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*Research Article*

# Agronomic and Economic Performance of Rain-Fed Maize (*Zea mays* L.) Production under Varying Sowing Dates and Multinutrient Fertilizer Levels in Shire Area, Northern Ethiopia

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The present study was carried out to examine the combined effects of varying seed sowing and multinutrient fertilizer levels on maize yield in Shire area, Northern Ethiopia, in two consecutive cropping seasons (2018-2019). The experimental plots were designed in a split plot design with three replications. Sowing dates were determined based on the rainfall criteria of the AquaCrop model. Accordingly, the sowing date treatments were set as June 1, June 7, June 12, and June 16 for the 2018 cropping season, and the corresponding sowing dates for the 2019 cropping season were May 26, June 3, June 8, and June 12. The multinutrient fertilizer levels included 0, 100, 200, and 300 kg·ha$^{-1}$. Agronomic related data were subjected to the analysis of variance, and partial budget analysis was applied for the economic performance evaluation. Maize yield was agronomically and economically influenced by sowing dates and multinutrient levels. Relative yield superiority that varies between 48.9 and 87.7% was found for each 100 kg·ha$^{-1}$ multinutrient applied. On the other hand, with 4–6 days shifted towards earlier sowing resulted in an average yield increase by 4.9–66.9%. Application of 300 kg·ha$^{-1}$ multinutrient for the early sown maize seems agronomically the superior treatment. However, from the economic analysis perspective, early maize sowing combined with the application of 200 kg·ha$^{-1}$ multinutrient fertilizer was reported as the most profitable treatment. Late sowing of maize with the application of multinutrient fertilizer beyond 200 kg·ha$^{-1}$ resulted in negative economic returns. The regression analysis results also indicated that maize grain yield tends to increase with the level of multinutrient fertilizer application ($R^2 = 0.841$–$0.864$), whereas yield decreased with the delay in sowing dates ($R^2 = 0.927$–$0.995$). Hence, this study concluded that the treatments with the best agronomic performance are not necessarily the best in terms of profitability.

## 1. Introduction

Maize (*Zea mays* L.) is one of the most staple food crops in Ethiopia as it is the first in its grain production and the second in the area coverage of the cereal crops under rain-fed agriculture. However, maize crop average national yield is not more than 4 tons·ha$^{-1}$ [1], which is low as compared to the current world average productivity, which is close to 6 tons·ha$^{-1}$ [2, 3]. Ethiopia's rain-fed maize yield is characterized by production uncertainties caused mainly by poor cultural practices associated with unreliable rainfall, low soil fertility, poor nutrient management, unimproved crop variety, and cropping system that resulted in yield variability and low productivity [4–7]. Maize production is strongly affected by rainfall variability within and across seasons in which this influences the planting date. Rainfall variability includes variability in the onset and cessation, amount, frequency, and duration [5]. Hence, the challenge to fix the planting time is one of the major causes of rain-fed maize yield reduction. Under variable rainfall conditions and the consequence on planting time, crop response to fertilizer application could not be effective. The implication is that there is a need to examine such cultural and agronomic practices that increase rainwater use efficiency and thereby yield per unit area in diversified agroecological conditions [6, 8, 9].

Although most maize production in Ethiopia is under low-input and rain-fed conditions, many research findings verified that the best fertilizer use efficiency can be attained by timely sowing and application of the multinutrient fertilizer rate that is compatible with the rainfall conditions [6, 8–10]. However, fertilizer use in Ethiopia is very low and unbalanced due to less access and high purchasing costs, and it is also unbalanced due to the sole application of N and P sourced from urea and diamonium phosphate (DAP) fertilizers. Such fertilizers have been used continuously as blanket recommendations for the last three decades in Ethiopia [6, 11, 12]. The application of nutrients based on the actual nutrient requirement of a crop and the nutrient supplying capacity of the soil whereby the crop is grown can ensure balanced nutrition for the crops [11]. Nevertheless, the soil fertility status Atlas developed by the Ethiopian Soil Information System (EthioSIS) indicates that most Ethiopian soils, including the study area, are deficient in potassium (K), sulphur (S), zinc (Zn), and boron (B), besides N and P [13]. The continuous use of imbalanced fertilizers for many years causes crop yield reduction and a decline in soil fertility due to erosion, leaching, and removal with crop harvest (ATA, 2016). Thus, assessing site-specific multinutrient fertilizers' trial targeting to improve plant nutrients is essential for selecting the best economically profitable and environmentally judicious use of fertilizers in the northern Ethiopian soil and climatic conditions.

The application of timely and proper type and rate of plant nutrients is essential for optimal crop growth and production and thereby for achieving maximum profit per unit of land. The profit of farmers from the application of fertilizer depends on the amount of crop yield producing per unit of land that keeps production costs below the selling price. For achieving profitable yield, efficient application of correct types and rates of fertilizers that consider the agronomic limitations such as the sowing date is an important approach. Application of multinutrient fertilizer levels should be based on the profit in which a farmer is actually to be acquired a maximum crop yield from the field conditions [11, 14–16].

The existing literature has shown that besides the other factors, the sowing date can influence the effectiveness of crop yield response to fertilizer rates' application significantly. Variation in the sowing date affects significantly crop yield even if the same rate of fertilizer is added. Determining the optimum sowing date is thus vital for crop-efficient utilization of moisture, nutrients, and solar radiation and will thereby improve crop yield and yield components and their profitability [8, 17, 18]. In spite of the fact that the time of seed sowing alone in combination with the nutrient rate affects maize crop production, most of the reports are based on a specific set of agronomic field experiments that are rarely repeatable at spatial and temporal scales [6]. In addition to this, maize sowing time varies with the onset and distribution of rainfall (climatic condition) as well as with the other agronomic practices, sources of soil nutrient management, and soil types. However, the use of plot-level maize fertilizers and/or agronomic and cultural practices trials' data to extrapolate for similar site-specific conditions using the existing report is inadequate [11, 14, 15], indicating the need for additional site-specific experiments on maize production limiting factors on the diversified agroecological conditions [19]. Determining the site-specific optimum sowing date coupled with multinutrient fertilizer levels for maize production through field experimentation requires repeated trials for many years and sites so as to capture the effects related to the rainfall and soil type variability. The objective of this study was, therefore, to examine agronomic performance and economic profitability of rain-fed maize cropping as influenced by sowing dates and multinutrient fertilizer levels of application in Shire area, northern Ethiopia.

## 2. Materials and Methods

*2.1. Description of the Study Areas.* This experiment was carried out in Shire area (specifically in Shire Agricultural College Demonstration Site) in northern Ethiopia, for two successive cropping seasons (2018-2019). The experimental site is located at $14°08'57''$ N latitude and $38°17'02''$ E longitude and altitude of 1907 metres above sea level. According to Alemneh [20], the study area belongs to the subhumid agro-climatic zone. The daily rainfall and maximum and minimum temperatures of the study site for the 2018 and 2019 cropping years are displayed in Figure 1. The study area is characterized by unimodal rainfall patterns, where more than 90% of the rainfall is concentrated in the periods of June to September with the mean annual rainfall of 851 mm. As of the Ethiopia National Meteorology Agency [21], the long term (30 years) average temperature of the study site is 24°C, with a mean maximum and minimum temperature of 30.25 and 11.4°C recorded in the months of April and January, respectively.

