Abstract: Pearl millet production in Niger is characterized by manual sowing and weeding and low use of inputs like mineral and organic fertilizer. This objective of the study was to compare a traditional production package (control) against a new production package consisting of mechanized sowing and weeding, seed priming, seed treatment with a fungicide/insecticide, and microdosing at rate of 0.3 g NPK 15–15–15 hill\(^{-1}\). The experiment was conducted for 2017 and 2018 and at three sites each year. The average time used for sowing and weeding was reduced from 70.2 hours ha\(^{-1}\) in manual operations to 20.3 hours ha\(^{-1}\) in mechanized operations. The new production package reduced the time to maturity by 11 days compared with the traditional package. Average grain yield in the traditional and new production package was 947 and 1470 kg ha\(^{-1}\), respectively, while the corresponding stover yields were 2460 and 3005 kg ha\(^{-1}\), respectively. The increased yield as a result of the new production package is likely an effect of more precise sowing, better weed control, and faster crop development. The improved package increased the gross margin by 80.2% compared with the traditional production method. The improved package will be interesting for the farmers because of the increase in land and labour productivity.

Keywords: pearl millet; fertilizer micro-dosing; seed priming; labour-use; weed density; time to maturity; animal traction

1. Introduction

Pearl millet cultivation is a cornerstone in food production in Niger as it accounts for 73% of cereal production in the country [1]. The crop is sown on more than 7 million hectares [1], and the average yield of pearl millet in Niger is 544 kg ha\(^{-1}\) (average 2012) [1]. Niger has a population growth of 3.9% year\(^{-1}\), and the country’s self-sufficiency in cereals in 2050 will only be about 20% if yield remains at the yield levels of 2010 [2]. The current food security situation in the country is also worrying, as 16.5% of the population is considered undernourished [1]. It is thus of great importance to increase pearl millet production in the country.

Pearl millet is a crop that is well adapted to the semi-arid tropics owing to its ability to tolerate drought, high temperatures, and sand blasting [3]. The crop is generally produced on sandy soils that are low in organic matter and plant nutrients and sowing is undertaken without prior tillage [3,4]. Plant density is as low as 5000 hill ha\(^{-1}\) [4].
Mechanization has been out of the development agenda in Africa since the mid-1980s, but there is currently an increased interest in agricultural mechanization [5]. It is very difficult to imagine agricultural development without equipment [6]. Mechanization of sowing and weeding should be an interesting option for the farmers because it enables timelier and more precise sowing, which can increase yield and reduce labour demand [5].

This study compared farmers’ practice against a crop production package consisting of seed priming, microdosing, seed treatment with a combined fungicide/insecticide, and sowing and weeding using a combined planter/weeder (multicultivator). This is, to our knowledge, the first time that the effects of these technologies on yield, labor use, and weed infestation have been studied in the Sahelian zone. The effects of the individual technologies are well known. Seed priming, which consists of soaking the seeds in water for a specific time for each crop, has been found to increase yield by 30% in Sudan [7] and 26% in Mali [8]. It is a well proven method to improve crop establishment under dry and marginal tropical environments [9]. Microdosing has been tested since the early 1990s in the Sahelian zone, but mixed results have been obtained using rates in the order of 2 g diammonium phosphate (DAP) or 6 g NPK per hill [10]. In Niger, it was found that microdosing gave a negative economic return in 36% of the experiments [10]. However, 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 [8], while in Sudan, a dose of 0.3 g hill$^{-1}$ gave a yield advantage over the control of 31.3% [8]. Seed treatment with a combined fungicide/insecticide increased pearl millet yield by 15% in Mali [11]. Sowing of pearl millet is normally done by hand, but mechanized sowing has been found to increase sorghum yield by 14% compared with manual sowing [5]. This is likely an effect of more precision in terms of sowing depth, distance between plants, and seed rate. The results from Mali have shown that a combination of seed priming, microdosing (0.3 g NPK 15–15–15 hill$^{-1}$), and seed treatment with a fungicide gave a yield increase in pearl millet in the Sahelian zone of 77.6% compared with a control [8].

The objective of this study was to compare farmers’ traditional practices against an improved practice consisting of mechanized sowing, seed treatment, and hill place application of mineral fertilizer (microdosing). The study assessed the effect of the two treatments on labour demand, weeds infestation, days to germination, time to maturity, yield, and economic return.

2. Materials and Methods

2.1. Study Sites

The study was conducted in the Sahelian regions of Niger between the 12th and 14th degree of North Latitude at three research stations of the Institut National de Recherche Agronomique du Niger (INRAN) (Figure 1). The sites were Lossa (13°56’02” N and 1°34’29” E), N’Dounga (13°56’29” N and 2°14’51” E), and Magaria (12°58’27” N and 8°55’06” E). The soils on these sites are acid sandy soil (Arenosols). Lossa is located on the isohyet 300–400 mm, whereas N’dounga and Magaria is located on the isohyet 400–600 mm. The experiment was conducted for the years 2017 and 2018.
2.2. Plant Material and Planting

The pearl millet variety HKP was used because this is a variety well adapted to the agro-ecological conditions in Niger. This variety is resistant to stem borer (Coniesta ignefusalis (Hampson, 1919)) and downy mildew (Sclerospora graminicola (Sacc.) J. Schröt). Time to maturity is between 70 and 80 days after sowing.

