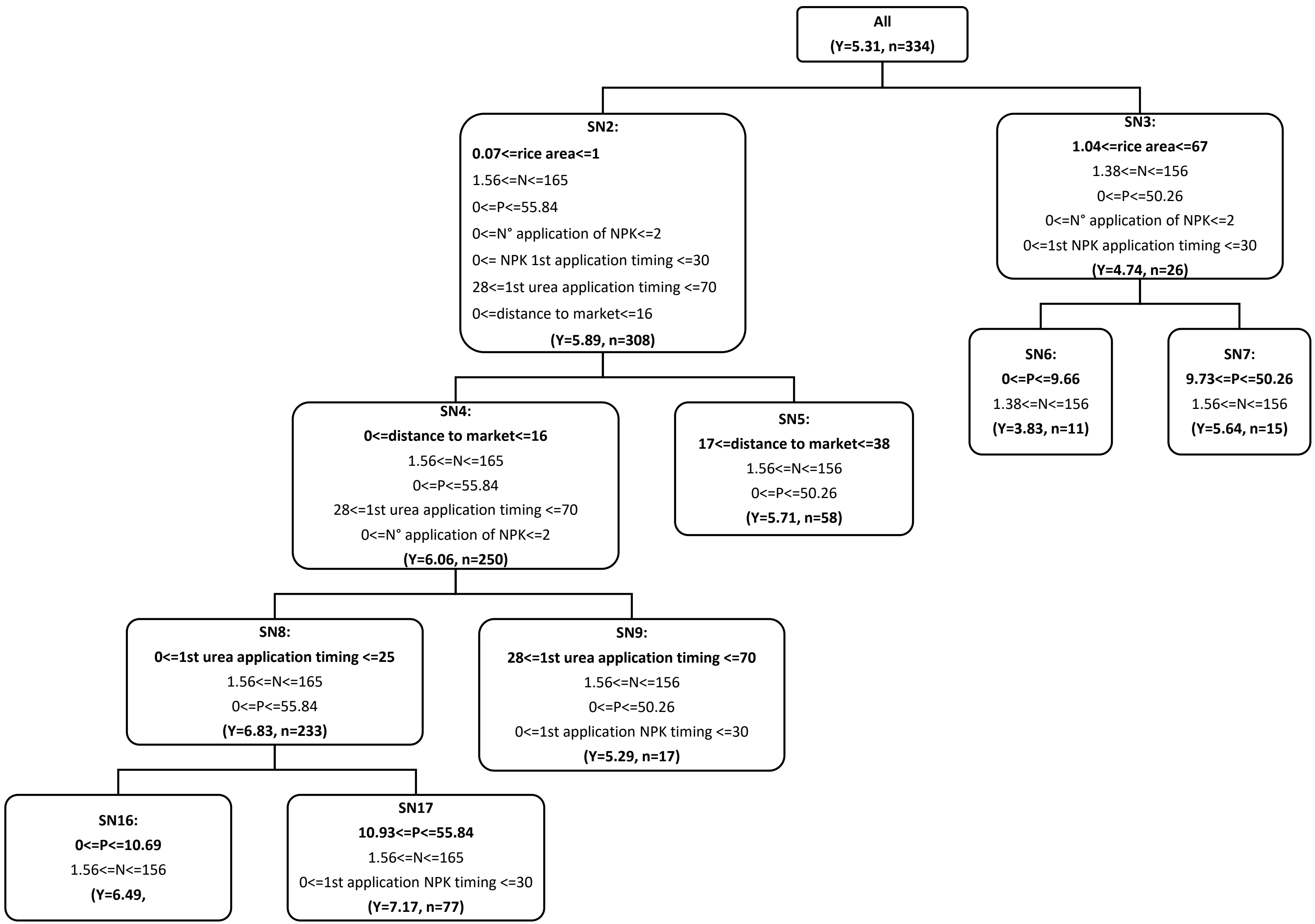