*2.2. Soil Characteristics of the Study Area.* Routine soil analysis procedures described in the soil and plant laboratory manual by Sahlemedhin and Taye [22] were followed to determine the selected presowing soil characteristics of the experimental area. Pits were opened up to 90 cm depth (at 3 different depths of 0–30 cm, 31–60 cm, and 61–90 cm) to see the trend in soil characteristics from the top soil, which is highly disturbed by the conventional tillage, soil management, and erosion deposition. Such soil depth for soil sampling was considered due to the fact that maize rooting depth is mainly concentrated up to 100 cm soil depth. One composite soil sample from each soil depth was collected before the experiment imposed in the 2018 cropping season. In 2019, one composite soil sample from each subplot at the three depths was collected. The total soil samples were 4 subplots × 3 depths = 12. Soil samples were analyzed following the standard soil analysis procedure of soil texture,

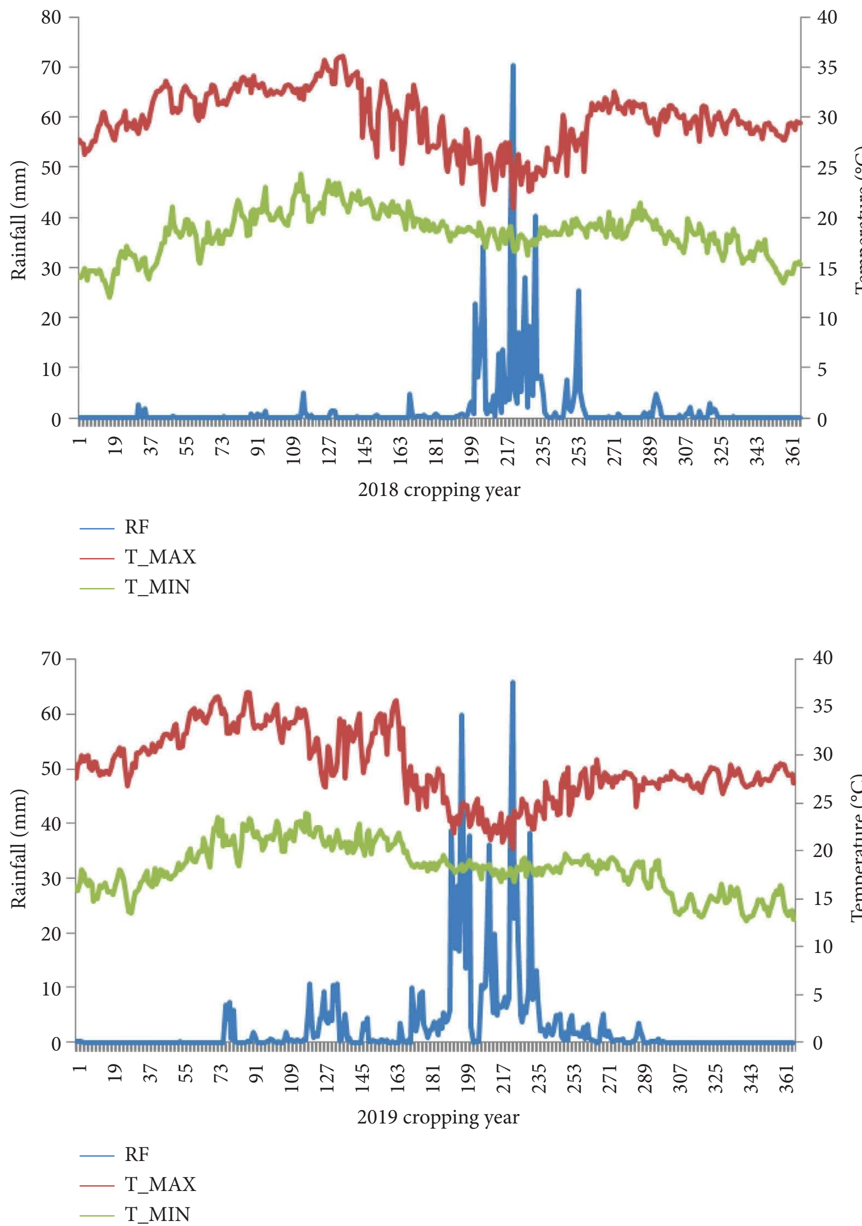



Figure 1: Daily rainfall and maximum and minimum temperatures of 2018-2019 cropping years.

soil dry bulk density (DBD), soil pH, electrical conductivity (EC), soil organic carbon (OC), available phosphorus (Pav), total nitrogen (TN), exchangeable bases ($Ca^{2+}$, $Mg^{2+}$, $K^{+}$ and $Na^{+}$), cation exchange capacity (CEC), and available S, Zn, and B.

Accordingly, the trial site soil analysis result was reported as a nonsaline soil with slightly alkaline pH and was low in organic matter content (Table 1). The relatively higher soil pH can have an effect on the availability of nutrients such as sulphur, zinc, and boron, which are mostly available with a pH value ranging between 5.5 and 6.5 [23]. The soil texture of the study site was classified using USDA Soil Taxonomy [24] as clay loam soil. In terms of the soil particle distribution, relatively high clay and lower silt proportion were recorded.

According to Havlin et al. [25], soils of the study site were deficient in macro- and micronutrients, besides the low organic matter content. Soil N and P are the major nutrients for crop growth, and SOC is also a nutrient reserve. The low SOC level (1.14–1.35%) indicates the severe degree of soil degradation in the experimental site. The study soil is relatively medium in CEC content (22.37–28.68 cmol (+)/kg). Generally, the soil of the study site was characterized as low in the fertility status and needs to be supplemented with a multinutrient fertilizer for the deficit nutrients in the soil.

*2.3. Experimental Design and Treatments.* Nutritionally improved medium maturing white seed hybrid maize variety (MHQ138) released in 2012 was used as a test crop.

Table 1: Chemical and physical characteristics of the study soil prior to maize seed sowing in both cropping seasons.

| Soil property | Soil depths 0–30 cm | | 31–60 cm | | 61–90 cm | |
|---|---|---|---|---|---|---|
| | 2018 | 2019 | 2018 | 2019 | 2018 | 2019 |
| *Chemical properties* | | | | | | |
| pH (1 : 2.5 water) | 7.4 | 7.5 | 7.7 | 7.7 | 7.6 | 7.9 |
| EC (ds/m) | 0.17 | 0.17 | 0.09 | 0.08 | 0.12 | 0.12 |
| Exchangeable Na (cmol (+)/kg) | 0.38 | 0.38 | 0.84 | 0.56 | 1.63 | 1.28 |
| Exchangeable K (cmol (+)/kg) | 0.53 | 0.67 | 0.50 | 0.86 | 0.24 | 0.22 |
| Exchangeable Ca (cmol (+)/kg) | 12.58 | 14.21 | 15.24 | 15.86 | 15.48 | 16.32 |
| Exchangeable Mg (cmol (+)/kg) | 8.04 | 9.24 | 7.15 | 7.98 | 3.08 | 4.62 |
| CEC (cmol (+)/kg) | 26.85 | 28.68 | 24.42 | 24.69 | 25.52 | 22.37 |
| SOC (%) | 1.35 | 1.314 | 1.34 | 1.21 | 1.32 | 1.14 |
| Total *N* (%) | 0.088 | 0.084 | 0.074 | 0.081 | 0.064 | 0.72 |
| Available S (ppm) | 6.45 | 6.4 | | 5.8 | | 4.1 |
| Available P (ppm) | 3.85 | 4.93 | 4.85 | 3.33 | 3.86 | 3.19 |
| Zn (ppm) | 0.31 | 0.24 | 0.28 | 0.32 | 0.23 | 0.27 |
| B (ppm) | 0.20 | 0.24 | 0.26 | 0.22 | 0.21 | 0.24 |
| *Physical properties* | | | | | | |
| Bulk density (g/cm$^3$) | 1.24 | 1.26 | 1.32 | 1.39 | 1.45 | 1.44 |
| Particle size distribution (%) | | | | | | |
| Sand | 32 | 36 | | | | |
| Silt | 31 | 29 | | | | |
| Clay | 37 | 35 | | | | |
| Soil texture | Clay loam | Clay loam | | | | |

EC: electrical conductivity, CEC: cation exchange capacity, SOC: soil organic carbon.