The seeds were placed in hills (planting pocket) at a density of 10,000 hills ha\(^{-1}\), representing a spacing between hills of 1 m. In manual sowing, a pinch of seeds (using the thumb and the index finger) is placed in each hill. As there will be many plants emerging in each hill, there is a need for thinning. Each hill is thus thinned to 2–3 plants hill\(^{-1}\) about two weeks after sowing. Manual sowing gives a higher number of seeds per hill than sowing using a planter. There was thus no need for thinning in mechanized sowing.

2.3. Experimental Design

The experimental design was a randomized block design with 18 replications of each treatment at each site. The high number of replications was used because it was not known at the start of the experiment how uniformly the seeds were delivered by the planter, and a high number of replicates guaranteed more reliable results. The elementary plot was 250 m\(^2\) (5 m \(\times\) 50 m).

The experiment had the following two treatments:

- T0. Control with manual sowing and weeding and without seed priming, fungicide/insecticide treatment of seeds, and microdosing. No fertilizer was applied.
- T1. Improved practice consisting of using a planter/multicultivator for sowing and weeding, seed priming, NPK microdosing 0.3 NPK g hill\(^{-1}\) equivalent to 3 kg NPK ha\(^{-1}\), and seed treatment with a combined insecticide/fungicide.

The control treatment (T0) was sown using a small bladed hoe, while the hiliare was used for weeding. Seed priming in the T1 treatment consisted of soaking the seeds in water for eight hours at ambient temperature. After soaking, the seeds were dried on a canvas on a shaded airy place for two
hours. The seeds were thereafter treated with the combined insecticide/fungicide Calthio D5 (20% lindane and 25% thiram) (produced by Arysta LifeScience, Paris, France) at a rate of 0.5 g per kg seeds.

Prior to sowing, the fields were ploughed and leveled in order to facilitate the sowing. Seeds and fertilizer were mixed in a 1:1 ratio and sown by a combined planter/weeder (multicultivator). The planter used was the Malian super-eco (produced by Agric. Construction Cissé et Frères, Koutiala, Mali). This planter delivers seeds by a perforated disc that turns inside a hopper. The disc in the planter had perforations of 10 mm diameter, giving a fertilizer rate of 0.3 g hill$^{-1}$. The planting density and the amount of seed/fertilizer delivered depends on the thickness of the disc, the distance between the perforations in the disc, and the diameter of the disc. Tines were mounted to the frame of the planter to make the planter/multicultivator suitable for intra-row weeding. In addition, it was necessary to undertake manual within-row weeding.

2.4. Agronomic Measurements

The observations included germination rate 2.5 days after sowing, time to 50% maturity, grain yield, and stover yield. The germination rate was estimated by counting the number of hills per elementary plot.

The grain and stover biomasses were sundried for two to three weeks and their weight was determined.

2.5. Working Hours

The time use for sowing was measured on the six lines of all the elementary plots in the experiment. The mechanical seeding was carried out using an ox as traction animal. We measured time for weeding in all the elementary plots in the experiments. For mechanical weeding, the time use for manual weeding between the plants within the line was also measured. In addition, we measured the number of millet plants destroyed by the multicultivator and by the hooves of the ox.

2.6. Estimating Time for Weed Emergence and Weed Density after Weeding

The number of days between weeding and weed emergence was measured after the first and second weeding. The observations began on the first day after weeding and were repeated in the following days. The weed density was estimated at the time of installation by counting the number of weeds in quadrants of 1 m$^2$ (1 m $\times$ 1 m). For each plot, weed counts were undertaken in six quadrants. The same plots were observed at the first and second weeding.

2.7. Economic Analysis

The income was calculated based on the value of the grain and straw. This calculation was based on an average market price in the villages for grain and millet stover of 200 and 8.2 franc CFA (FCFA) kg$^{-1}$, respectively. The treatments had input costs related to seeds, fertilizer, and fungicide and labour costs related to sowing, thinning, weeding, harvesting, transport of harvest, and threshing/winnowing. The price of seeds was 1000 FCFA kg$^{-1}$, NPK fertilizer 400 FCFA kg$^{-1}$, and fungicide 300 FCFA ha$^{-1}$. The elabour cost is 2500 FCFA man-day$^{-1}$. The labour cost for harvesting, transport of harvest, and threshing/winnowing is 150, 100, and 200 sheafs$^{-1}$, respectively. For mechanized sowing, there is no labour cost related to thinning because the seed rate is lower than in mechanized sowing. The gross margin was calculated by subtracting the production cost from the income.