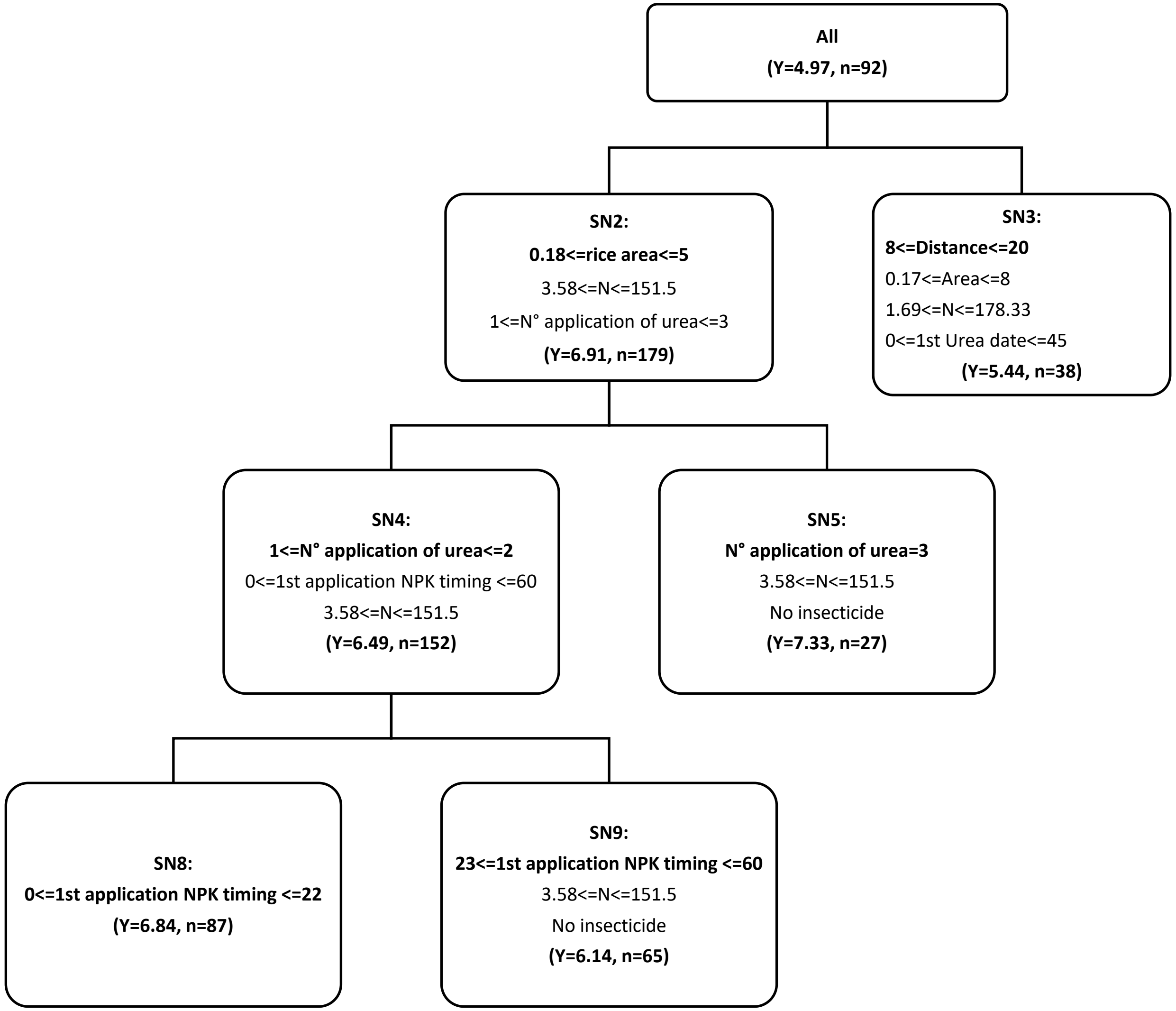


