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Pearl Millet (*Pennisetum glaucum*) Seedlings Transplanting as Climate Adaptation Option for Smallholder Farmers in Niger

Bouba Traore [1,2,*], Abdourazak Alio Moussa [1], Amadou Traore [2], Yahaya Seydou Abdel Nassirou [1], Malick N. Ba [1] and Ramadjita Tabo [1]

[1] International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Niamey BP 12404, Niger; abdoulrazakalio@gmail.com (A.A.M.); ay02121990@gmail.com (Y.S.A.N.); b.malick@cgiar.org (M.N.B.); r.tabo@cgiar.org (R.T.)

[2] Institut D'Economie Rurale (IER-Mali), Koutiala BP 28, Mali; traoreamadou73@yahoo.fr

* Correspondence: b.traore@cgiar.org; Tel.: +223-7941-4757

Abstract: Pearl millet is the most widely grown cereal crop in the arid and semi-arid regions of Africa, and in Niger in particular. To determine an optimized management strategy for smallholder farmers in southern Niger to cope with crop production failure and improve cropping performance in the context of climate change and variability, multi-site trials were conducted to evaluate the impacts of transplanting on pearl millet growth and productivity. Eight treatments viz. T1-0NPK (100% transplanting without NPK), T1-NPK (100% transplanting + NPK), T2-0NPK (100% transplanting of empty hills without NPK), T2-NPK (100% transplanting of empty hills + NPK), T3-0NPK (50% transplanting of empty hills without NPK), T3-NPK (50% transplanting of empty hills + NPK), T4-0NPK (farmer practice without NPK), and T4-NPK (farmer practice + NPK) were included in the experiment. Compared to farmer practice, transplanting significantly reduced time to tillering, flowering, and maturity stages by 15%, 27%, and 11%, respectively. The results also revealed that T1-NPK significantly increased panicle weight, total biomass, grain yield, and plant height by 40%, 38%, 27%, and 23%, respectively. Farmers' evaluations of the experiments supported these findings, indicating three substantial advantages of transplanting, including higher yield (37.50% of responses), larger, more vigorous and more panicles (34.17% of responses), and good tillering (28.33% of responses). An economic profitability analysis of the system revealed that biomass gain (XOF 359,387/ha) and grain gain (XOF 324,388/ha) increased by 34% and 22%, respectively, with T1-NPK. Therefore, it can be inferred that transplanting is a promising strategy for adapting millet cultivation to climate change and variability in southern Niger.

Keywords: food security; crop failure; mineral fertilization; crop management; Sahel

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1. Introduction

Pearl millet (*Pennisetum glaucum*) is one of the most significant staple crops of arid and semi-arid regions of Africa, particularly in the West African Sahel [1–4]. It is cultivated as the most resilient crop [5,6] and the only cereal crop that gives reliable yield under severe abiotic stresses that limit crop production due to erratic rainfall, drought, low soil fertility, high salinity, low pH, and high temperature [7]. The Sahel is regarded as a hotspot for climate change threats and risk to weather-dependent sectors such as agriculture [8,9].

In Niger, pearl millet dominates the agricultural production sector and accounts for approximately 75% of the national cereal production [10,11]. The onset of the rainy season is the most important driver of agricultural management [8,12]. It directly affects crop management practices, especially planting date, which has a significant effect on crop yield [13]. Given the unpredictability of the onset of the rainy season and subsequent individual rainfall events, as well as the large variability in total seasonal rainfall, agricultural production in the Sahel region of West Africa has become insufficient and uncertain to meet food security [14].

Commonly, subsistence farmers in Niger (with little or no access to irrigation water) wait for the beginning of the rains before sowing. Given the unpredictability of the onset of the wet season and of subsequent individual rainfall events, and the large variability in the total seasonal rainfall, the initial sowing may completely or partly fail and/or the crop may not reach maturity before soil moisture is exhausted. Most often, crop establishment becomes effective only after one or more planting failures, resulting in large losses in seed and capital for farmers [4]. This trend is worsened by the high variability of the start and end dates of the rainy season, as well as dry spells, which no longer allow rainfed cereals to complete their developmental cycles effectively [15]. This has particularly detrimental impacts on the agricultural production and yields [8,16–19]. In this context, ensuring food security, particularly in light of climate change and variability, remains challenging and constantly urges for the modification of agro-techniques [3,8]. One such modification that is gaining attention in recent years for enhancing cereal productivity, including sorghum, and pearl millet, is the adaptation of transplanting techniques as an option to direct sowing for crop establishment, especially in unfavorable agro-climatic circumstances where traditional methods are not plausible [3]. This study compared farmer practice against a crop production package consisting of transplanting and mineral fertilizer microdosing. The effects of the individual technologies are well known. The transplanting approach has proved successful for reducing risk and boosting yield in many semi-arid regions of the world. This approach has already been extensively utilized around Lake Chad, where sorghum nurseries are formed during the rainy season and transplanted at the end of the rains into sandy clay and clay soils that store water during the wet season [20–22]. Additionally, various literature evidence implies that transplanting has been attempted in cereals such as sorghum and pearl millet, with mostly promising outcomes. In the event of a delayed beginning of rainfall or an early break, transplanting pearl millet seedlings is a feasible alternative to direct sowing, since seedlings can still be grown in a nursery for another few days [3]. Upadhyay et al. [23] and Singh et al. [24] noticed enhancement of pearl millet yield and recoupment of yield reduction under late sowing conditions. Young et al. [25] reported that transplanted pearl millet achieved earlier flowering, maturity, and higher grain and stover yields than direct sowing. Microdosing has been tested since the early 1990s in the Sahelian zone using rates in the order of 2 g diammonium phosphate (DAP) or 6 g NPK per hill [26]. Research from Mali and Sudan has shown that even lower microdosing rates can increase yield. In central Mali, it was found that 0.6 g NPK.hill−1 gave a yield increase in pearl millet of 54.9% compared with the control [27], while in Sudan, a dose of 0.3 g hill−1 gave a yield advantage over the control of 31.3% [27]. However, there are very few reports on the effects of transplanting and microdosing in southern Niger.

Therefore, to guide future adaptive responses and to disseminate the transplanting approach to more resource-poor subsistence farmers who experience food insecurity in high-risk environments, multi-site experiments were conducted to evaluate with the farmers the effects of transplanting combined with microdosing on pearl millet production. The overall objective of this study was to determine an optimized management strategy for smallholder farmers to mitigate pearl millet production failure and improve cropping performance in the context of rainfall scarcity. More specifically, the study seeks to: (i) assess the effects of transplanting on pearl millet growth, productivity, and economic return; (ii) determine farmers' perceptions to pearl millet transplanting; and (iii) propose potential adaptation options for pearl millet producers in southern Niger.