This variety is one of the quality protein maize (QPM) varieties released by the Ethiopian National Maize Research Program and is recommended for the moist midaltitude areas of Ethiopia [26]. It has a yield potential of 7.5–8 and 5.5–6.5 ton·ha$^{-1}$ in research stations and farmers field, respectively [27]. In this experiment, a split plot design was employed by allotting four maize sowing dates as a main plot and four multinutrient fertilizer application rates as a subplot. Each treatment was replicated thrice.

The sowing dates were determined based on the rainfall criteria of the AquaCrop model as first, second, third, and fourth occurrences when at least 30 mm of rainfall was accumulated in 5 consecutive days. Due to the difference in the onset of the rainfall, variable sowing date treatments were set for both study years. Early rainfall onset was observed during the 2019 cropping season relative to the 2018 one. Hence, shifting of planting dates in accordance to the rainfall onset is essential. Therefore, the sowing date treatments were set as SD1 (June 1), SD2 (June 7), SD3 (June 12), and June 16 (SD4) for the 2018 cropping season, and the corresponding sowing dates for the 2019 cropping season are May 26, June 3, June 8, and June 12.

The multinutrient fertilizer treatments were no fertilizer application (F0), 100 kg·ha$^{-1}$ multinutrient (F1) sourced from 50 kg complete fertilizer + 50 kg urea, 200 kg·ha$^{-1}$ multinutrient (F2) sourced from 100 kg complete fertilizer + 100 kg urea, and 300 kg·ha$^{-1}$ multinutrient (F3) sourced from 150 kg complete fertilizer + 150 kg urea. The multinutrient fertilizer treatments were set to be 0, 50, 100, and 150% of the nationally recommended multinutrient fertilizer dose, which is 100 kg complete fertilizer combined with 100 kg urea [13]. The 100 kg complete fertilizer constitutes 17.8 N: 35.7 P: 7.7 S: 0.1 B: 2.2 Zn, and 100 kg urea constitutes 46 kg·N. Complete fertilizers are fertilizers produced by chemical reaction containing both macro- and micronutrients [28].

The experimental plots were previously covered by tef crop and were ploughed three times at different time intervals starting from early May and leveled manually prior to field layout. The area of each experimental plot was 4 m by 4.5 m, having 96 maize plants per plot. The spacing between the main plots and blocks was 1.5 m each, whereas the spacing between subplots was 1 m. Two seeds were sown by hand per station at 5 cm depth in a flat seedbed at the recommended spacing of 75 cm and 25 cm between rows and within rows (plants), respectively, to have a plant density of 53333 plants per hectare [4, 26]. Mechanical mix of the complete dose of the complete fertilizer and one-third of urea was applied at planting time. Whereas, the remaining urea fertilizer was applied in split as half dose during the first weeding and the other half during the second weeding. All the fertilizers were applied in spot 5 cm away from the seeds/plants.

In order to avoid early stage weed-maize competition, hand weeding was carried out at 20 and 40 days after planting time for the first and second weeding, respectively. No chemicals were used, and hand weeding was continued throughout the whole growing season in both experimental seasons so that the experimental area was completely free from weeds.

*2.4. Agronomic Data Collection Procedures and Analysis.* From each experimental plot, ten randomly selected ears were used for collecting data on ear length, kernel number per ear (row number per ear x number of kernels per row), ear seed weight, and 100 seed weight. Ear length was measured using a graduated ruler from the bottom to the tip of the ear, while ear seed weight and 100- seed weight were measured using an electronic sensitive balance. The number of 100 seeds was counted using an electronic seed counter. Grain yield data were determined from the fifty plants that were selected for the final harvest from the net plot size of $9\,m^2$ (3 m by 3 m) from each experimental plot and measured using a weighing balance. Maize grain yield was adjusted to standard moisture contents to 10% as described in Abebe and Feyisa [4] report as follows: adjusted yield = actual yield × 100 − M/100 − D, where M and D are measured and standard moisture contents, respectively. The data collected in the present study were analyzed using the Statistical Analysis System (version 9.1, SAS Institute Inc., Cary, NC). The least significant difference (LSD) was used for treatment mean comparison at the 5% probability level (P). Moreover, regression analysis was carried out to show the contribution of the sowing date and multinutrient fertilizer levels to grain yield.

*2.5. Economic Analysis.* Partial budget analysis approach was applied for the economic performance evaluation among the treatments [29]. Gross returns, net returns, and marginal rate of return were calculated using the following formulas:

$$\begin{gathered}\text{Net return} = \text{gross return} - \text{total varying cost},\\ \text{Gross return} = \text{yield} \times \text{price},\\ \Delta\text{total variable cost Marginal Rate of Return (MRR)} = \left(\frac{\Delta\text{gross return}}{\Delta\text{total variable cost}}\right).\end{gathered} \tag{1}$$

Moreover, to identify the most economically acceptable treatments by farmers, marginal and dominance analysis was carried out as described by Mebrahtu and Teklay [30]. For farmers to adopt a new technology, scholars suggested the minimum rate of return to be 100% [30–32]. Accordingly, in the present study, a 100% minimum acceptable marginal rate of return was considered.