**Fig. 3c. Dry season in Dagana (Senegal)**



During the wet season, results on 459 fields produced the tree with several variables as splitting criteria in the ON scheme (Fig.4a). In order of importance they were: phosphorus application rate, distance to input and output market, frequency of urea application after sowing, bird control, man day for weeding and use improved variety. The average yield obtained at plot level during the wet season was 4.2 t $ha^{-1}$ (node 1). The highest yield (6.2 t $ha^{-1}$, node 31) was obtained when phosphorus application rate was between 9.5-15.0 kg $ha^{-1}$ (node 7), bird control was used (node 15) and improved rice variety was used (node 31). The lowest yields (2.88 t $ha^{-1}$, node 18) were observed when phosphorus application rate is less than or equal 4.4 kg $ha^{-1}$ (node 4), distance to the market is between 6-40 km (node 9) and one single frequency of urea application after sowing (node 18). However, among the farmers who applied low dose of phosphorus (at most 4.4 kg $ha^{-1}$, node 4), with farms located at most 5 km from the market (node 8) and whose number of man day for weeding was between 2-7, obtained a yield of 5.1 t $ha^{-1}$ (node 17).

In the OPIB scheme, the distance to the market was the main splitting node (Fig. 4b). In farms with short distance to market (1-7 km, node 2), yields were lower on average by 0.9 t $ha^{-1}$ than on farms where the distance to the market was greater than 7 km (node 3). In the ODRS scheme, phosphorus application rate was the primary splitting node (Fig. 4c). Plots with a low dose of phosphorus (less than 5.8 kg $ha^{-1}$, node 2), compared with those fertilized with phosphorus in a slightly higher dose (6.6-16.4 kg $ha^{-1}$, node 3), gave lower yields on average by 2.1 t $ha^{-1}$ against 3.2 t $ha^{-1}$, i.e. a decrease of 35% (1.1 t $ha^{-1}$). On farms with phosphorus in a slightly higher dose, the failure to use transplanting led to a decrease in the average yield by 1.1 t $ha^{-1}$ (node 6). The highest yield (4.13 t $ha^{-1}$) was obtained when phosphorus application rate was between 6.6-16.4 kg $ha^{-1}$, transplanting was used to sowing (node 7) and with high nitrogen application rate (69.0-153.8 kg $ha^{-1}$, node 11). In the wet season, levelling method were the most important factor affecting in yield variation in Podor (Fig. 4d) and average yields were

3.9 t $ha^{-1}$ (node 1, n = 191). Farms with manual levelling method obtained the lowest yields of 3.0 t $ha^{-1}$ (node 2, n = 12), i.e. a decrease of 38% (1.9 t $ha^{-1}$). Plots with seed rates between 20-44 kg $ha^{-1}$ yielded average 4.1 t $ha^{-1}$ (Node 6, n = 25), whereas an average yield of 5.68 t $ha^{-1}$ was achieved when more than 44 kg seed $ha^{-1}$ (Node 7, n = 154) was used. On farms where the seeding rate is higher, the highest yield (6.00 t $ha^{-1}$) were obtained when the first application NPK fertilizer was between 20-30 days after sowing (node 11, n = 86). However, lower seed rate combined with higher N application rate (47-144 kg $ha^{-1}$) increase yields on average by 0.9 t/ha (node 9, n = 17). Rice farm size was the primary splitting node of differentiation during the wet season in Dagana (Fig. 4e). The highest yield (5.3 t $ha^{-1}$, node 5) was obtained when farm size grown is between 0.25-4 ha (node 2) and first date of application of the urea occurred 21-45 days after sowing (node 5). However, the lowest yields (2.6 t $ha^{-1}$) were observed in plot with farm size more than 5 ha (node 3).