2. Materials and Methods

2.1. Study Area

This study was carried out in the Zinder region located in southern Niger. The experiments were conducted in the departments of Magaria and Dungass during the growing season of 2021. The selected villages were Angoual Gamdji (13°03′ N, 8°87′ W), Katirgé (13°06′ N, 8°17′ W), Sawaya (13°09′ N, 8°80′ W), Dan Kirey (12°98′ N, 9°25′ W), Tanti (12°99′ N, 9°33′ W), and Jan Majé (13°03′ N, 9°39′ W) (Figure 1). These villages were selected based on their representativeness of the region and their accessibility during the whole season. The Zinder region covers a large area of climatic and environmental zones. The rainy season lasts from May to October with rainfall peaks in August. The dry season comprises a relatively cold period from November to February and a hot period lasting from March to May. In the northeast part of the region, the average rainfall is less than 100 mm/year and the vegetation is sparse and of the Saharan type, while at the southern limit, it exceeds 600 mm/year. Magaria and Dungass are located on the isohyet 400–600 mm. The vegetation is of the Sahelian type, characterized by agroforestry parks, generally dominated by species belonging to the *Combretaceae* and *Fabaceae* families. The study sites' soils are mainly sandy with low fertility. Soil property average values were 5.57 for pH, 1.23 g kg^{-1} for organic C, 0.08 g kg^{-1} for total N, 10.7 mg kg^{-1} for P, 0.10 $cmol^{+}$ kg^{-1} for exchangeable K, 887 g kg^{-1} for sand, and 63 g kg^{-1} for clay [28]. The pH level relates a very high acidity of the soil, while the other parameters are very low compared to standards [29].

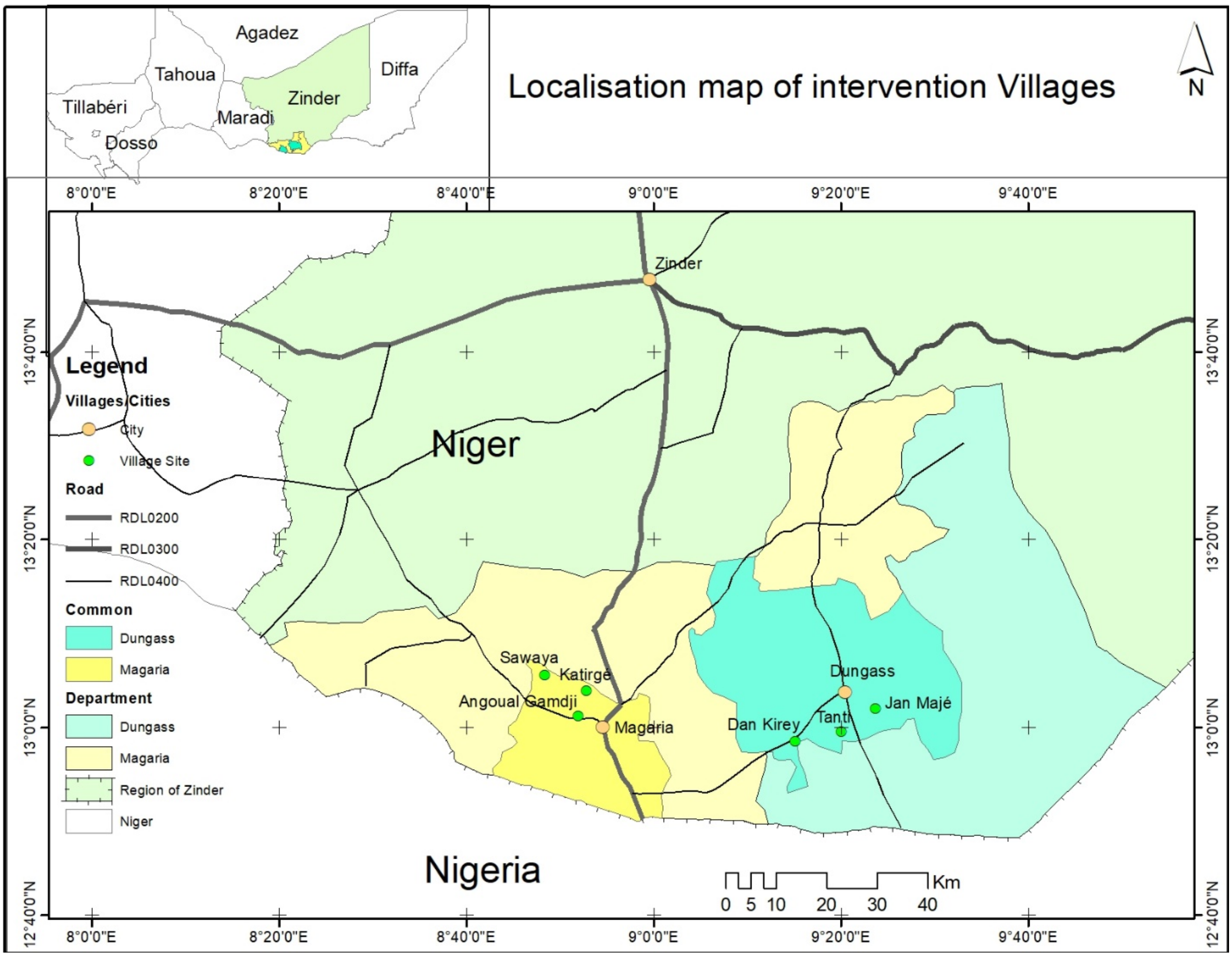

Figure 1. Sites of transplanting.

2.2. Experimental Design

The experimental design was a split-plot with mode of planting on the main plot and microdosing on the smaller plots. The mode of planting comprised 4 levels viz. 100% transplanting, 100% transplanting of empty hills, 50% transplanting of empty hills, and farmer practice (as a control). The split factor was fertilization with 2 levels viz. micro-dose of 6 g/hole of NPK and no application of NPK. The 100% transplanting treatment consisted of transplanting the whole plot. The 100% transplanting of empty hills treatment consisted of replanting (by seedlings produced in nurseries) all the hills that failed to emerge (gaps from classical sowing) whereas the 50% transplanting of empty hills treatment consisted of replanting half of the empty planting hills. Therefore, the experiment included eight treatments viz. T1-0NPK (100% transplanting without NPK), T1-NPK (100% transplanting + NPK), T2-0NPK (100% transplanting of empty hills without NPK), T2-NPK (100% transplanting of empty hills + NPK), T3-0NPK (50% transplanting of empty hills without NPK), T3-NPK (50% transplanting of empty hills + NPK), T4-0NPK (farmer practice without NPK), and T4-NPK (farmer practice + NPK). The experiment consisted of four plots (eight subplots) per study site. The plot size was 50 m^2 (10 m $\times$ 5 m) in both experiments. Each site (village) was considered as an experimental replicate for data analysis.