2.8. Statistical Analysis

The data collected from the trial were analyzed using Microsoft Excel and Genstat version 9.2 (VSN International, Hemel Hempstead, UK). An analysis of variance was undertaken to statistically analyze the experiment. Confidence intervals are presented to separate the means.
3. Results

The results are presented on man-days ha$^{-1}$ use for sowing and weeding, weed infestation, number of days for weeds to emerge after weeding, germination rate 2.5 days after sowing, time to maturity, grain and stover yield, and gross margin.

3.1. Effect of Treatment on Time Use (Sowing and Weeding), Days to Weed Emergence after Weeding, Weed Density, and Destruction of Millet Plants during Weeding

Sowing using a planter significantly reduced labour use for all three sites and in both years. The average labour use in the manual control (T0) was 12.1 hours ha$^{-1}$, while the labour use when the planter was used was 6.1 hours ha$^{-1}$ (Table 1). The variation between the sites and years was generally small.

The reduction in labour use was higher for weeding as compared with sowing (Table 1). The average labour use in the first weeding was 30.1 hours ha$^{-1}$ using manual weeding, while mechanized weeding required 7.6 hours ha$^{-1}$. In the second weeding, the time was on average reduced from 28.4 hours ha$^{-1}$ in manual weeding to 6.7 hours ha$^{-1}$ in mechanized weeding. This represents a 74.9% and 76.4% reduction in labour use for the first weeding and second weeding, respectively. Total time use for the two weedings was 58.1 hours ha$^{-1}$ in manual weeding and 14.1 hours ha$^{-1}$ in mechanized weeding. The labour reduction effect was highly significant in all sites and in both years.

Mechanized sowing and weeding greatly reduced time use compared with manual sowing and weeding (Table 1). The average time use for these operations was reduced from 70.2 hours ha$^{-1}$ in manual operations to 20.3 hours ha$^{-1}$ in mechanized operations, representing a reduction in time use for these two operations by 71.1%.

The effect on weeds of the two treatments was measured in terms of days for weeds to emerge after weeding and weed density. For these two variables, mechanized weeding gave a better effect than manual weeding. Weeds emerged seven days after the first weeding, while in mechanized weeding, the weeds emerged after 11 days (Table 1). In the second weeding, it took eight days for the weeds to emerge in manual weeding, while under mechanized weeding, the weeds emerged after 13 days.

The two treatments also affected weed density differently (Table 1). Mechanized weeding significantly reduced weed density after the first and second weeding in all three sites and in both years. In the first weeding, the average weed density across two years was 57.7 weeds m$^{-2}$ in manual weeding, while in mechanized weeding, the density was 37 weeds m$^{-2}$. In the second weeding, the weed density was 47 weeds m$^{-2}$ after manual weeding, while the corresponding number was 27 weeds m$^{-2}$ after mechanized weeding. Average weed density after the first and second weeding in manual weeding was 52 weeds m$^{-2}$, while the corresponding number was 33 weeds m$^{-2}$ when mechanized weeding was practiced.

Mechanized weeding resulted in a slight reduction in pearl millet density as some of the millet plants were destroyed because the traction animal was not always able to move on a straight line. There was no destruction of plants when manual weeding was practiced. The average number of plants destroyed (across two years and three sites) was 100 and 106 plants ha$^{-1}$ for first and second weedings, respectively.
Table 1. The effect of treatments on labour use (sowing and weeding), days to weed emergence, and weed density. Probability of main effects and interactions included.