**Fig. 4a. Wet season in ON (Mali)**

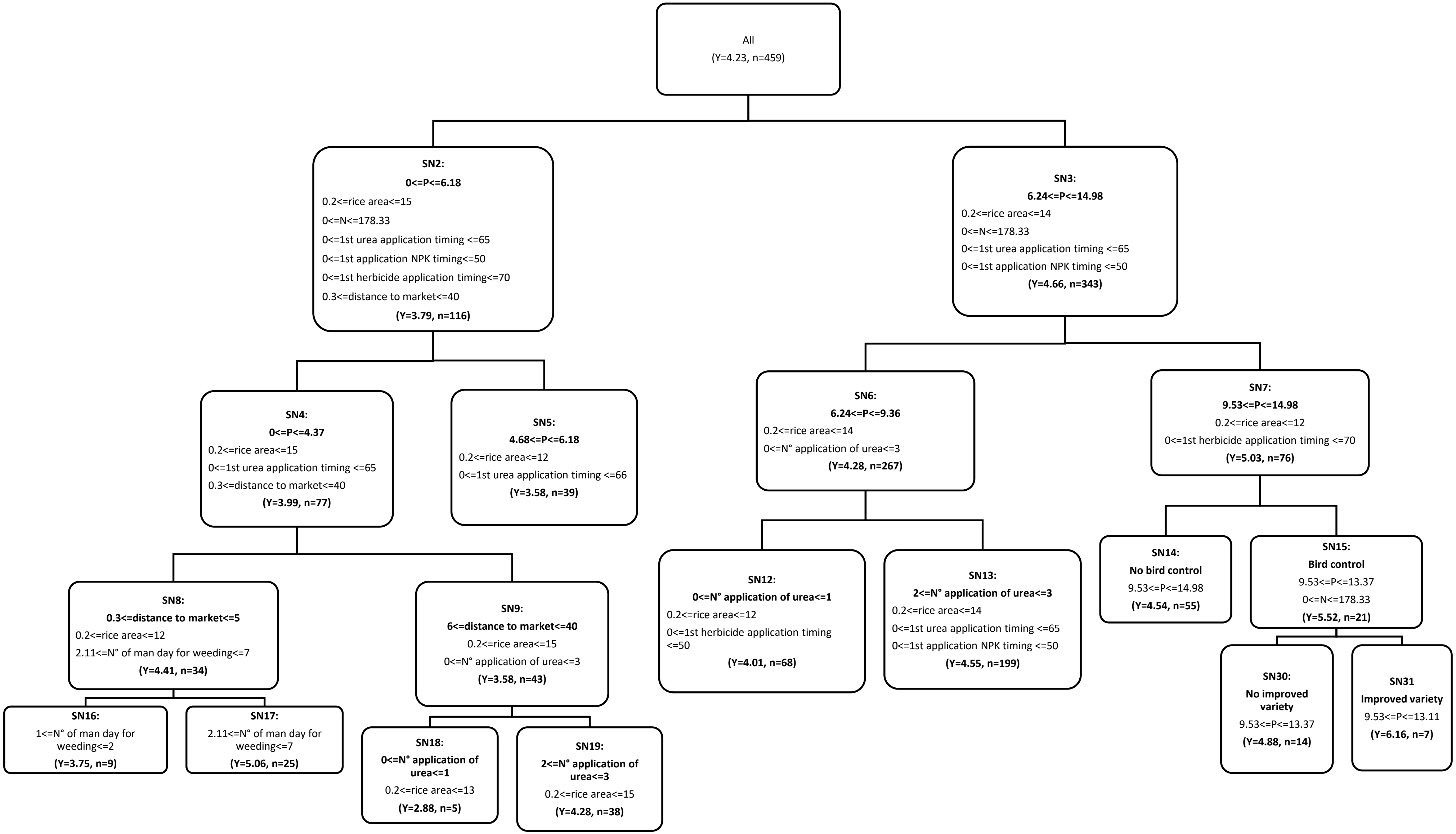


**Fig. 4b. Wet season in OPIB (Mali)**