2.3. Crop Management

Local pearl millet varieties produced and grown by farmers in the area were used as plant material. Seeds with an average density of 20 g/m^2 were planted in a nursery (3 m $\times$ 1 m) installed in a restricted area where the water supply and fertilizer were controlled (Figure 2A). Depending on the occurrence of the first useful rainfall ($\geq$15 mm) [4], in each site, thirty-seven- to forty-day-old seedlings from nurseries were transplanted into each experimental field (Figure 2B). A plot without any interventions (transplanting or replanting) was considered as an experimental control. Plant density was fixed at 19,600 hills/ha with 0.75 m between and within rows. All rows were thinned (3 plants/hill) to achieve the above density. NPK fertilizer in a rate of 6 g/hole was applied by microdose to 50% of the subplots between 17 and 19 days after transplanting, depending on the study site. To ensure better plant growth (Figure 3A), weeds and insects were cautiously controlled until harvesting time (Figure 3B). The specifications and details of all cropping operations are given in Table 1.

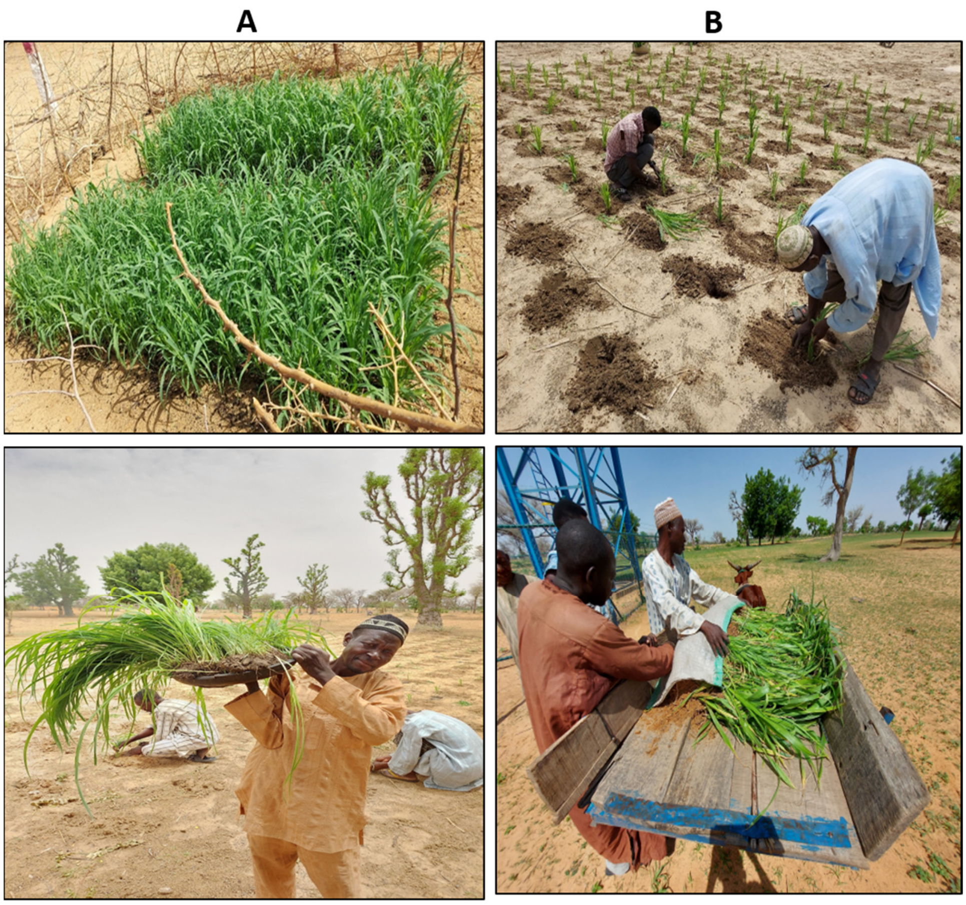

Figure 2. Nursery (**A**) and transplanting operations (**B**) at the village of Dan Kirey.

Figure 3. Transplanted field (**A**) and harvested field (**B**) at the village of Katirgé.

Table 1. Cropping operations calendar.

Operations	Katirgé	Sawaya	A. Gamdji	Dan Kirey	Tanti	Jan Majé
Setting of nursery	2 June 2021	2 June 2021	2 June 2021	31 May 2021	31 May 2021	31 May 2021
Planting	4 July 2021	4 July 2021	4 July 2021	5 July 2021	5 July 2021	5 July 2021
Transplanting	9 July 2021	9 July 2021	9 July 2021	10 July 2021	10 July 2021	10 July 2021
Transplanting of empty holes	27 July 2021	27 July 2021	27 July 2021	29 July 2021	29 July 2021	29 July 2021
Thinning	11 July 2021	13 July 2021	16 July 2021	14 July 2021	14 July 2021	14 July 2021
NPK application	26 July 2021	27 July 2021	27 July 2021	29 July 2021	29 July 2021	29 July 2021
First weeding	12 July 2021	17 July 2021	15 July 2021	12 July 2021	14 July 2021	12 July 2021
Second weeding	4 August 2021	7 August 2021	2 August 2021	8 August 2021	5 August 2021	3 August 2021

2.4. Data Collection

Weather data were obtained from the National Meteorological Department of Niger. These included rainfall, the maximum and minimum temperatures, and relative humidity. Data collection involved traits related to phenology (plant height, tiller number, 50% tillering, 50% flowering, 50% maturity), biomass, and yield for each treatment (Tables 2 and 3). For plant height and tiller number, the measurements concerned two central rows (to avoid border effects) accounting for 10 hills per row (one plant per hill) and 20 plants per treatment at the heading stage. Plant density was obtained by counting the plant number for three central rows per treatment. For traits such as 50% tillering, 50% flowering, and 50% maturity, the number of days from sowing/transplanting until 50% of the plants per plot had reached the stage were counted. For yield and its components, such as panicle weight and grain yield, the measurements were taken in three central rows per treatment at harvest (16.9 m^2). For total dry biomass determination, three central rows per treatment were also weighed after sun-drying.

Table 2. Phenological stages according to the mode of planting.