| Location | Treatments | Sowing Time (hours ha$^{-1}$) | Weeding Time (hours ha$^{-1}$) | Weed Emergence (days) | Weed Density (weeds m$^{-2}$) | Weeding Time (hours ha$^{-1}$) | Weed Emergence (days) | Weed Density (weeds m$^{-2}$) | Total Time Use (hours ha$^{-1}$) |
|----------|------------|-------------------------------|--------------------------------|-----------------------|-------------------------------|-------------------------------|-----------------------|-------------------------------|---------------------------------|
|          |            | 2017 | 2018 | 2017 | 2018 | 2017 | 2018 | 2017 | 2018 | 2017 | 2018 | 2017 | 2018 | 2017 | 2018 |
|          |            |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |
| Lossa    | T0         | 12.1 ± 0.3 | 12.04 ± 0.22 | 30.26 ± 0.59 | 30.35 ± 1.4 | 7.1 ± 1 | 6.7 ± 0.5 | 63.1 ± 8.1 | 57.3 ± 9.9 | 27.1 ± 0.7 | 28 ± 1.5 | 8.3 ± 0.7 | 8.1 ± 0.9 | 42.1 ± 7.3 | 47.9 ± 8.2 | 69.43 ± 0.8 | 70.4 ± 1.8 |
|          | T1         | 5.52 ± 0.41 | 5.65 ± 0.35 | 7.52 ± 0.65 | 7.4 ± 0.6 | 11.6 ± 1.1 | 11.2 ± 1 | 43.3 ± 10.3 | 36.6 ± 10 | 6.6 ± 0.5 | 6.5 ± 0.5 | 13.8 ± 0.8 | 13.3 ± 1.3 | 26.1 ± 7.1 | 27 ± 7.2 | 19.6 ± 0.9 | 19.6 ± 0.9 |
| Magaria  | T0         | 12.04 ± 0.28 | 12.2 ± 0.33 | 29.69 ± 0.75 | 29.69 ± 0.75 | 6.6 ± 1.1 | 6.8 ± 0.8 | 60.9 ± 9.7 | 76.3 ± 7.8 | 27.9 ± 0.8 | 29.1 ± 1.5 | 8.5 ± 1.1 | 8 ± 0.7 | 45.1 ± 8.3 | 61 ± 11.6 | 69.6 ± 1.3 | 71.4 ± 1.8 |
|          | T1         | 6.54 ± 0.85 | 6.48 ± 0.58 | 7.54 ± 0.54 | 7.42 ± 0.4 | 10.2 ± 1.7 | 10.8 ± 1.1 | 39.3 ± 7 | 56.3 ± 6.6 | 6.6 ± 0.4 | 7.1 ± 0.8 | 12.7 ± 1.3 | 13.1 ± 1.2 | 28.5 ± 7 | 39.6 ± 11.1 | 20.7 ± 1.3 | 21.0 ± 1 |
| N’Dounga | T0         | 11.94 ± 0.29 | 12.17 ± 0.26 | 29.98 ± 0.71 | 30.49 ± 0.9 | 6.7 ± 0.7 | 7.7 ± 1.1 | 77.9 ± 5.9 | 54.3 ± 12.1 | 27.7 ± 1.1 | 28.3 ± 1.5 | 7.7 ± 0.7 | 8.6 ± 0.6 | 53 ± 9.5 | 49.3 ± 9.4 | 69.6 ± 1.2 | 70.91 ± 1.7 |
|          | T1         | 6.49 ± 0.76 | 6.63 ± 0.65 | 7.91 ± 0.34 | 7.57 ± 0.5 | 11.3 ± 1 | 12 ± 1 | 56.9 ± 6.6 | 33.4 ± 8.8 | 6.5 ± 0.6 | 6.5 ± 0.7 | 12.5 ± 1.2 | 12.6 ± 1.3 | 37 ± 10.1 | 27.1 ± 6.9 | 20.9 ± 0.9 | 20.2 ± 0.9 |
| Average  |            | 12.08 ± 0.29 | 12.04 ± 0.22 | 30.15 ± 0.97 | 30.3 ± 0.97 | 6.9 ± 0.9 | 6.5 ± 1.2 | 28.0 ± 1.3 | 28 ± 1.3 | 8.1 ± 0.8 | 8.1 ± 0.8 | 49.7 ± 10.8 | 49.7 ± 10.8 | 70.2 ± 1.6 | 70.2 ± 1.6 | 0.9 ± 2.3 | 1.1 |

|          |            | 2017-2018 | 2017-2018 | 2017-2018 | 2017-2018 | 2017-2018 | 2017-2018 | 2017-2018 | 2017-2018 | 2017-2018 |
|----------|------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| Location (L) |            | <0.001 | NS | <0.001 | NS | <0.001 | NS | <0.001 | NS | <0.001 | NS |
| Treatments (T) |            | <0.001 | NS | <0.001 | NS | <0.001 | NS | <0.001 | NS | <0.001 | NS |
| Year (Y) | NS | NS | 0.034 | NS | <0.001 | NS | 0.005 | NS | <0.001 | NS |
| L × T | <0.001 | NS | NS | NS | NS | 0.044 | NS | NS | NS | NS |
| L × Y | NS | NS | <0.001 | NS | <0.001 | NS | NS | NS | NS | NS |
| T × Y | NS | 0.006 | NS | NS | NS | NS | NS | NS | NS | NS |
| L × T × Y | 0.048 | NS | NS | NS | NS | NS | NS | NS | NS | NS |

± standard error; NS: not significant.
3.2. The Effect of the Treatments on Percent Germination and Time to 50% Maturity

There was a clear effect of the treatments on percent germination 2.5 days after sowing (Table 2). Average percent germination 2.5 days after sowing was 17.1% for the T0 treatment, while it was 93.5% for the T1 treatment. Only the average across years and sites is presented because there was not much variation between years and sites.

