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Tillage Methods and Inorganic Nutrients Source's Interactive Effects in Maize and Beans Performance

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Abstract

Maize and bean production have been on a declining trend in the majority of households in sub-Saharan African nations, Kenya inclusive. To improve the production of these crops, the current study aimed at assessing the interactive effects of minimum tillage and conventional tillage coupled with inorganic nutrient sources. The experiment was laid under a split-plot arrangement in a randomized complete block design where the tillage methods comprised the main plots whereas the sub plots were occupied by five inorganic fertilizers: NK, NP, KP, NPK, and NPK+Zn+B+Mg+Ca+S. The results indicated maize growth, yields, and chlorophyll concentration were significantly higher under minimum tillage and the combination of NPK+Zn+B+Mg+Ca+S nutrients. In addition, there was a significant effect on the interaction of tillage and inorganic nutrients on maize growth, yields, and chlorophyll concentration. The study, therefore, recommends the use of a combination of NPK+Zn+B+Mg+Ca+S in minimum tillage as viable options for optimal growth and production of maize and beans.

Keywords: Minimum tillage; Conventional tillage; Conservation agriculture

Abbreviations: CA: Conservation agriculture; SR: Short Rains; LR: Long Rain; UM: upper midlands

Introduction

Soil degradation on the small farms in Africa is the primary reason for the consistent decrease in crop production, which cannot guarantee food security [1]. There have been low production levels that have reduced economic income and increased poverty in the rural [2,3]. The principal reasons for soil degradation in sub-Saharan Africa can be attributed to the continuous utilization of the inadequate methods of soil management including the burning of vegetative residues, excessive tillage, and mono-cropping [4,3]. Exposure of bare soil to climatic agents like high temperatures and high-intensity rains that accelerate the soil degradation process, rapid decomposition of biomass that favors erosion, and leaching of nutrients has contributed to low production [5]. Many farmers have tried to compensate for the low yields through increasing tillage and cropping regimes to meet basic household food requirements, but they have not fully achieved their potential [6]. In Kenya, deteriorated soils, lack of adequate nutrients, and increased soil erosion are among the obstacles to small-scale farmers from reaching their production potential [7,5,8-11]. The central highlands of Kenya suffer from insufficient rains and degraded soils [12]. With a growing population to feed, there is the need to develop techniques that will utilize the available water adequately and protect the soils from deterioration to ensure food security for the region and the country at large [13]. Paudel et al. [6] state that Conservation Agriculture spearheads an alternative to farming that can make an increasing contribution to sustainable food production. The conventional tillage system is unable to deliver cost-effective environmental services due to high externalities like climate change and the inability to serve the needs of resource-poor farmers [14]. Further, many organizations are promoting conservation agriculture since it has a set of principles and practices that can contribute to sustainable agricultural production [15]. It addresses missing components in the intensive tillage-based, standardized seed-fertilizer-pesticide approach to agriculture. In Kenyan highlands, farmers are faced with problems of low maize and bean yields and a decline in soil fertility [12,16,17]. This is a result of continuous cropping, nutrient loss through crop harvests, and the inability to replenish the soils by the use of expensive external inputs. To reverse the current trend of soil fertility depletion and low maize productivity, there is an urgent need to develop effective strategies for sustainable maize production intensification based on balanced nutrient management and crop residue management. Conservation agriculture (CA), based on reduced tillage and surface retention of crop residues offers smallholder farmers in Sub-Saharan Africa an opportunity to reverse land degradation and support the sustainable intensification of crop production (Raed, 2002).

Despite the importance of nutrient management for crop yield and residue productivity under the CA system, very limited scientific knowledge has been developed in Kenya to improve the understanding of nutrient efficiencies and dynamics under conservation agriculture [13] Nutrient management recommendations used are often those developed for CT systems, without adjustments to change in tillage and residue management system under CA. Effective nutrient management involves the development of site-specific nutrient recommendations including the balanced application of nitrogen, phosphorous, and potassium, micronutrients at the optimum rates, and application of the nutrients at the right time and place (MoA, 2010). Balanced fertilization is key to achieving higher productivity and nutrient use efficiency [18- -20]. Correction of soil pH through liming significantly improves crop productivity and leads to nutrient use efficiency and profitability under variable soil fertility conditions. In addition, balanced NPK fertilization is an important entry point for increasing yields. Although much focus has been placed on N, the agronomic efficiency of applied N can be largely increased by adequate P and K fertilization. Deficiencies of secondary and micronutrients, especially S, Mg, and Zn are increasingly being observed in dominant Kenya soils [13,10,11]. Conservation agriculture is one of the options for the farmers as it can halt and reverse land degradation and boost agricultural productivity leading to food security [21]. Nevertheless, there is limited information on the effects of interactions of inorganic nutrients on soil and crop performance under conservation agriculture. Thus, there is a need to supply macronutrients and micronutrients for plant growth and adjust fertilizer applications to fit the soil fertility status and minimum tillage practices. The purpose of the study was, therefore, to investigate the interactive effects of inorganic nutrients on soil and crop performance on both conservation and conventional al tillage practices.