Mode of Planting	50% Tillering	50% Flowering	50% Maturity
T1	14^{b}	35^{b}	59^{b}
T2	19^{a}	61^{a}	74^{a}
T3	19^{a}	61^{a}	74^{a}
T4	19^{a}	61^{a}	74^{a}
SD	2.88	0.42	5.24
CV (%)	16.81	1.20	7.51
p.value	*0.014*	*<0.0001*	*<0.0001*

T1 (100% transplanting), T2 (100% transplanting), T3-0NPK (50% transplanting of empty hills), T4 (farmer practice); SD: standard deviation; and CV: coefficient of variation. The different superscript letter (a,b) per column indicate significant differences (Tukey's test, $p < 0.05$) in the mean value of the treatments.

Table 3. Effects of mode of planting, fertilization, and their interactions on plant height, tiller number, and yield-related traits.

Treatments	Plant Density (Plants/ha)	Panicle Weight (kg/ha)	Total Biomass (kg/ha)	Grain Yield (kg/ha)	Plant Height (m)	Tiller Number
T1-NPK	58,800 ^{a}	2636.67 ^{a}	4176.67 ^{a}	1275.56 ^{a}	1.62 ^{a}	5.98 ^{c,d}
T1-0NPK	56,233.33 ^{a,b}	1625.56 ^{b}	2498.89 ^{c}	871.11 ^{c,d}	1.66 ^{a}	5.53 ^{d}
T2-NPK	58,800 ^{a}	1594.44 ^{b}	3087.78 ^{b}	1065.56 ^{a,b,c}	1.30 ^{b}	7.53 ^{b}
T2-0NPK	56,700 ^{a}	1322.22 ^{c,d}	2822.78 ^{b,c}	706.67 ^{d}	1.04 ^{c,d}	6.62 ^{c}
T3-NPK	55,300 ^{a,b,c}	1625.56 ^{b}	3406.67 ^{b}	1104.44 ^{a,b}	1.03 ^{c,d}	8.76 ^{a}
T3-0NPK	50,166.67 ^{b,c,d}	1067.22 ^{e}	1758.33 ^{d}	722.78 ^{d}	0.92 ^{d}	5.43 ^{d}
T4-NPK	47,833.33 ^{d}	1442.78 ^{b,c}	2925 ^{b,c}	890.56 ^{b,c,d}	1.11 ^{c}	7.54 ^{b}
T4-0NPK	49,466.67 ^{c,d}	1127.78 ^{d,e}	1866.67 ^{d}	727.22 ^{d}	1.02 ^{c,d}	6.64 ^{c}
p.value	*0.164*	*<0.0001*	*0.021*	*0.001*	*<0.0001*	*<0.0001*
SD	6531.5	488.1	1146.8	403.2	0.7	3.7
CV (%)	12.88	34.38	42.14	45.73	57.63	54.70
Mode of planting	*0.001*	*<0.0001*	*0.001*	*0.015*	*<0.0001*	*<0.0001*
Fertilization	*0.186*	*<0.0001*	*<0.0001*	*<0.0001*	*0.024*	*<0.0001*
Mode of planting × Fertilization	*0.465*	*<0.0001*	*0.008*	*0.343*	*0.127*	*<0.0001*

T1-0NPK (100% transplanting without NPK), T1-NPK (100% transplanting + NPK), T2-0NPK (100% transplanting of empty hills without NPK), T2-NPK (100% trans-planting of empty hills + NPK), T3-0NPK (50% transplanting of empty hills without NPK), T3-NPK (50% transplanting of empty hills + NPK), T4-0NPK (farmer practice without NPK), and T4-NPK (farmer practice + NPK); SD: standard deviation; and CV: coefficient of variation. The different superscript letter (a,b,c,d,e) per column indicate significant differences (Tukey's test, $p < 0.05$) in the mean value of the treatments.

2.5. Farmers' Perception of Pearl Millet Transplanting

This investigation was based on individual interviews survey and field observations. Data were collected using a well-structured questionnaire. From all villages, with the help of villages' chiefs, one hundred and twenty (120) millet producers (20 per village) were selected and surveyed. Throughout the survey, data collection was focused on the prevalence of farmers' perceptions on transplanting and its appropriateness to mitigate and cope with pearl millet production failure in southern Niger.

2.6. Statistical Analyses

Descriptive statistics including mean, standard deviation, and coefficient of variation were calculated to discriminate the different traits assessed. Each site was considered as an experimental replicate for data analysis. The conditions for normality and homogeneity of variance of the residuals were verified using Ryan–Joiner and Levene tests, respectively. Analysis of variance (ANOVA) using the general linear model was performed to evaluate the effects of the different treatments. The Newman–Keuls method was used for pairwise comparisons. The relationship between yield and rainfall amounts recorded between planting and harvest date was evaluated using the Pearson correlation test. A *p*-value of 5% was considered as threshold for significant differences. The analyses were performed using Minitab17.0 statistical software (Minitab Inc., State College, PA, USA) and GraphPad Prism 8.0.1 was used for graphs preparation.

2.7. Economic Gain Analysis

To evaluate the economic gain per hectare for each treatment, we used a gross margin (GM) analysis model, which is equal to the difference between total revenue (TR) and total variable cost (TVC) per hectare [30,31]:

$$\mathbf{GM} = \sum \mathbf{TR} - \sum \mathbf{TVC}$$

Total revenue was defined as the total market price of production per hectare multiplied by crop yields (grain or biomass), whilst total variable cost included costs of production such as nursery management, seedling transportation, labor, seeds, fertilizers, and other farmer operations. Land and environmental externalities were not accounted into the total cost. The economic gain was expressed in West African CFA francs (XOF).

3. Results

3.1. Weather Variability

High variability in rainfall was noted across villages as well as between months (Figure 4). Dan Kirey received 641 mm, while Angoual Gamdji received 439 mm. The beginning of the season was almost dry in Jan Majé, Tanti, and Dan Kirey, with rainfall amounts of 10 mm, 13 mm, and 16 mm in June, respectively, whereas Angoual Gamdji, Sawaya, and Katirgé had considerably greater rainfall amounts of 48 mm, 46 mm, and 34.5 mm in June, respectively. The wettest month was August, with 218 mm, and the driest month was October, with 22 mm. Overall, 34% to 39% of total rain occurred between July and August against 5% in June (starting of the season) and 4% in October (end of the season). The end of the season was completely dry in Angoual Gamdji, with no rain recorded in October against 50 mm and 40 mm in Sawaya and Jan Majé, respectively.