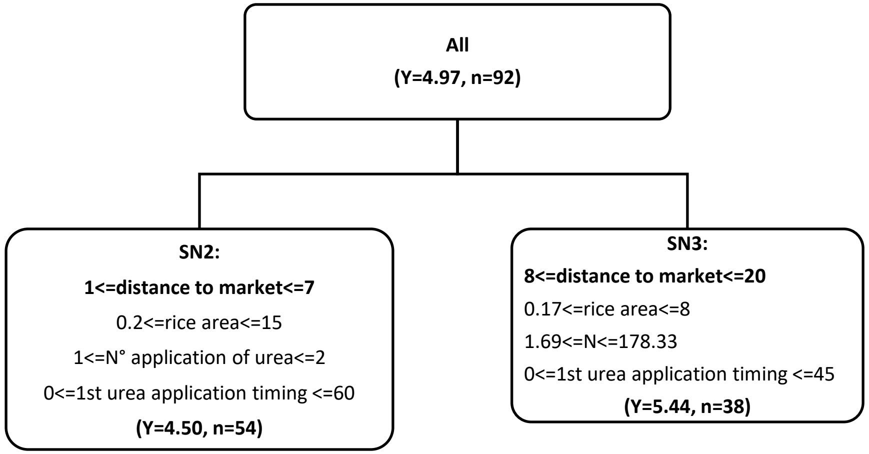



**Fig. 4c. Wet season in Mali (ODRS**

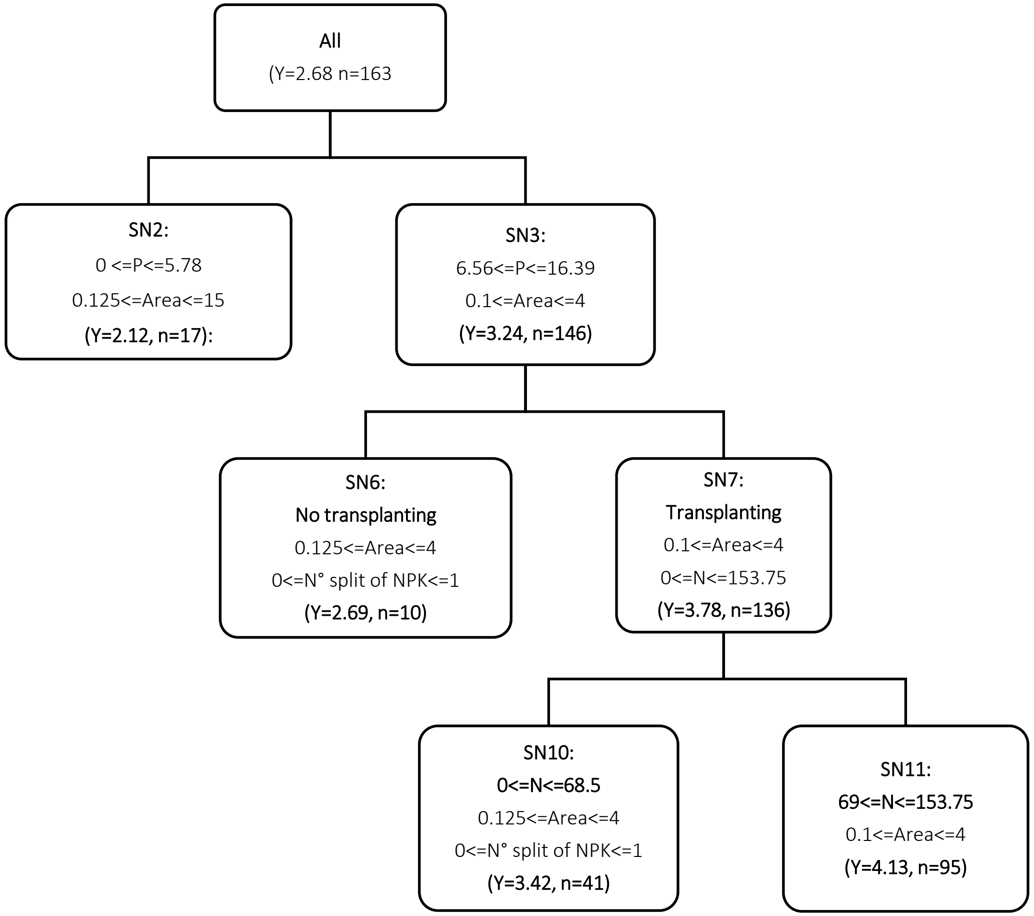