Table 2. Effects of treatments on percent germination 2.5 days after sowing and number of days to 50% maturity. Probabilities of main effects and interactions included.

| Location | Treatments | Percent Germination 2.5 Days after Sowing | Number of Days to 50% Maturity |
|----------|------------|----------------------------------------|--------------------------------|
|          |            | 2017        | 2018       | 2017       | 2018       |
| Lossa    | T0         | 18.17 ± 1.7 | 11.56 ± 1.0 | 78.9 ± 1.7 | 79.2 ± 1.0 |
|          | T1         | 95.67 ± 1.4 | 94.44 ± 1.3 | 69.1 ± 1.4 | 67.8 ± 1.3 |
| Magaria  | T0         | 23.44 ± 2.5 | 18.83 ± 1  | 79.7 ± 2.5 | 80.9 ± 1   |
|          | T1         | 91.94 ± 1.7 | 94.28 ± 1.6 | 69.1 ± 1.7 | 68.8 ± 1.6 |
| N’Dounga | T0         | 14.39 ± 0.7 | 16.28 ± 0.9 | 80.0 ± 0.7 | 80.6 ± 0.9 |
|          | T1         | 90 ± 1.1    | 94.5 ± 1.3  | 69.1 ± 1.1 | 68.9 ± 1.3 |
| Average  | T0         | 17.11 ± 11.7| 93.47 ± 6.5 | 79.4 ± 1.5 | 68.7 ± 1.5 |
|          | T1         |             |            |            |            |

± standard error; NS: not significant.

A clear effect on time to 50% maturity was observed for all sites and in both years (Table 2). The average time to maturity was 69 days for the T1 treatment, while it was 80 days for the T0 treatment (Table 2). There was only limited variation between years and sites, and we thus present the average data across years and sites.

3.3. The Effect of Treatments on Grain and Stover Yield

The improved treatment (T1) increased grain yield compared with the control (T0) in all sites and in both years (Table 3). In the first year, the average grain yield for the three sites for the T0 and T1 was 955 and 1474 kg ha\(^{-1}\), respectively, representing an increase in grain yield of 54.3%, while in the second year, the average grain yield of T0 and T1 was 953 and 1483 kg ha\(^{-1}\), respectively. Across the two years, the average grain yield increased from 947 kg ha\(^{-1}\) in the T0 treatment to 1470 kg ha\(^{-1}\) in the T1 treatment, representing an average grain yield increase of 55.3%.

Table 3. Effect of treatments on grain and stover yield (kg ha\(^{-1}\)). Probabilities of main effects and interactions included.

| Location | Treatments | Grain Yield    | Stover Yield   |
|----------|------------|----------------|----------------|
|          |            | 2017          | 2018          | 2017          | 2018          |
| Lossa    | T0         | 868.7 ± 156.3 | 884.5 ± 101   | 2048 ± 152.9  | 2083 ± 255    |
|          | T1         | 1411.8 ± 119.2| 1468.3 ± 119.2| 2493 ± 122.8  | 2837 ± 225.7  |
| Magaria  | T0         | 1042.5 ± 148.4| 1016.2 ± 80.9 | 2558 ± 511.5  | 2647 ± 571.4  |
|          | T1         | 1511.7 ± 106.6| 1547.3 ± 76.2 | 3092 ± 586.6  | 3122 ± 444    |
| N’Dounga | T0         | 953.8 ± 191.8 | 914.4 ± 136.9 | 2844 ± 384.1  | 2579 ± 285.5  |
|          | T1         | 1499.3 ± 78.3 | 1380.7 ± 105.6| 3504 ± 568.4  | 2979 ± 298.5  |
| Average  | T0         | 946.7 ± 149.8 |                | 2460 ± 463    |
|          | T1         | 1469.9 ± 115.7|                | 3005 ± 475    |
| 2017–2018 |           |                |                |               |
Table 3. Cont.

| Location | Treatments | Grain Yield | Stover Yield |
|----------|------------|-------------|--------------|
|          |            | 2017        | 2018         | 2017         | 2018         |
| Location (L) | <0.001 | <0.001 |
| Treatments (T) | <0.001 | <0.001 |
| Year (Y) | 0.454 | 0.318 |
| L × T | 0.245 | 0.711 |
| L × Y | 0.819 | 0.974 |
| T × Y | 0.018 | <0.001 |
| L × T × Y | 0.190 | 0.055 |

± standard error; NS: not significant.

The relative increase in straw yield was less as the T1 treatment increased average stover yield by 22.5% compared with T0 (Table 3). Average stover yield for T0 and T1 was 2460 and 3005 kg ha$^{-1}$, respectively. There was a significant difference between the treatments for all three sites and in both years.

3.4. Economic Analysis of Treatments

The economic analysis showed that the gross margins for the T0 and T1 treatments were 149,322 and 269,110 FCFA ha$^{-1}$, respectively (Table 4). This represented an increase in gross margin for T1 compared with T0 of 80.2%. The higher yield in the T1 treatment compared with the T0 treatment was the main factor explaining the higher income for the improved treatment (T1). The production costs for T0 and T1 treatments were 60,250 and 49,900 FCFA ha$^{-1}$, respectively. The T0 treatment had higher production costs than T1 because of higher labour costs related to sowing, thinning, and particularly weeding. The weeding costs in manual and mechanized weeding were 29,100 and 12,150 FCFA ha$^{-1}$, respectively. The T1 treatment had higher input costs related to mineral fertilizer and fungicide treatment, but this only amounted to 1500 FCFA ha$^{-1}$.