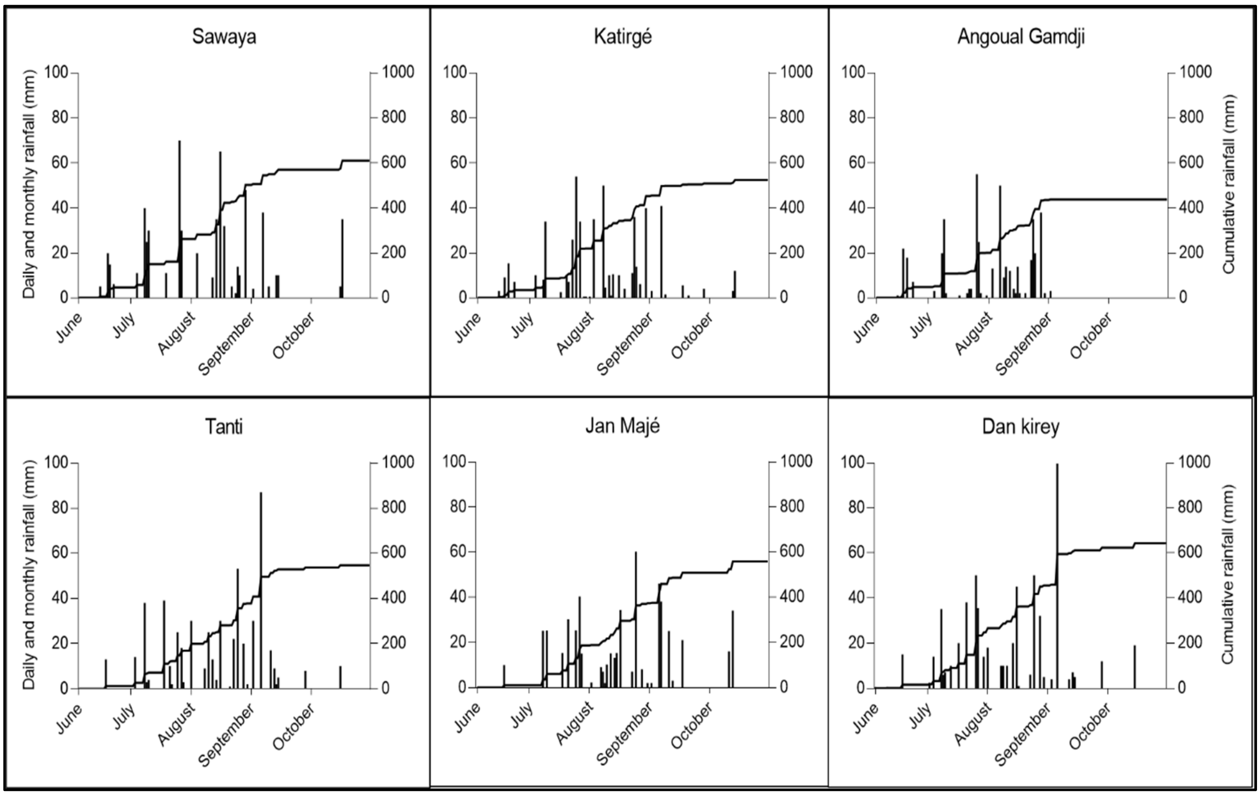

Figure 4. Daily and cumulative rainfall during the growing season at the study sites.

Similar weather conditions were observed across study sites for temperature and relative humidity. During the trials, regardless of the study site, the maximum temperature varied from 25.63 °C (October) to 42.11 °C (June) while the minimum temperature varied from 28.13 °C (June) to 15.01 °C (October). The relative humidity varied from 93.44% to 32.88% (Figure 5).

Rainfall Variability Correlation with Pearl Millet Yield

Grain and biomass yields of millet varied substantially depending on seasonal rainfall (Figure 6). The correlation of grain yield with seasonal rainfall recorded from planting to harvest was highly significant (r = 0.56; $p < 0.0001$). Similarly, there was also a very significant positive correlation between seasonal rainfall and total plant biomass (r = 0.55; $p < 0.0001$).

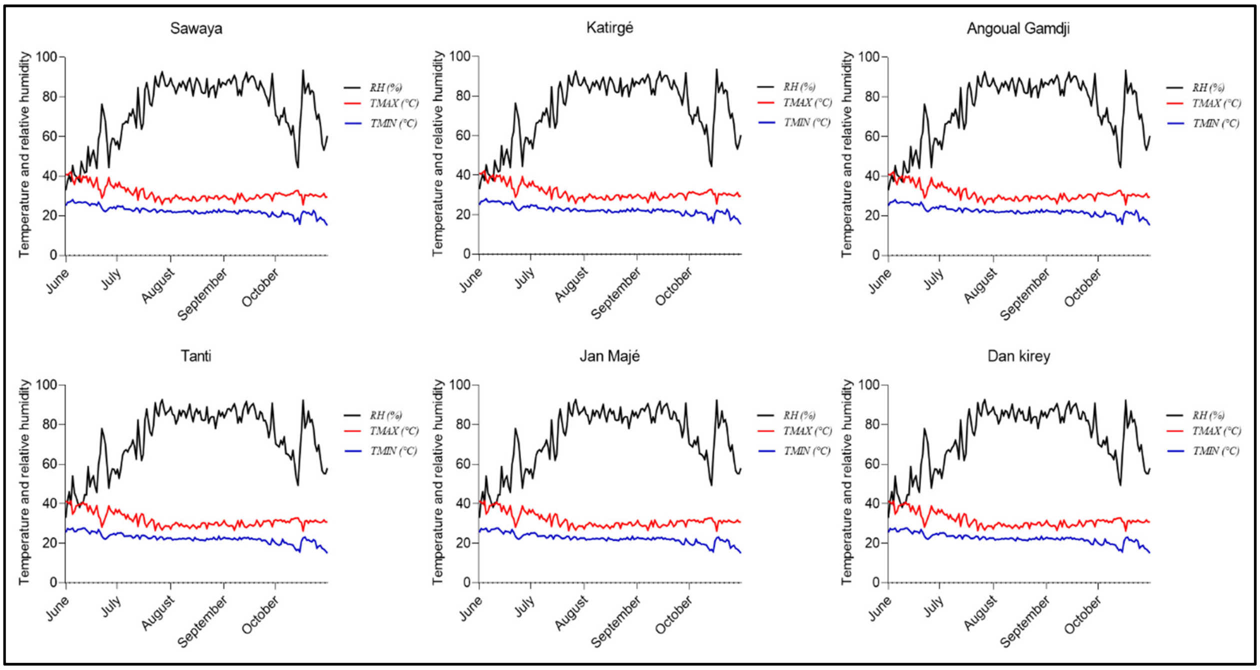

Figure 5. Temperature and relative humidity during the growing season at the study sites.