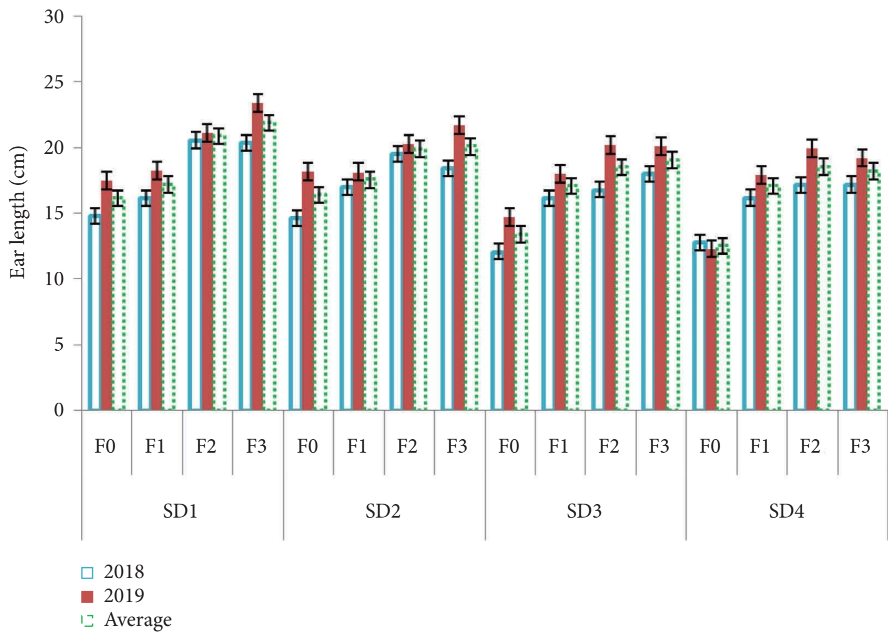
## 3. Results and Discussion

### 3.1. Maize Agronomic Performance Analysis

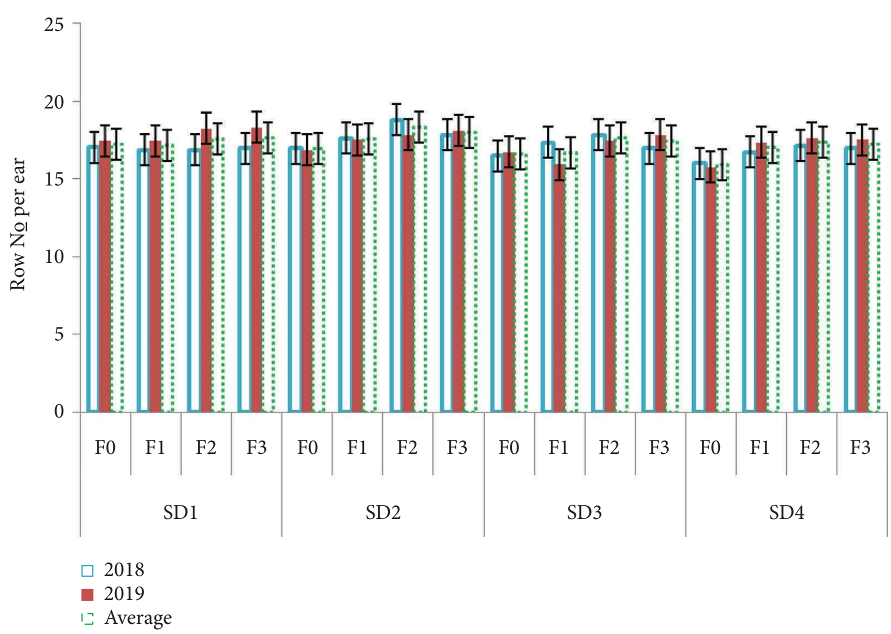
*3.1.1. Ear Length, Number of Rows, and Kernel Number per Row.* In this study, the combined analysis results of the two consecutive experimental years indicated that yield contributing attributes, namely, ear length, number of rows per ear, and kernels number per row, were significantly affected by maize seed sowing dates and multinutrient fertilizer application levels (Figure 2). Ear length was significantly affected due to seed sowing dates and multinutrient fertilizer applications, which varied from 12.78 cm to 20.58 cm and from 12.31 to 23.40 cm in 2018 and 2019 cropping seasons, respectively. The highest ear lengths, 20.58 cm in 2018 and 23.4 cm in 2019 cropping seasons, were recorded from SD1F3 treatment combinations. The pooled data recorded from both experimental years showed that each 1 cm round ear length contains almost 39 kernels; an ear scored an average of 855.6 kernels in 18.56 rows with which a row contains 46.1 kernels.

Due to variation in the sowing date and multinutrient fertilizer rates, a noticeable difference in the number of rows per ear, which ranged from 16 to 18.80 in 2018 and 15.76 to 18.32 in 2019, was obtained. Similarly, the sowing date and multinutrient fertilizer application rates affected the number of kernels per row ranging from 24.4 to 45.67 and 25.91 to 46.54 in 2018 and 2019 cropping seasons, respectively. The overall better values of ear length, row number per ear, and kernel number per row were recorded from early sown (SD1) experimental plots treated with $300\,kg{\cdot}ha^{-1}$ multinutrient fertilizer level. Conversely, the lower values were recorded from the late sown (SD4) plots with no fertilizer application. The differences between these values may have been due to treatment effects on the water and nutrient use efficiency, which could be affected by temperature and rainfall variability. This result is in agreement with the previous research reports elsewhere [5, 8, 18, 33–37] who reported that yield and yield components of maize were affected significantly due to shifts in the planting time under rain-fed conditions. Similarly, other researchers reported that delay in the sowing date decreases yield and yield components [6, 18, 37, 38], although extents of decrement depend on the level of fertilizer applied [37]. Charles et al. [10] and Ali et al. [19] reported that maize yield increased with the earliness of the sowing date and amount of nutrients applied as the earliness in the maize seed sowing date amplified the efficiency of the nutrient uptake.

*3.1.2. Ear Seed Weight, 100 Seed Weight, and Grain Yield.* According to the yearly and pooled data of the present study, maize grain yield, ear seed weight, and 100 seed weight were markedly influenced by the interaction effects of sowing dates and multinutrient fertilizer application levels (Figure 3). The pooled data of this experiment indicated that the

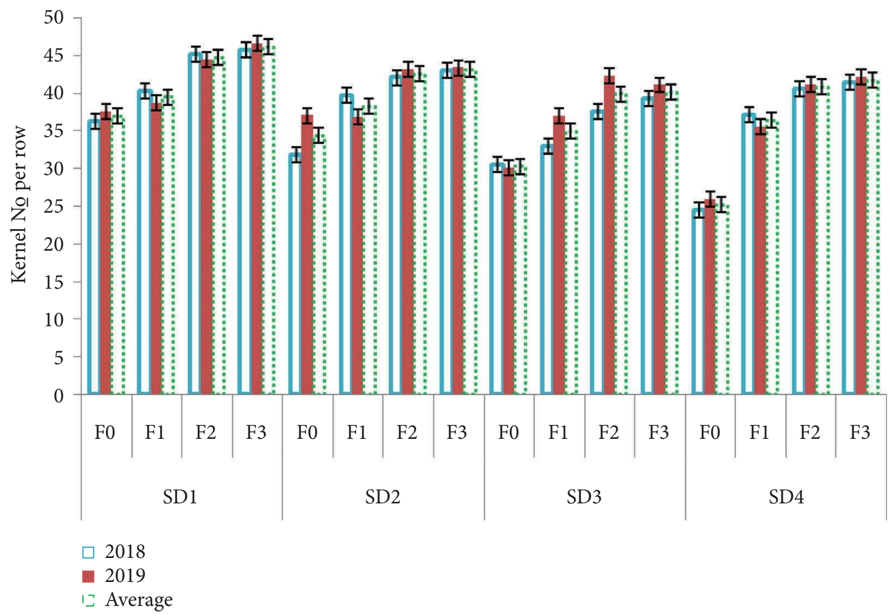



(a)




(b)

Figure 2: Continued.