Table 4. Effect of the treatments on income, production cost, and gross margin.

| T0. Manual Sowing and Weeding without Seed Priming, Seed Treatment, and Microdosing | T1. Mechanical Sowing and Weeding with Seed Priming, Seed Treatment, and 0.3 g NPK hill$^{-1}$ |
|----------------------------------|----------------------------------|
| Quantity | Unit Price | Value | Quantity | Unit Price | Value |
| Grain | 947 | 200 | 189,400 | 1470 | 200 | 294,000 |
| Stover | 2460 | 8.2 | 20,172 | 3050 | 8.2 | 25,010 |
| Income | 209,572 | | | 319,010 | |
| Sowing | 12.1 h | 500 | 6050 | 6.1 h | 500 | 3050 |
| Seeds | 8 kg | 600 | 4800 | 3 kg | 600 | 1800 |
| Fungicide | - | - | - | 1 unit | 300 | 300 |
| Mineral fertilizer | - | - | - | 3 kg NPK ha$^{-1}$ | 400 | 1200 |
| Thinning | 1 | 5000 | 5000 | - | - | - |
| Weeding | 58.2 | 500 | 29,100 | 14.2 | 500 | 7100 |
| Harvesting | 34 sheafs | 150 | 5100 | 81 sheafs | 150 | 12,150 |
| Transport of harvest | 34 sheafs | 100 | 3400 | 81 sheafs | 100 | 8100 |
| Threshing cleaning | 34 sheafs | 200 | 6800 | 81 sheafs | 200 | 16,200 |
| Production costs | 60,250 | | | 49,900 | |
| Gross margin | 149,322 | | | 269,110 | |
4. Discussion

The study showed that mechanized sowing and weeding combined with seed priming, seed treatment with fungicides/insecticide, and microdosing significantly reduced labour use for sowing and weeding, delayed emergence of weeds, reduced weed density, shortened germination time, reduced time to maturity, and increased grain and straw yield.

Labour use for sowing was reduced from 12.1 hours ha\(^{-1}\) in manual sowing (T0) to 6.1 hours ha\(^{-1}\) in mechanized sowing (T1). In Mali, it was found that the use of an animal drawn planter required 7.1 hours ha\(^{-1}\), while manual sowing required 64 hours ha\(^{-1}\) [5]. The large difference in labour in manual sowing between Mali and Niger can partly be explained by a higher planting density in southern areas of Mali. In Mali, the planting density is approximately 25,000 hills ha\(^{-1}\), while in Niger, the planting density is 10,000 hill ha\(^{-1}\). A reduction in planting time is important as there are few days that are appropriate for sowing in the drylands of West Africa and labour is also in short supply during this time.

Labour use for first and second weeding was 30.1 and 28.0 hours ha\(^{-1}\) in manual weeding (T0), while the corresponding values in mechanized weeding were 7.6 and 6.6 hours ha\(^{-1}\) (T1), representing a 75.5% reduction in time use with mechanized weeding compared with manual weeding. A study in southern Mali showed that labour use in manual weeding was 184 hours ha\(^{-1}\), while in mechanized weeding (ox traction), the weeding time was 67 hours ha\(^{-1}\) [5]. Southern Mali has more rainfall than in the pearl millet growing areas in Niger, and this may result in more weed infestation and a higher labour demand for weeding in Mali compared with in Niger.

The total labour use in manual sowing and weeding (T0) was 70.3 hours ha\(^{-1}\) compared with 20.3 hours ha\(^{-1}\) in mechanized sowing and weeding (T1), representing a time saving of 71.2% in mechanized sowing and weeding compared with manual operations.

Weeds emerged more rapidly after manual weeding as compared with after mechanized weeding. Time to emergence of weeds after manual weeding (first and second weeding) was on average 7.5 days, while it was on average 12.1 days after mechanized weeding.

Mechanized weeding (T1) was also more efficient than manual weeding (T0) in reducing weed density. Average weed density after first weeding and second weeding was 52.1 weeds m\(^{-2}\) when manual weeding was practiced, while after mechanized weeding, it was 32.5 weeds m\(^{-2}\). This delay in weed emergence and lower weed density in mechanized weeding compared with manual weeding may be explained by the fact that mechanized weeding cuts the weed roots to a depth of 7 to 10 cm, while the hillier used in manual weeding hardly exceeds a depth of 5 cm. This also implies that the weeds and weeds seeds are buried to a greater depth in mechanized weeding compared with when manual weeding is practiced.

A negative impact of mechanical weeding (T1) was destruction of millet plants by the traction animal and plants being eliminated accidentally by the multiculтивator. In total, 206 plants ha\(^{-1}\) were destroyed for the two weedicings. However, this reduction in plant density is not likely to reduce yield to any significant degree as there are 10,000 hill ha\(^{-1}\). This destruction of plants represented only a 2% loss in plant density. It is also likely that the surviving plants to some degree will be able to compensate for the minor loss in plant density.