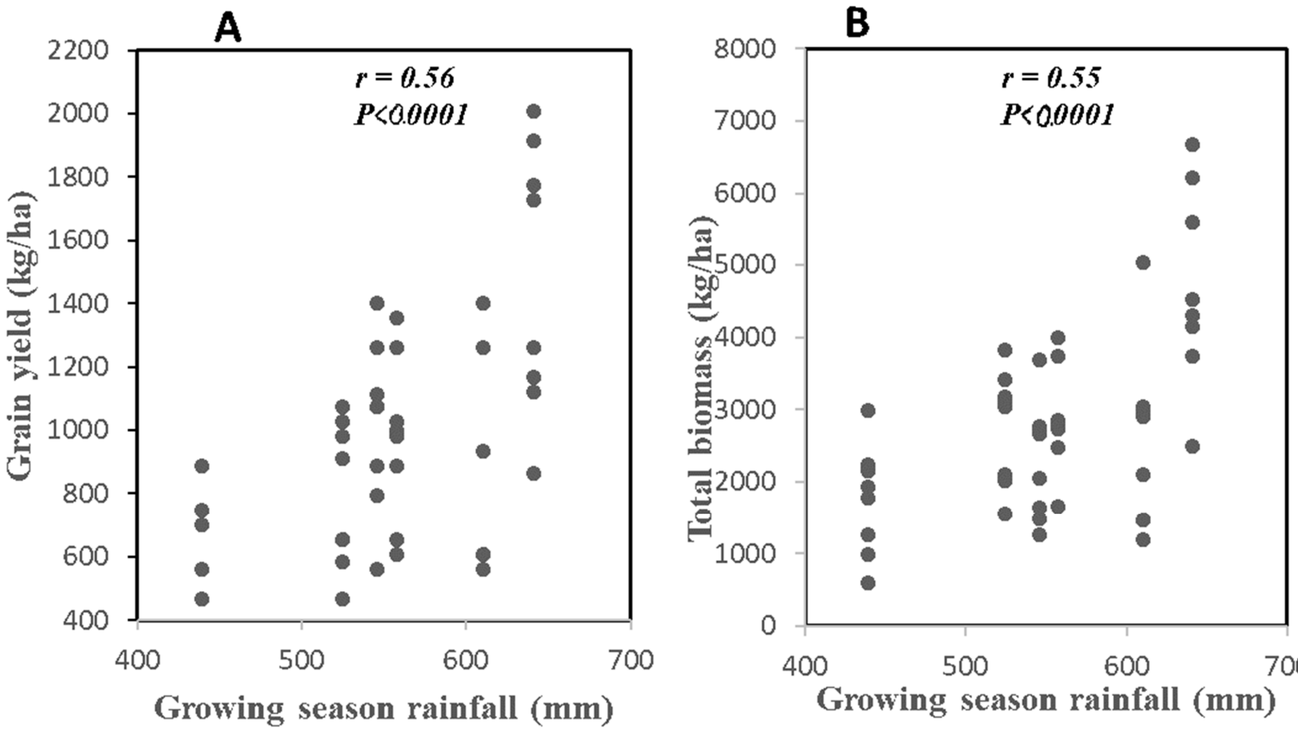

Figure 6. Scatter plots of grain yield (**A**), total plant biomass (**B**), and growing season rainfall from planting to harvest for the different study sites. The points represent the average of six replicates.

3.2. Effect of Pearl Millet Transplanting on Phenology

The durations of the period from planting to the different phenological stages of millet were significantly reduced ($p < 0.05$) with millet transplanting (Table 2). The treatment T1 reached the tillering, flowering, and physiological maturity stages at 14 days, 35 days, and

59 days after transplanting compared to 19 days, 61 days, and 74 days for T4. Therefore, 100% transplanting decreased the time to 50% tillering, 50% flowering, and 50% maturity by 15%, 27%, and 11%, respectively, as compared to farmer practice.

3.3. Effect of Transplanting and NPK Application on Plant Growth Parameters

The ANOVA results regarding plant growth parameters are presented in Table 3. A highly significant effect was observed for mode of planting ($p = 0.001$). Mean plant density obtained was statistically similar amongst the treatments T1, T2, and T3, while they were significantly higher to that of farmer practice (T4). Fertilizer application did not show any significant differences between treatments. Highly significant differences were observed among treatments for tillers number ($p < 0.0001$). In all, 50% transplanting of empty pockets combined with NPK (T3-NPK) followed by 100% transplanting of empty pockets combined with NPK (T2-NPK) significantly achieved the highest tiller number, while 50% transplanting of empty pockets without NPK (T3-0NPK) followed by 100% transplanting without NPK (T1-0NPK) treatments showed the lowest tiller number. Remarkably, farmer practice treatment without NPK (T4-0NPK) showed a significantly higher number of tillers as compared to 100% transplanting without NPK (T1-0NPK). The interaction effects were also highly significant among treatments. The mode of planting and NPK application significantly influenced plant height. The highest plant heights among all treatments were observed from T1-0NPK and T1-NPK treatments, with 1.66 cm and 1.62 cm, respectively. T3-0NPK and T4-0NPK showed the lowest plant heights with 0.92 cm and 1.02 cm, respectively. Therefore, compared to farmer practice, 100% transplanting with NPK significantly increased the plant height by 23%. However, the interaction effects for NPK application and mode of planting were not significant.

Mode of planting and NPK application significantly improved the grain yield ($p = 0.015$) and total dry biomass ($p = 0.001$) of the millet crop. The largest observed grain yield was obtained with 100% transplanting of millet associated with fertilizer application with a mean of 1275 kg/ha. This was statistically similar to the yield obtained with treatment T2 (1065 kg/ha) and treatment T3 (1104 kg/ha) associated with fertilizer application. However, that was significantly greater than the yields obtained under farmer practice (T4) by 27%. Grain yield obtained under treatments T1, T2, T3, and T4 with fertilizer application was significantly greater than that of no fertilizer application by 19%, 20%, 21%, and 10%, respectively.

Likewise, with a mean of 4176 kg/ha, 100% transplanting of millet associated with fertilizer increased the biomass yield by 38%, compared to farmer practice. Biomass yields obtained with T2 (3088 kg/ha) and T3 (3407 kg/ha) were 25% and 29% higher than those obtained with farmer practice. The highest observed panicle weight (2637 kg/ha) was obtained with 100% transplanting of millet associated with fertilizer application, which was 40% higher than that obtained with farmer practice.

3.4. Systems Economic Gains

Results from economic analysis showed that biomass and grain gains per hectare with millet under different planting modes varied substantially, with biomass gain relatively greater than grain gain (Table 4). Higher biomass and grain gains were obtained with 100% transplanting combined with NPK (XOF 359,387/ha for biomass and XOF 324,388/ha for grains) which were comparatively higher than gains obtained with T2, T3, and T4. Grain gain for T1-NPK (XOF 324,388/ha) was 22% higher than that obtained with T4-0NPK (XOF 208,166/ha). Similarly, biomass gain from T1-NPK (XOF 359,387/ha) was 34% higher than that of T4-0NPK (XOF 176,667/ha). In this study, with 100% transplanting combined with the application of 6 g/hole of NPK by microdose, the biomass and grain gains of millet increased by 34% and 22%, respectively.