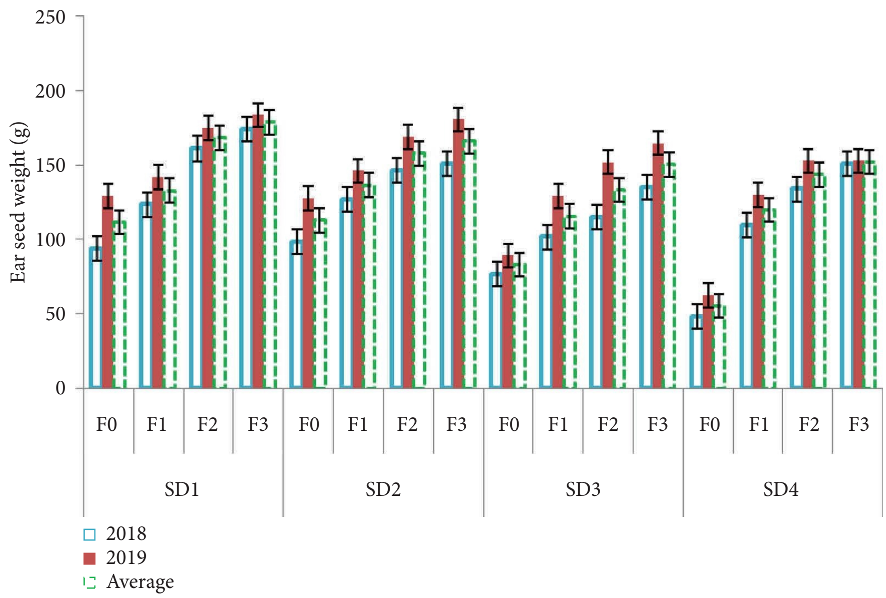

(c)

Figure 2: Effect of sowing dates as main plot and multinutrient fertilizer application levels in the subplot on ear length (a), number of rows per ear (b), and number of kernels per row (c) in two consecutive growing seasons in 2018-2019 and their average values. Vertical bars represent the standard error of the mean. The treatments are noted as SD1, sowing date 1 (June 1 in 2018 and May 26 in 2019); SD2, sowing date 2 (June 7 in 2018 and June 3 in 2019); SD3, sowing date 3 (June 12 in 2018 and June 8 in 2019); SD4, sowing date 4 (June 16 in 2018 and June 12 in 2019): F0, no fertilizer application; F1, 100 kg·ha$^{-1}$; F2, 200 kg·ha$^{-1}$; F3, 300 kg·ha$^{-1}$ multinutrient fertilizer levels.

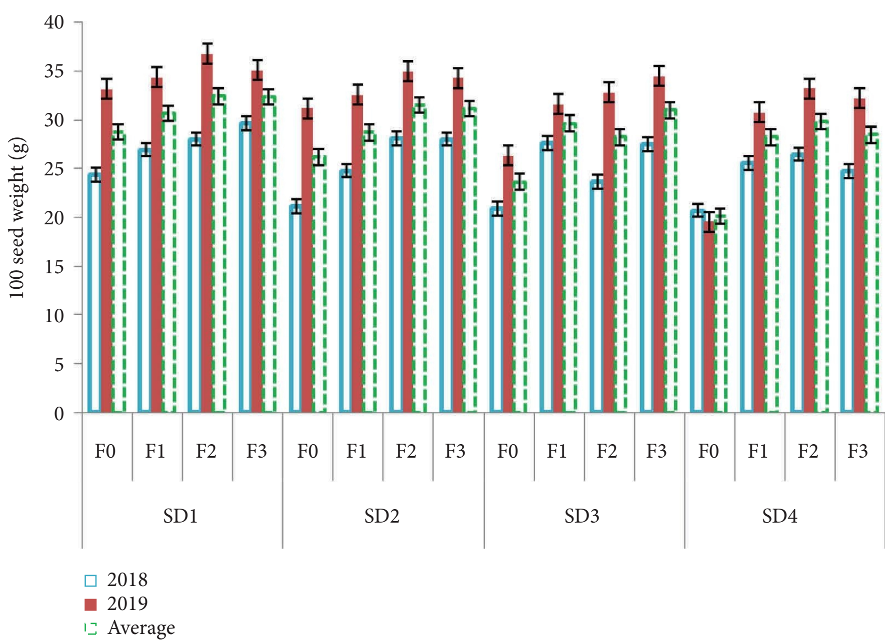
best treatment combination, SD1F3 (early sowing with 300 kg·ha$^{-1}$ multinutrient fertilizer levels), is the most superior by 60.78% in 100 grain weight, by 223.89% ear seed weight, and by 190.96% grain yield as compared to the lowest treatment combination, SD4F0 (late sowing date with no fertilizer application). Therefore, delay in the sowing date and lowering in multinutrient fertilizer application levels lead to a significant reduction in the rain-fed maize growth and yield. Such effects could be due to rainfall variability, lower air temperature during the maize establishment period as well as due to less multinutrient fertilizer application rate during the crop growing periods. Likewise, Charles et al. [10] reported that delay in the sowing date and lowering in fertilizer application levels cause significant reductions in maize seed yield due to decreasing rainfall amount and lowering of air temperatures.

Grain yield is mainly determined by kernel number, grain row number per ear, ear length, ear seed weight, and total grain weight. As a result, during this study, all these parameters' maximum values were reported in the early sowing with the higher level of multinutrient fertilizer application in which their cumulative effects increased the grain yield (Figures 2 and 3). Agronomically, the optimum integration of the sowing date and multinutrient fertilizer application level for higher maize yield were due to early sowing dates (01 June 2018 and 26 May 2019) combined with the relatively high multinutrient fertilizer application levels (300 kg·ha$^{-1}$). As a result of such treatments, the greatest maize yields of 9.18 tons·ha$^{-1}$ during 2019 and 8.71 tons·ha$^{-1}$ during 2018 cropping seasons were attained. This result is slightly higher than that of the report from research station (7.5–8 ton·ha$^{-1}$) and to a large extent as compared to the farmers' field (5.5–6.5 tons·ha$^{-1}$) as reported by Teklewold et al. [26]. This could be due to the better combination of the sowing date and multinutrient fertilizer levels. Significantly lower maize yield (3 tons·ha$^{-1}$ in 2018 and 2.75 tons·ha$^{-1}$ in 2019) was recorded when maize was sown late (16 June 2018 and 12 June 2019) with no fertilizer application in both cropping seasons.

The low yields in both experimental years recorded from lately sown (SD4) plots treated with no fertilizer application were likely due to the result of lower temperatures and intensive rainfall events in few days. Maize yield response to multinutrient fertilizer application levels in the late sown plots is also limited by high amounts of rainfall, which may lead to nutrient leaching from the root zone. This indicates that nutrient supply can limit maize yield to a greater extent than water supply alone. Maize yield response to planting date is very similar in different years and locations attributing yield benefits to early planting [39, 40]. Though maize yield pattern was similar in both years of the present study, grain yield was higher during 2019 than the 2018 cropping year, probably because of the better rainfall pattern observed during the 2019 cropping year and residual effects of the nutrients which were applied during the 2018 cropping season. Numerous publications have reported an increase in yield with early sowing and a reduction in yield when sowing is delayed after the optimum time [10, 18, 19, 33–35, 37, 41–48], implying an advantage of early sowing dates when combined with multinutrient fertilizer application.