**Fig. 4d. Wet season in Podor (Senegal)**

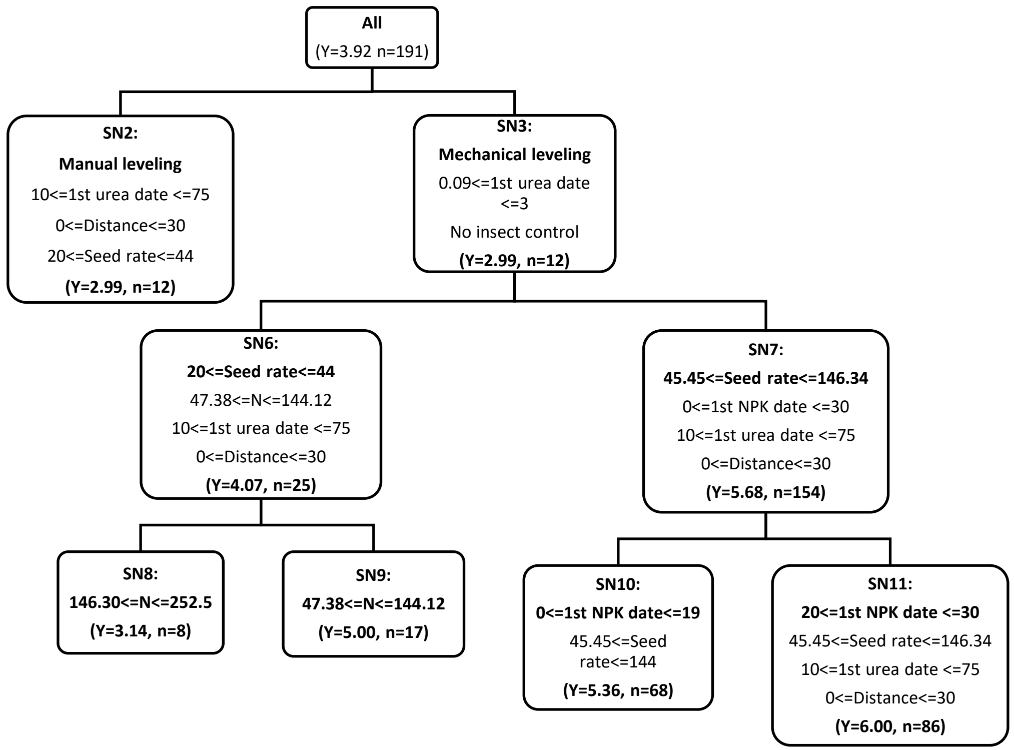
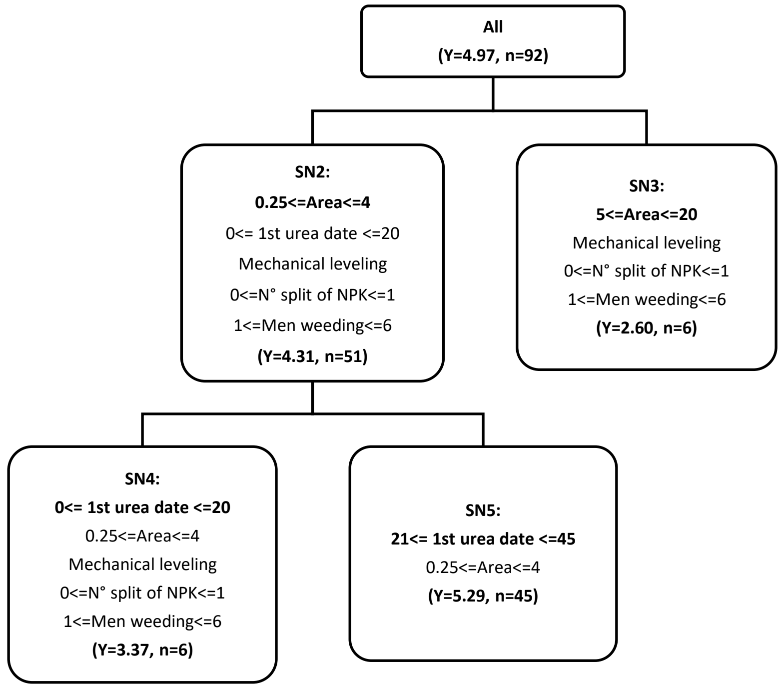