Table 4. Systems economic gains (per hectare) expressed in West African currency, the Franc CFA (XOF).

Treatments	Total Cost	Gross Margin Biomass	Gross Margin Grain
T1-NPK	58,280	359,387	324,388
T1-0NPK	23,000	226,889	238,333
T2-NPK	53,280	255,498	266,388
T2-0NPK	18,000	264,278	194,001
T3-NPK	52,280	288,387	279,052
T3-0NPK	17,000	158,833	199,834
T4-NPK	45,280	247,220	221,888
T4-0NPK	10,000	176,667	208,166

T1-0NPK (100% transplanting without NPK), T1-NPK (100% transplanting + NPK), T2-0NPK (100% transplanting of empty hills without NPK), T2-NPK (100% trans-planting of empty hills + NPK), T3-0NPK (50% transplanting of empty hills without NPK), T3-NPK (50% transplanting of empty hills + NPK), T4-0NPK (farmer practice without NPK), and T4-NPK (farmer practice + NPK).

3.5. Farmers Perception of Pearl Millet Transplanting

From this investigation, only 15.83% of the surveyed farmers had previously practiced transplantation with millet, while 84.17% had never practiced transplanting (Figure 7). Farmers who claim to use this strategy do so by replacing empty pockets (100% of responses). When asked if they intend to use transplanting as a new approach to mitigate millet production failure in the future, 98.33% responded positively.

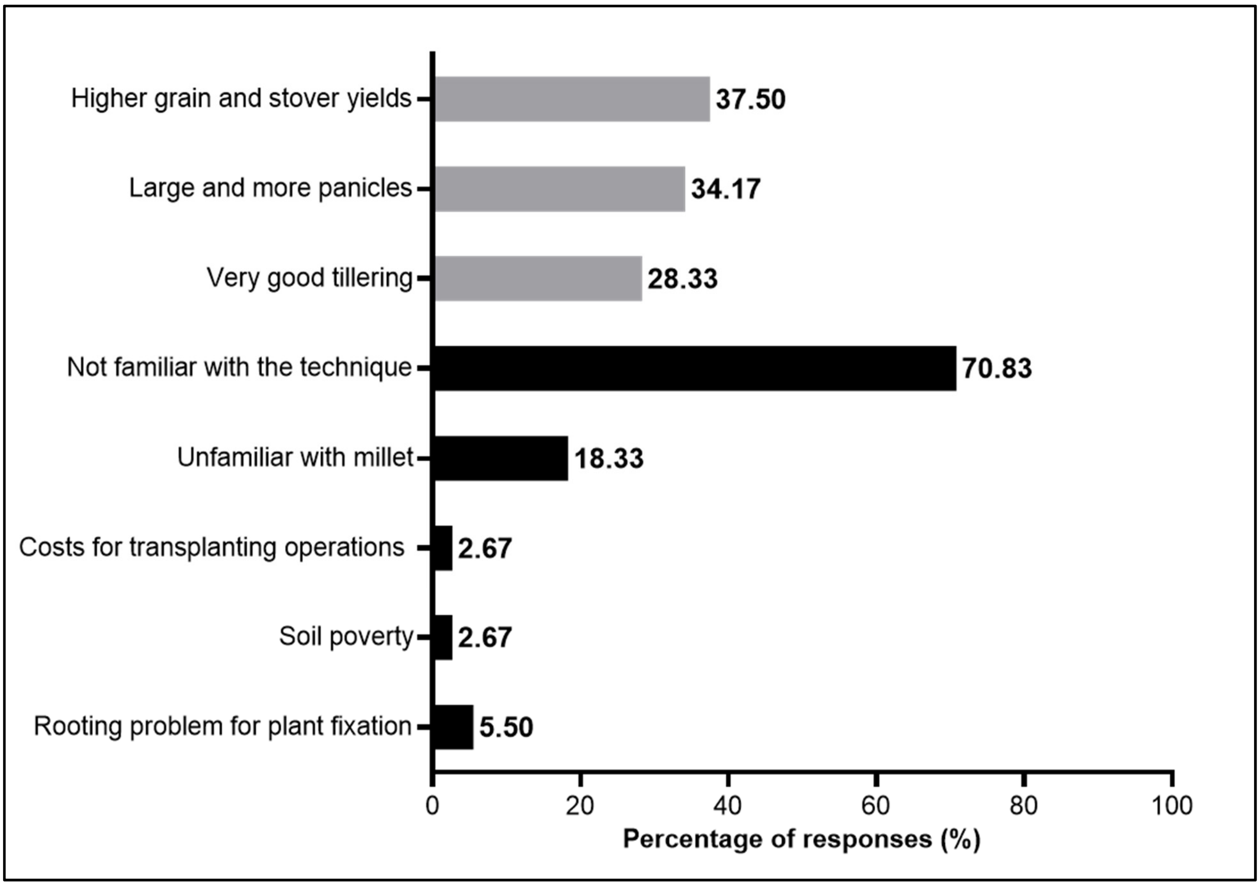

Figure 7. Major benefits (in gray) and constraints (in black) of transplanting as listed by farmers.

All surveyed millet producers who practice or intend to use transplanting noted three major benefits of transplanting viz. high productivity (37.50% of responses), large and more panicles (34.17% of responses), and very good tillering (28.33% of responses).

Although more than 98% of the farmers were satisfied with this strategy, around 2% of the farmers were not, mainly because they are not familiar with the technique (70.83% of responses), transplanting is not adapted with millet (18.33% of responses), and it causes rooting problems for plant fixation (5.5% of responses). The constraints regarding soil poverty (2.67% of responses) and costs for transplanting operations (2.67% of responses) were the less cited by farmers.

4. Discussion

4.1. Transplanting to Avoid Rainfall Scarcity at the Beginning/End of Rainy Season

Our results indicate that the yield of millet decreases when planting is delayed, suggesting an important role for timely planting in dealing with rainfall variability. Other studies have also shown that delayed planting of millet resulted in significant yield losses [13,32,33]. Farmers' evaluation of the experiments indicated that transplanting plays an important role for a better crop stand establishment (by reducing the need for replanting and gap filling) as well as for increasing yield. Additionally, improved germination in the nursery compared to a direct-sown field can facilitate pest/disease control and fertilizer application to the plant [22]. Furthermore, transplanting (owing to the high leaf area index (for seedlings) at the period of maximum soil moisture) can enable efficient use of available soil moisture in a given season, thereby reducing the risk of early/terminal drought and hunger gap between seasons (crucial for family welfare and survival) [22].