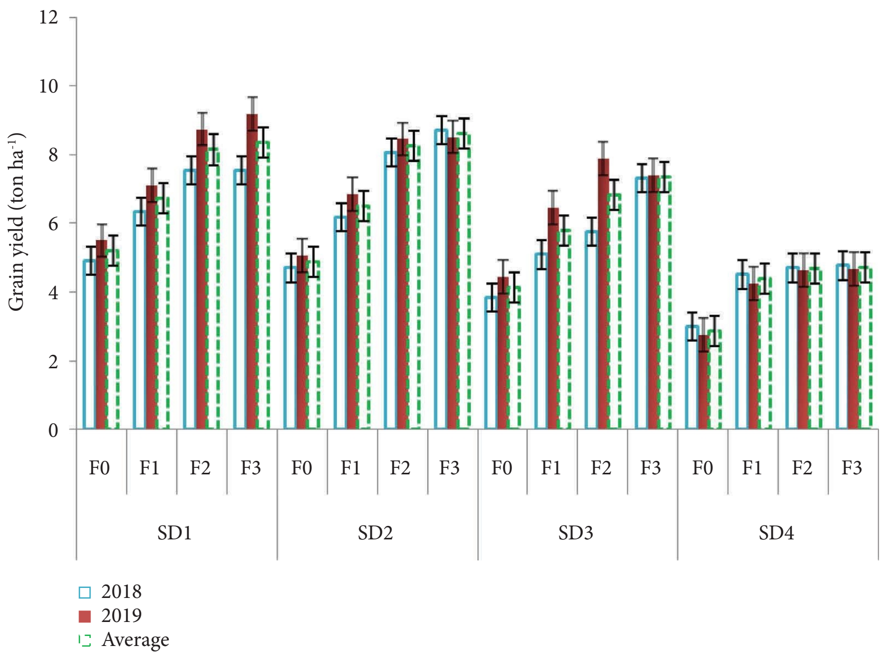



(a)




(b)

Figure 3: Continued.




(c)

Figure 3: Effect of sowing dates and multinutrient fertilizer application levels on ear seed weight (a), 100 seed weight (b), and grain yield (c) for the two consecutive growing seasons in 2018-2019 and their average values. Vertical bars represent the standard error of the mean. The treatments are noted as SD1, sowing date 1 (June 1 in 2018 and May 26 in 2019); SD2, sowing date 2 (June 7 in 2018 and June 3 in 2019); SD3, sowing date 3 (June 12 in 2018 and June 8 in 2019); SD4, sowing date 4 (June 16 in 2018 and June 12 in 2019): F0, no fertilizer application; F1, 100 kg·ha$^{-1}$; F2, 200 kg·ha$^{-1}$; F3, 300 kg·ha$^{-1}$.

*3.2. Relative Change in Yield Caused by a Change in Sowing Date and Multinutrient Level.* The effect of sowing dates and multinutrient fertilizer levels' application significantly affected the changes in maize yield. It was illustrated that an early planting date with a higher nutrient level increased significantly maize yield in both cropping seasons and their average values (Figures 3(c), 4 and 5). A delayed seed sowing date significantly reduced maize grain yield, as every 4–6 days' shift from earlier towards late sowing time decreased the grain yield by 4.9–66.9% and 5.7–48.4% in 2018 and 2019 cropping seasons, respectively (Figure 4). The highest yield, decreased by 66.9% in 2018 and 48.4% in 2019 cropping seasons, was observed by a change in the sowing date from SD1 to SD4. A shift of the sowing date from SD1 to SD2, SD1 to SD3, and SD1 to SD4 leads to an average maize yield decreased by 5.29, 19.28, and 34.0%, respectively, in both cropping seasons. Similarly, changing of the sowing date from SD2 to SD3, SD2 to SD4, and SD3 to SD4 decreased maize yield on average by 13.29, 27.28, and 12.35%, respectively.

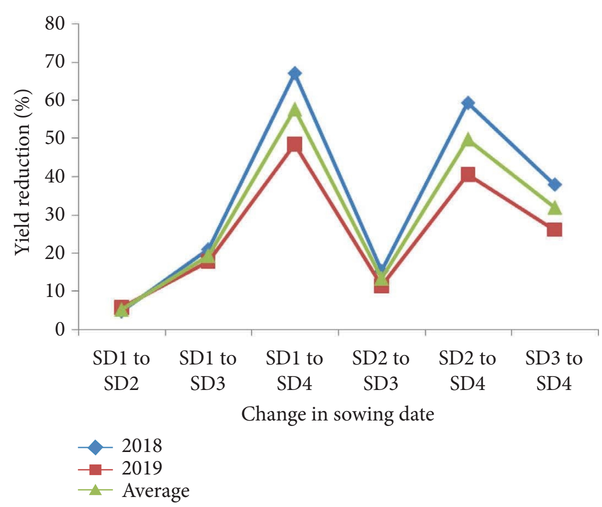



Figure 4: Relative grain yield decreased as a result of changes in the sowing date.

The delayed maize sowing date by six days from the first sowing date increased grain yield loss by 4.86% and 5.68% in the 2018 and 2019 cropping seasons, respectively. Correspondingly, when the sowing time was delayed by 15 days from the first sowing date, the respective yield loss was about 2.77 t·ha$^{-1}$ (66.9%) and 2.5 t·ha$^{-1}$ (48.44%) in 2018 and 2019 cropping seasons, respectively. Jiang et al. [42] found long-season maize hybrids with the highest yield when planted earlier. This implies that a delay in the sowing date could lead to a reduction in the grain yield due to the lowering of temperature, which could delay seed germination and retard crop growth [10]. On the other hand, intensive rainfall during seed sowing and fertilizer application period might lead to nutrient loss through runoff and leaching, causing significant grain yield reductions. Therefore, superiority of the early sowing date (SD1 and SD2) treatments resulted from relatively low amount of rainfall and higher

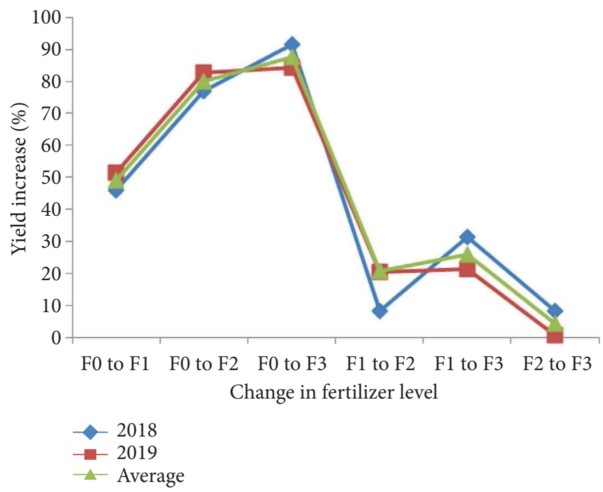



Figure 5: Relative grain yield increased due to changes in multinutrient fertilizer levels.

temperature, which was observed at the time of maize seed sowing and emergence. The beneficial effects of early seed sowing on maize yield are in agreement with earlier reports [10, 18, 19, 33–35, 37, 41, 43, 44, 46–48].