**Fig. 4e. Wet season in Dagana (Senegal)**



## 4. Discussion

Aiming to understanding the productivity variability and its determinants for reduce the yield gap and increase production, this study evaluated factors influencing rice yield variability in different irrigation schemes in both dry and wet seasons. Results showed that, most rice farmers grew rice during the dry season in Senegal while in Mali, rice was mostly grown during the wet season. This can be justified by the yield level in each growing season. Indeed, Senegal, yields were significantly higher in the dry season (6.3 to 6.6 t $ha^{-1}$) than in the wet season (4.9 and 5.3 t $ha^{-1}$). The season-to-season variation was less observed in Mali however except for ORDS, the yield in ON and OPIB were higher in the wet season than in the dry seasons. (3.6 to 4.8 t $ha^{-1}$ in the dry season and 4.2 to 4.3 t $ha^{-1}$ in the wet season). The estimated yields in the wet season in Senegal agree with the findings of Tanaka et al. (2015) and similarly, the average yield in Mali was in concordance with the yield of group 1 identified by Tanaka et al., (2017). Rice yields were higher in irrigation rice schemes in Senegal than in Mali. This gave room for Mali to work towards increasing its rice productivity in both wet and dry seasons. Senegal also needs to improve its yield in the wet season.

Results revealed that socioeconomic and crop management characteristics were of great importance in explaining rice yield variability during the wet and dry seasons in irrigation scheme in Mali and Senegal. However, the hierarchy of these variables differed between the seasons, zones and countries. This was in line with the previous studies (Sussy et al., 2019; Ran et al., 2018; Tanaka et al., 2015; Banerjee et al., 2014; Tittonell and Giller, 2013; Delmotte et al., 2011; Ferraro et al., 2009). In general, the findings showed that the rice yield variability among the rice farmers was largely dependent on distance to input and out[put market, rate and first application date of phosphorus, rate and first application date of nitrogen, number of nitrogen fertilizer applications after sowing, rice area, amount seed and the use of improved varieties. In addition to these main variables, other influencing factors were the contact with extension agent, bird control, transplanting, mechanical levelling and number of man day for weeding. This points out that both socio-economic and farm characteristics do matter for reducing yield gap and improve rice production in West Africa.

Distance from the farm to the input and output market had significant influence on rice yield in two sites in Mali (during the two seasons in ON and the wet season in OPIB) during the two seasons in Podor. The results showed that the closer the households to markets the higher the rice yields. This means that when markets are closer, farmers had easy access to inputs but also could easily market the outputs. Access to output market may increase the profit and encourage farmers to invest more in modern input and getting higher yield. Similarly access to input market may lower the production cost leading to higher profit and investment in modern inputs. Indeed, farmers close to markets can access more easily new technologies, which is consistent with the pervious findings (Sussy et al., 2019). This result implies that shorter market distance is likely to reduce transaction cost and improve access to market information, thereby influencing easily adoption of news innovations and increase the yield (Chandio and Yuansheng, 2018; Romney et al., 2003). Another socioeconomic factor influencing the rice yield was the contact with extension agents. Indeed, the highest yield was obtained in ON by farmers with contact with extension agent. This confirms that agricultural recommendations remain critical to improve the rice yield.