4.2. Transplanting for Boosting Pearl Millet Productivity and Resilience

In this study, transplanting was found to significantly influence plant density, plant height, and yield of millet as compared to the farmer practice. These findings are in line with those reported recently by Gudadhe et al. [2], who found that transplanting millet could optimize crop density and yield. Transplanting of pearl millet assures high crop stand establishment as chances of seedling mortality are comparatively less than direct seeded millet due to choosing healthy seedlings for transplanting. Furthermore, transplanting requires less seed rate to produce optimum plant population than direct sowing. Fanadzo et al. [34] stated that transplanted maize in South African conditions ensured better plant stand (96% of target) as compared to direct seeded maize (78% of target). Thus, raising pearl millet seedlings in a nursery under controlled conditions and sufficient monitoring followed by their transplanting under favorable field conditions can be a suitable strategy to cope with seedlings' damage-related problems [34]. Based on results, transplanting increased significantly grain and total biomass yields. Earlier, Pal [35] and Mapfumo [36] also confirmed the increments of grain yield of pearl millet grown through the transplanting method. Further, Jan et al. [37] observed that pearl millet transplanting achieved best plant height, number of leaves per plant, panicle length, panicle weight, number of grains per panicle, 1000 grain weight, and grain yield as it utilized more photoperiod for light interception, production, and translocation of photosynthates to various sinks. The works of several researchers around the world suggest that transplanted pearl millet expresses better growth and out-yields direct seeded/broadcasted pearl millet. Moreover, transplanting has been reported to successfully reduce downy mildew infestation [38] and millet stem borer attack [39] in the crop period.

Our findings showed that transplanting negatively affects tiller number as compared to farmer practice, which disagree with farmer's evaluation of the experiments. Previous research has indicated that transplanting was detrimental to the development of tillers in millet, most likely due to the sudden bolting stimulus that seedlings from nurseries would have received prior to being transplanted into the field [4]. This stimulus would have oriented the seedlings' reaction to no longer waste time producing tillers by anticipating the other phenological stages (jointing, heading, flowering, and maturation), thus allowing the crop to complete its cycle before being subjected to any other stress [22,40,41].

This study also revealed that transplanting significantly reduced the duration of the different phenological stages of millet, in particular tillering, flowering, and maturity.

This can increase the possibility of avoiding terminal drought, thereby increasing farmers' flexibility and adaptability. Transplanting of pearl millet and sorghum seedlings was previously reported to compensate the crop growth period to complete crop life cycle [42]. Transplanting was also indicated to relief millet crops in avoiding the impacts of dry spells, which are particularly prevalent at the beginning and the end of the cropping season in the Sahel [4]. Transplanting by reducing the plant cycle duration also enables farmers an early harvest (by 2 weeks), which can greatly contribute to reduce the hunger gap between seasons, extremely crucial for poorer farmers. Further, an early harvest while the price is high can allow farmers to sell grains for a high price and avoid buying food when it is most expensive. Early maturity of transplanted pearl millet was also stated to reduce hunger days for the people of arid and semi-arid areas of Zimbabwe and Ghana, where even women are expressing their strong interest in transplanting techniques [25]. Thus, in an unpredictable climatic context, transplanting ought to be a resilient option for farmers and could promote millet crop yield.

4.3. Combined Effect of Transplanting and Fertilization on Millet Productivity and Gain

Our findings showed that using NPK by microdose could substantially increase millet yield. For all treatments, yields obtained without fertilizer application were significantly lower as compared to the treatment with fertilizer, indicating the crucial role of mineral fertilization in transplanting, as well as in farmer practice. This increase in yields is in agreement with the results of several other authors in Sudano-Sahelian countries [8,43–45]. However, proper adaptation requires an integrated approach including proper planting, for there is an important interaction between fertilizer application and mode of planting for most of the traits evaluated [8,46].

Understanding the economic benefit is critical for targeting and for guiding research, investment, policies, and institutional objectives, including extension and input service delivery systems, and ultimately to close the gaps in yield and gross margin [31]. In this study, the greatest gains for grain and biomass were achieved with 100% transplanting. This is mainly due to the highest grain and biomass yield obtained with that treatment. However, this gain can be subjected to variation depending particularly on market opportunities regarding the price variation across the same year for cereal grains in the region. Despite the fact that biomass gain was greater than grain gain in this investigation, farmers' preferences are often oriented toward grains to meet urgent food needs. Selling millet grains is not a priority for most of the farmers, but it occurs, especially when there is a surplus of production or a social emergency requiring cash. However, the profitability of the millet production system depends mainly on farm size, family labor, seed access and quality, and fertilization, as well as crop protection strategies.

4.4. Constraints for Pearl Millet Transplanting

Apart from having exciting outcomes with pearl millet, transplanting also has various adoption limits as well as drawbacks. Since the transplanting technique for millet is highly unusual, farmers' stereotypic mentality in sticking to traditional crop establishing methods instead of updating themselves with technological initiatives is predominant. Furthermore, insufficient extension services, lack of adequate demonstration and awareness, lack of assistance and guarantee in case of risk, etc., contribute to the unpopularity of pearl millet transplanting. Another important reason for farmers' reluctance to adopt transplanting is labor shortage, as it is a labor-intensive approach involving more steps than farmer practice. Furthermore, transplanting necessitates an initial capital investment for fencing, nursery preparation, and monitoring, which marginal smallholder farmers cannot afford. In addition, as opposed to farmer practice, which takes less mind focus, transplanting necessitates more care and attention in terms of seedling management and preservation. Another constraint is the long distance between the nursery and the main field, as transplanting requires a quick response from uprooting seedlings from the nursery to implantation in the main field [3].

5. Conclusions

Farmers' agricultural practices can be substantially improved by the use of the transplanting approach, therefore enhancing the ability to tackle challenges posed by interannual rainfall variability, particularly in the Sahelian context. In this study, pearl millet transplanting as compared to farmer practice, a significantly higher pearl millet yield and reduced durations of tillering, flowering, and physiological maturity were achieved through seedling transplanting combined with mineral microdosing. Farmers' evaluation of the experiments indicated several advantages of transplanting, including higher yield, good tillering, and larger and more vigorous panicles. An economic analysis of the systems showed a significant profitability increase for grain and biomass production. Transplanting therefore offered the prospect of reducing risk and improving millet yield in marginal areas, thereby increasing local food security. This approach needs to be disseminated properly through strong engagement of local extension services. Training of farmers on transplanting techniques could be critical to inform decision making in crop production.

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