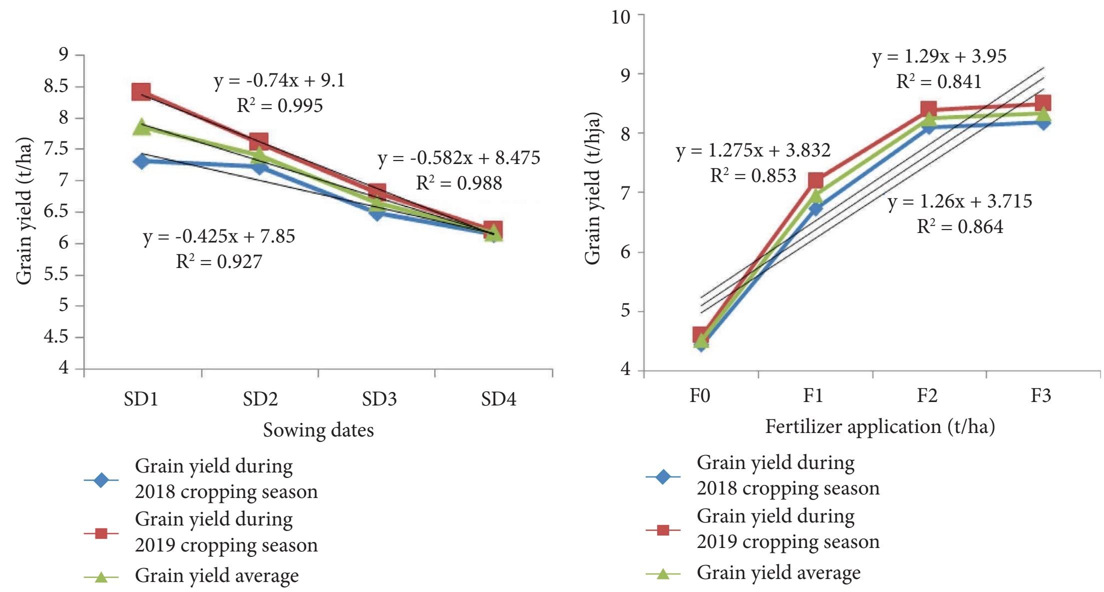
Fan et al. [49] reported that an increase in fertilizer nutrient input has made a significant contribution to the improvement of crop yields. Similarly, the present study reveals that increasing multinutrient fertilizer application levels from no application to the relatively higher rate significantly increased the maize yield. For instance, 300 kg·ha$^{-1}$ significantly increased the grain yield over the other treatments that range from 46.0 to 91.7% and 51.6–84.2% in 2018 and 2019 cropping seasons, respectively (Figure 5). Relative average yield superiority that varies between 48.9 and 87.7% was found for each 100 kg·ha$^{-1}$ multinutrient addition in both cropping seasons. The highest relative yield increase of 91.7% in 2018 and 84.2% in 2019 cropping seasons was observed by a change from no fertilizer to the 300 kg·ha$^{-1}$ multinutrient fertilizer application level. An increase in the multinutrient fertilizer level from F0 to F1, F0 to F2, and F0 to F3 leads to an average yield increase of 48.9, 80.0, and 87.8%, respectively, in both cropping seasons. Similarly, the increase in the multinutrient fertilizer application level from F1 to F2, F1 to F3, and F2 to F3 improved the yield on average by 20.9, 26.1, and 4.0%, respectively, in both cropping seasons. A lower average relative yield increase (4.03%) was recorded from a shift of 200 to 300 kg·ha$^{-1}$ multinutrient fertilizer application level, indicating that the application of the multinutrient fertilizer beyond 200 kg·ha$^{-1}$ is not expected to cause significant effects on maize yield. A similar effect of nutrient application levels on maize yield and its components was reported by [6, 8, 50–53].

*3.3. Yield Relationship with the Sowing Date and Multinutrient Application Level.* The regression analysis demonstrated significant contributions of seed sowing dates as well as multinutrient fertilizer application levels to the change in maize yield in both cropping seasons and their average yield values (Figures 6(a) and 6(b)). Grain yield showed very strong linear relationship with the seed sowing dates ($R^2$ = 0.923, 0.995, and 0.988 in 2018, 2019, and their average, respectively). Similarly, the relationship between maize yield and multinutrient fertilizer application levels showed strong linear relation ($R^2$ = 0.864, 0.841, and 0.853 in 2018, 2019, and their average, respectively). This indicated that any shift in sowing dates and/or multinutrient fertilizer application level strongly impacted the relationship with maize grain yield.

Maize yield tended to increase with the level of multinutrient fertilizer application, whereas it decreased with delay in sowing dates. Contribution of sowing dates to the maize yield increment was higher than the multinutrient fertilizer application level in both years and their average. Significantly highest $R^2$ values of 0.927 and 0.995 were recorded from the sowing date in 2018 and 2019 maize growing seasons, respectively (Figure 6(a)). Likewise, the maize yield also had a positive relationship with multinutrient application levels described with the $R^2$ values of 0.864 in 2018 and 0.841 in 2019 cropping seasons (Figure 6(b)). Though the sowing date rather than the multinutrient fertilizer application level tended more to enhance yield, the rise in the nutrient application level and earliness in the sowing date significantly increased the maize grain yield. Therefore, the identification of a proper seed sowing date could enhance the efficiency of nutrient uptake and ultimately result in a higher maize grain yield.

Maize yield varied with the date of sowing and multinutrient fertilizer application rates with a tendency of yield reduction when the sowing date is too late. Results of the present study suggested that in both experimental seasons, there was an increasing trend in maize yield as the multinutrient fertilizer application level increased from 0 to 200 kg·ha$^{-1}$multi-nutrient level, while it starts to decrease with an increasing fertilizer level beyond this rate (Figure 6(b)).

*3.4. Economic Performance Analysis.* The comprehensive economic performance analysis of the treatments evaluated based on the partial budget analysis for both cropping seasons is presented in Table 2. A higher net income was obtained from the early sown (SD1) plots treated with 200 and 300 kg·ha$^{-1}$ multinutrient fertilizers. A higher net income was obtained in 2019 than that obtained in the 2018 cropping season, perhaps due to the better rainfall reliability in 2019 than in the 2018 cropping season. A higher net income of 2098 USD and 2080 USD was obtained from early sown maize (SD1) with 200 kg·ha$^{-1}$ and 300 kg·ha$^{-1}$ multinutrient fertilizer applications, respectively, in 2019, while the corresponding values in 2018 cropping season were 1918 USD and 1957 USD. The significantly lowest net income was recorded from late sown (SD4) plots treated with no fertilizers in both cropping seasons. Net income was consistently enhanced with an increase in the multinutrient fertilizer application level from 0 kg·ha$^{-1}$ to 200 kg·ha$^{-1}$multi-nutrient fertilizer applications, while




(a) (b)

FIGURE 6: Regression analysis: maize yield relationship with sowing dates (a) and multinutrient fertilizer application levels (b). The black-coloured straight lines indicate the linear trend line.