These results showed that mechanized weeding was more efficient than manual weeding in reducing weed infestation. Mechanized weeding ensures that weeding can be undertaken at the most appropriate time and the competitive ability of weeds against the crop will be reduced as the weed will emerge later after mechanized weeding.

The improved technology package (T1) also influenced the plant development cycle as germination 2.5 days after sowing was 93.2% in T1 versus 17.0% for T0. Furthermore, time to 50% maturity was reduced by 11 days in the T1 treatment compared with in the T0 treatment. The pearl millet variety HPK reached 50% maturity after 69 days in the T1 treatment, which is six days earlier than the number of days to maturity given in the National Catalogue of Plant Species and Varieties (CNEV) of Niger [12]. This shows that the introduced technologies can reduce the growth cycle greatly, thereby making the crop less vulnerable to “end-of-cycle” drought. The shortening of the growing cycle in the T1
treatment compared with the T0 treatment is likely a combined effect of precise sowing, seed priming, and microdosing. Faster emergence, more vigorous plant growth, and earlier maturity have also been documented in studies on seed priming [9].

The average grain yield was 54.3% higher for the T1 treatment compared with the T0 treatment in the first year, while it was 55.6% higher in the second year. The effect on straw yield was less, as it was found that the T1 treatment increased average stover yield by 22.5% over the T1. The yield enhancing effect on the yield of the T1 treatment is likely a combination of the effects of seed priming, microdosing, seed treatment with a combined fungicide/insecticide, more precise sowing with mechanization, and better weed control in mechanized weeding [11]. This resulted in faster crop establishment, less competition from weeds, and reduced time to maturity. Seed priming combined with microdosing has been found to give a yield enhancing effect of 26% in pearl millet in central Mali [8], which has similar agro-ecological conditions as southern Niger. Microdosing in pearl millet in central Mali with 6 kg NPK ha$^{-1}$ has been found to give an average yield increase of 54.9% [8].

The gross margin was 80.2% higher in the improved treatment (T1) compared with the control (T0). This improved income was particularly related to higher yield in the T1 treatment compared with the control (T0). Surprisingly, the production costs were lower in the improved treatment (T1) compared with the control. This could be explained by the lower weeding costs in the treatment with manual weeding. The input costs related to fertilizer and fungicide were only 1500 FCFA ha$^{-1}$ in the improved treatment. The high economic return of such a production package with mechanization has also been shown in sorghum in Mali [5].

Questions can be raised if mechanization of sowing and weeding (T1) is economically feasible as the cost of the planter was not included in the calculation of the gross margin. The price of the Super-eco planter used in this experiment is about 70,000 FCFA. However, the gross margin was about 120,000 FCFA ha$^{-1}$ higher in the treatment with mechanized sowing compared with the treatment with manual sowing. It is thus possible to justify purchasing a planter/multicultivator even if the planter is only used for one ha. The household survey showed that the households on average are cultivating 4 ha. This makes the use of the planter even more economically attractive. The results show that the use of mechanization is only economically attractive if yields are increased. If yields remain at the same level as before the introduction of mechanization, it would not be economically interesting to use mechanization. Mechanization should thus be part of a package that also includes low-cost yield enhancing technologies like seed priming and microdosing. This planter has low weight and can thus be pulled by a donkey. That brings this form of mechanization within reach for many farmers in Niger. A study on mechanization in Eastern and Southern Africa also showed that mechanization of crop establishment and weeding are appropriate entry points for mechanization [13].

The planter used in this experiment functioned satisfactorily and there were no problems related to the delivery of seeds and fertilizer. However, this machine has a clear limitation because the seeds and fertilizer are not delivered independently, but as a mixture. This makes it difficult to adjust the seeds and fertilizer rates. The project is working on developing a new planter that can deliver seeds and fertilizer independently.

The technologies included in the T1 treatment will also make the crops less exposed to drought because of timelier and more precise sowing, faster and more uniform crop establishment, less competition from weeds, and shorter time to maturity. Microdosing has also been found to promote better root development [14].