The results showed that, depending on the season and the region, the application of NPK and Urea fertilizer exhibited significant impact on rice yield, both individually and in combination. This agrees with the previous findings (Saito et al., 2019; Sussy et al., 2019; Ran et al., 2018; Niang et al., 2017; Tanaka et al., 2015; Banerjee et al., 2014) which observed that effectiveness fertilizer management including rate and quantity of application were key determinant of rice yield.

We found a negative relationship between farm size and yield in the irrigation schemes of Senegal. This implied that the smaller the rice field the higher the rice yield. This is consistent with the pervious findings (Tanaka et al., 2015) but ail to confirm the scale effect. Producers often lack the means to purchase inputs during the growing season, so they prefer to farm small areas that allow them to more efficient input management. This leads them to make better use of labor especially the family, available resources per unit area and to adopt good agricultural practices as reported previously (Ali and Deininger, 2014). On the other hand, large-scale farmers used more hired labor which may tend to profit than the quality of work. In addition, large-scale farmer may tend to crop more farm than their capacity leading to low performance. This is in line with other findings (Banerjee et al., 2014).

The quantity of seed rate use showed a significant effect on rice yield in ON and Podor. Indeed, the highest rice yields had found with higher quantity of seed. In line with this result, Diawara et al. (2018) reported that the highest number of effective tillers was obtained with 80 kg $ha^{-1}$ seed rate and was about 68% higher than the one obtained with lower seed rate. Banerjee et al. (2014) obtained similar results between seed rate and maize yield. In addition, combined with the seed rate and fertilizer management, the mechanical field levelling method had positive effect on the yield ii irrigation scheme of Podor. This agrees with the previous findings of (Poussin et al., 2003); Niang et al., 2017; Tanaka et al., 2015) who showed the positive effect of field levelling on yield in the Senegal.

In the ON, the presence of birds in the fields influenced the level of yields of rice farmers. Indeed, we found that farmers who did not carry out the bird control activity had low yields. This shows the effect of bird damage on production. These results are consistent with those of

Tanaka et al. (2015); Rodenburg et al. (2014) and Mey et al. (2012) who showed that bird damage due to poor bird control is a well-known as major constraint reducing rice yield in SSA.

## 5. Conclusion

The aim of this paper was to assess and compare factors influencing rice yield variability in the dry and wet seasons among smallholder farmers in irrigation schemes of West Africa. Data were collected through household surveys during two growing seasons from five major irrigated rice schemes in Senegal and Mali. Considerable variation in yield between farms and two seasons were observed. Results showed that rice yields were higher in the dry season in Senegal justifying that most farmers preferred to grow rice in the dry season. Improved management practices are required to increase the rice yield in the wet season as well in Senegal. In Mali, the season-to-season effect was not pronounced while yield during the wet season when most farmers were growing rice tended to be higher. However, the yield rice in Mali were significantly lower in both seasons than in Senegal. We recommend urgent actions to improve yield in the wet and dry season in Mali. These actions could be based on the factors influencing the variability of rice yield in different irrigation schemes. In contract to literature, we found that a combination of socioeconomic and crop management factors resulted in high rice yield. Rice yield variability among smallholder farmers was largely dependent socioeconomic factors (distance to input and output market, size of plot and access to extension advice) and crop management practices (rate and first application date of phosphorus, rate and first application date of nitrogen, number of nitrogen fertilizer applications after sowing, amount seed and the use of improved varieties). We recommend a best combination of development/dissemination of seasonal good agricultural practices for irrigation schemes and reduction of socio-economic constraints to enhance yields of the smallholder farmers to achieve rice self-sufficiency in the West Africa.

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