TABLE 2: Marginal rate of return (MRR) and dominance analysis of treatment effects.

| Treatments | | Gross income | | Total varying cost | | Net income | | Net income over control | | MRR (%) | | Dominance analysis (%) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2018 | 2019 | 2018 | 2019 | 2018 | 2019 | 2018 | 2019 | 2018 | 2019 | 2018 | 2019 |
| SD1 | F0 | 1,228 | 1,437 | 0.00 | 0.00 | 1,228 | 1,437 | — | — | — | — | — | — |
| | F1 | 1,614 | 1,855 | 130.60 | 130.60 | 1,484 | 1,724 | 256 | 287 | 196.00 | 220.00 | 196 | 220 |
| | F2 | 2,105 | 2,286 | 187.45 | 187.45 | 1,918 | 2,098 | 690 | 661 | 368.20 | 352.87 | 763.78 | 658.11 |
| | F3 | 2,275 | 2,398 | 318.05 | 318.05 | 1,957 | 2,080 | 729 | 643 | 229.32 | 202.22 | 30 | −14[d] |
| SD2 | F0 | 1,283 | 1,324 | 0.00 | 0.00 | 1,283 | 1,324 | — | — | — | — | — | — |
| | F1 | 1,659 | 1,789 | 130.60 | 130.60 | 1,528 | 1,659 | 246 | 334 | 188.00 | 256.00 | 188 | 256 |
| | F2 | 1,972 | 2,210 | 187.45 | 187.45 | 1,785 | 2,022 | 502 | 698 | 267.87 | 372.38 | 451.35 | 639.73 |
| | F3 | 2,105 | 2,225 | 287.32 | 287.32 | 1,818 | 1,938 | 535 | 614 | 186.36 | 213.64 | 33.38 | −84.31[d] |
| SD3 | F0 | 1,003 | 1,162 | 0.00 | 0.00 | 1,003 | 1,162 | — | — | — | — | — | — |
| | F1 | 1,330 | 1,690 | 149.04 | 149.04 | 1,180 | 1,541 | 177 | 379 | 119.07 | 254.02 | 119.07 | 254.02 |
| | F2 | 1,502 | 2,064 | 205.89 | 205.89 | 1,296 | 1,858 | 293 | 695 | 142.31 | 337.69 | 203.24 | 557.03 |
| | F3 | 1,648 | 1,930 | 367.22 | 367.22 | 1,281 | 1,563 | 278 | 401 | 75.69 | 109.12 | −9.33[d] | −182.57[d] |
| SD4 | F0 | 784 | 718 | 0.00 | 0.00 | 784 | 718 | — | — | — | — | — | — |
| | F1 | 1,178 | 912 | 149.04 | 149.04 | 1,029 | 763 | 245 | 44 | 164.64 | 29.69 | 164.64 | 29.69 |
| | F2 | 1,228 | 1,081 | 224.33 | 258.13 | 1,003 | 823 | 220 | 105 | 97.95 | 40.65 | −34.08[d] | 55.63 |
| | F3 | 1,246 | 1,118 | 336.49 | 336.49 | 909 | 781 | 126 | 63 | 37.40 | 18.77 | −83.70[d] | −53.33[d] |

Returns and costs (USD).

[d], dominated treatment; USD, United States dollar.

a decreased trend in the net income was observed beyond this level. This implies that the application of the multinutrient fertilizer rate beyond 200 kg·ha$^{-1}$ seemed uneconomical for farmers.

Irrespective of the multinutrient fertilizer level applied, average net income was consistently decreased with delays in the maize seed sowing date in both cropping seasons. This implies that sowing dates have noticeable effects on the net benefit from maize yield. Therefore, in the present study, when mineral fertilizer is costly, better net income could be achieved using early seed sowing integrated with 200–300 kg·ha$^{-1}$ multinutrient fertilizer applications levels. However, considering the marginal rate of return (MRR), the highest values of 372.38% from the second sowing date (SD2) treated with the 200 kg·ha$^{-1}$ multinutrient fertilizer application level in 2019 and 368.20% from the first sowing date (SD1) treated with the 200 kg·ha$^{-1}$ multinutrient fertilizer application level in 2018 were reported.

Smallholder farmers prefer low cost of production with high income, and thus, it is necessary to conduct the stepwise treatment comparison (also known as dominance analysis). The MRR in dominance analysis showed the additional benefit accrued by changing from one treatment to the other in the order of increasing costs. The result of the dominance analysis indicated that higher marginal rates or returns of 763.78% during 2018 and 658.11% during 2019 cropping seasons were recorded from the early sown maize seeds (SD1) with the 200 kg·ha$^{-1}$ multinutrient fertilizer application level. In the 2019 cropping season, the sowing dates treatments received with the 300 kg·ha$^{-1}$ multinutrient fertilizer level were dominated and resulted in a rate of return below the farmer's minimum acceptable rate of return (100%). Similarly, in the 2018 cropping season, plots treated with the third sowing date with the 300 kg·ha$^{-1}$ multinutrient fertilizer level and fourth sowing date with 200 and 300 kg·ha$^{-1}$ multinutrient fertilizer levels were clearly dominated and scored negative returns.

In maize production, by changing the level of multinutrient fertilizer application from 100 to 200 kg·ha$^{-1}$ in the first and second sowing dates, for each 1 USD·ha$^{-1}$ on average, invested farmers can recover 1 USD plus an extra 6.58–7.64 USD·ha$^{-1}$ and 4.51–6.40 USD·ha$^{-1}$ net return, for the respective sowing dates. Similar results were reported by Tamene et al. [54]. On the other hand, the application of 300 kg·ha$^{-1}$ multinutrient fertilizer in the late sown treatments (SD3 and SD4) resulted in negative returns in both cropping seasons. Regardless of the maize seed sowing dates, changing in the multinutrient fertilizer application level from 200 to 300 kg·ha$^{-1}$ level makes a farmer to loss from 0.09 to 1.82 USD ha$^{-1}$ for each 1 USD invested. The marginal and dominance analysis results of the two consecutive experimental years clearly suggested that maize production using the first and second sowing dates integrated with the 200 kg·ha$^{-1}$ multinutrient fertilizer application rate was found to be economically profitable treatment combinations for maize growing under the rain-fed condition. Hence, this treatment is recommended for further demonstration at farmers conditions in the condition of the study site.

## 4. Conclusion

This study showed that an appropriate amount of multinutrient fertilizer application can not only be a guarantee for higher maize yield, but optimizing the seed sowing date could also be crucial for getting the best maize yield. Hence, their combined effects are more important than the separate impacts. The results of the two consecutive experimental years confirmed that maize yield and yield components were significantly affected by the dates of seed sowing and multinutrient fertilizer application levels. Grain yield reduces with a delay in the sowing date and lowering in soil fertility levels. The correct seed sowing time did not only adjust proper plant growth but also enabled the plants to utilize the nutrients efficiently. The implication of this experiment is that rain-fed maize is sensitive to sowing dates and multinutrient application, and thus, optimizing the multinutrient fertilizer application level in conjunction with the proper timing of seed sowing markedly improved the maize yield. The early sowing date (SD1) of maize at an adequate nutrient level (200 kg·ha$^{-1}$) contributes to having better maize yields in both cropping seasons. Maize yield reduces with delays in sowing dates due to the lowering of temperature and short duration of the intensive rainfall. Early sown maize has a better positive response to multinutrient fertilizer application rates than the late sowing dates. During the late seed sowing, it has less importance to apply inorganic fertilizers. Each 4–6 days' delay in the sowing date and 100 kg·ha$^{-1}$ reduction in the multinutrient fertilizer application level resulted in a noticeable maize yield loss. In both cropping seasons, the highest grain yield was observed at the first sowing date treated with a higher level of multinutrient fertilizer (300 kg·ha$^{-1}$). However, from the economic point of view, early sowing (SD1) combined with the 200 kg·ha$^{-1}$multi-nutrient fertilizer application level is the most profitable practice. Therefore, the sowing date and nutrient application level are critical factors for achieving higher maize yield and better economic benefit. On the basis of this experimental result, early maize seed sowing (SD1) with the 200 kg·ha$^{-1}$ multinutrient rate is recommended for further demonstration at farmers' field conditions across many locations in the conditions of the study site.

## Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

## Conflicts of Interest

The authors declare that they have no conflicts of interest.

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