The technologies included in the T1 treatment will be attractive for the farmers as they reduce labour demand and increase yield, thereby increasing both land and labour productivity. This double intensification will make it more attractive for the farmers to adopt the technologies. This will contribute to increasing the attractiveness of farming, particularly for young people.
5. Conclusions

This study showed that a production package consisting of mechanized sowing and weeding, seed priming, seed treatment with a combined fungicide/insecticide, and microdosing reduced labour use and weed infestation, shortened the growing cycle, and increased grain and stover year compared with a treatment without these technologies. Mechanized sowing and weeding reduced labour use by 71.2% compared with manual sowing and weeding. Weed infestation was less in mechanized sowing compared with manual weeding as a result of the delayed emergence of weeds and fewer emerging weeds. The package resulted in earlier germination and number of days to maturity was reduced by 11 days. Grain and stover yields were increased by 55.0% and 22.1%, respectively. The improved treatment increased the gross margin by 80.2% compared with the control. The improved package is economically attractive for the farmers even if the cost of mechanization is taken into consideration, as the gross margin was 120,000 FCFA ha\(^{-1}\) higher in the improved treatment with mechanization as compared with the control, while the cost of the planter/multicultivator was 70,000 FCFA. The improved package will make crop production more resistant to drought conditions as a result of more timely sowing and weeding, less weed infestation, faster crop establishment, and earlier maturity. This should be an attractive production package for the farmers because of the low cost, reduced labour input, increased yield, and gross margin.

Author Contributions: Conceptualization, A.I.M.N., A.K.S and J.B.A.; methodology, A.I.M.N., A.K.S and J.B.A.; validation, A.I.M.N., A.K.S, W.A. and A.O.A.; formal analysis A.I.M.N. and A.K.S.; investigation, A.I.M.N., A.K.S.; data curation, A.I.M.N.; writing-original draft preparation A.I.M.N.; writing–review and editing A.K.S., W.A., A.O.A. and J.B.A.; supervision A.K.S., W.A., A.O.A. and J.B.A.; funding acquisition, J.B.A. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Norwegian Ministry of Foreign Affairs through the REDSAACC project. Grant NER-15/0001.

Acknowledgments: The authors would like to thank CARE, Niger for facilitating this research and the technicians at the research centers assisting in implementing of the study.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. FAO stat 2020. Available online: http://www.fao.org/faostat/en/#data/QC (accessed on 16 March 2020).
2. Van Ittersum, M.K.; Bussel, L.G.J.; Wold, J.; Grassini, P.; van Wart, J.; Guiipart, N.; Claessens, L.; de Groot, H.; Wiebe, K.; Mason-D’Croz, D.; et al. Can sub-Saharan Africa feed itself. Proc. Natl. Acad. Sci. USA 2016, 113, 14964–14969. [CrossRef] [PubMed]
3. Mason, S.C.; Maman, N.; Palé, S. Pearl millet production practices in semi-arid West Africa: A review. Exp. Agric. 2015, 51, 501–521. [CrossRef]
4. Bationo, A.; Christianson, C.; Baethgen, W.; Mokwunye, A. A farm-level evaluation of nitrogen and phosphorus fertilizer use and planting density for pearl millet production in Niger. Fert. Res. 1992, 31, 175–184. [CrossRef]
5. Aune, J.B.; Coulibaly, A.; Woumou, K. Intensification of dryland farming in Mali through mechanization of sowing, fertilizer application and weeding. Arch. Agron. Soil Sci. 2019, 65, 400–410. [CrossRef]
6. Houmy, K. Guide de formulation d’une stratégie de mécanisation agricole. Etude de cas: stratégie nationale de la mécanisation agricole au Mali; FAO: Rome, Italy, 2008; p. 65.
7. Aune, J.B.; Ousman, A. Effect of seed priming and micro-dosing of fertilizers on sorghum and pearl millet in Western Sudan. Exp. Agric. 2011, 47, 419–435. [CrossRef]
8. Coulibaly, A.; Woumou, K.; Aune, J.B. Sustainable intensification of sorghum and pearl millet production by seed priming, seed treatment and fertilizer microdosing under different rainfall regimes in Mali. Agronomy 2019, 9, 664. [CrossRef]
9. Harris, D. Development and testing of “on-farm” seed priming. Adv. Agron. 2006, 90, 129–178.
10. Bielders, C.L.; Gerard, B. Millet response to microdose fertilization in south-western Niger: Effect of antecedent fertility management and environmental factors. Field Crop. Res. 2015, 171, 165–175. [CrossRef]
11. Aune, J.B.; Traoré, C.O.; Mamadou, S. Low-cost technologies for improved productivity of dryland farming in Mali. *Outlook Agr.* 2012, *41*, 103–108. [CrossRef]
12. République du Niger Ministère de l’Agriculture. *Catalogue National des Espèces et des Variétés Végétales (CNEV)*; République du Niger Ministère de l’Agriculture: Abuja, Niger, 2012; p. 276.
13. Baudron, F.; Misiko, N.; Getnet, B.; Nazare, R.; Sariah, J.; Kaumbutho, P. A farm-level assessment of labour and mechanization in Eastern and Southern Africa. *Agron. Sust. Devel.* 2019, *39*, 17. [CrossRef]
14. Ibrahim, A.; Abaidoo, R.C.; Fatondji, D.; Opoku, A. Determinants of fertilizer microdosing-induced yield increment of pearl millet on an acid sandy soil. *Exp. Agric.* 2016, *52*, 562–578. [CrossRef]

© 2020 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (http://creativecommons.org/licenses/by/4.0/).