Materials and methods

Study description

The study was conducted at the Kenya Agricultural and Livestock Research Organization-Embu in Embu County farm on the eastern slopes of Mt. Kenya at 00°33.18'S; 037°53.27'E; 1420m and in the upper midlands (UM3) zone. The region experiences an average annual rainfall of 250mm in a bimodal pattern with the long rains (LR) lasting from March to August and the short rains (SR) from October to January. About 65% of the rains come during the LR and in some years end in July–August with scanty showers. The maximum temperature ranges from 21ºC to 28ºC whereas the minimum temperatures range between 16 and 21ºC. The dominating soil type is Humic Nitisols characterized by moderate to high inherent fertility due to their high minerals, water and cation exchange capacity levels. However, over the years, fertility has declined due to inappropriate soil management and nutrient depletion. Such soils have their physical and chemical properties modified by cropping frequency, nutrient application, and residue return [12]. The area farming system is mainly of dairying and growing medium maturity maize and field beans.

Experimental design and treatments

A field station experiment was established in KALRO-Embu. The experiment consisted of five treatments with plots measuring 10 m and 10 m. The design was a randomized complete block design with a split-plot arrangement; the main plots were minimum tillage and conservation agriculture while the subplot consisted of different fertilizer inputs of NK, NP, KP, NPK, and NPK+Zn+B+Mg+Ca+S, respectively. The treatments were replicated three times at the site giving thirty plots. For each field, a field map indicating the experimental layout of key features or landmarks was drawn with the plot numbers clearly shown. The experiment was conducted for two growing seasons with the test crops being maize hybrid (DK 8031) and a newly released common bean variety, Embean 14. Maize was planted at a space of 75 cm by 25 cm and beans were planted at 45 cm by 5cm. Maize was planted during the long rains (April rains) and then rotated with the bean during the short rains that start in October.

Data collection

Maize and bean parameters that were considered were growth (chlorophyll concentration, days to tussling and flowering, number of leaves per plant) and yields (dry biomass and grain yields). Harvesting was done at the maturity stage per sub-plot leaving two outer lines around the sub-plot. The plants were cut at ground level and weighed using weighing balances. Grains were sundried and then threshed manually; a sample was drawn and taken to the laboratory for oven drying at 65ºC for 48 hours. The total grain and stover yields were determined on a ton per ha basis.

Results

Interactive effects of tillage and inorganic nutrients on maize growth, yields, and chlorophyll concentration at 100 days after emergence

Chlorophyll concentration was high at 100 days than at 60 days (Table 1). The results show that the interaction of minimum tillage and NPK+Zn+B+Mg+Ca+S>NPK>NP>NK>PK inorganic nutrients gave the highest to the lowest Soil Plant Analysis Development (SPAD) reading, respectively on 100 days compared to the same treatment interacting with convention practices. At 100 days, the interaction was only significantly different at the interaction of

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NPK and the combination of NPK+Zn+B+Mg+Ca+S in conservation agriculture. It was also observed that chlorophyll concentration was high on all treatments that had N. Further, the interactions with conservational tillage had the highest results for chlorophyll.

Table 1: Interactive effects of tillage type and inorganic nutrients on maize growth and yields.

Tillage* Fertility	Chlorophyll at 100 days	Days to 50% tasselling	Maize height at harvest(M)	Leaf area index (LAI)	No. of days to physiological maturity	Dry weight Stover (t/ha)	Dry weight grains (t/ha)
CA* NPK+Zn+B+Mg+-Ca+S	66.57^{a}	76.67^{e}	2.54^{a}	8.63^{a}	144.67^{d}	8.80^{a}	4.18^{a}
CT* NPK+Zn+B+Mg+-Ca+S	59.33^{bc}	80.33^{cd}	2.42^{ab}	8.23^{ab}	149.00^{ab}	8.20^{b}	3.57^{bc}
CA* NPK	61.47^{b}	79.67^{d}	2.45^{ab}	8.23^{ab}	147.33^{bc}	7.93^{bc}	3.83^{b}
CT* NPK	60.57^{bc}	82.67^{c}	2.29^{bc}	7.80^{b}	150.33^{ab}	7.57^{bc}	3.20^{cd}
CA* NK	60.17^{bc}	82.33^{c}	2.31^{bc}	6.93^{d}	150.67^{ab}	7.53^{c}	3.37^{c}
CT* NK	59.10^{bc}	84.33^{ab}	2.14^{c}	7.10^{cd}	149.67^{ab}	6.43^{d}	2.90^{de}
CA* NP	59.90^{bc}	81.67^{c}	2.52^{a}	7.20^{bc}	148.00^{cb}	7.07^{cd}	3.67^{bc}
CT* NP	58.63^{bc}	84.33^{ab}	2.03^{d}	6.63^{d}	151.33^{ab}	6.87^{cd}	3.01^{d}
CA* PK	59.37^{bc}	83.67^{bc}	2.42^{ab}	6.97^{d}	149.00^{ab}	6.63^{d}	2.77^{de}
CT* PK	57.50^{c}	86.00^{a}	2.11^{cd}	6.57^{d}	153.33^{a}	5.83^{e}	2.60^{e}
Mean	60.26	82.17	2.32	7.43	149.33	7.286	3.315
CV (%)	3.494	1.356	4.75	5.354	1.053	2.832	5.29
LSD (0.05)	3.438	1.82	0.18	0.65	2.569	0.595	0.356
P-value	0.049	0.039	0.044	0.013	0.003	0.035	0.019

Days to tasseling and days to maturity of maize

There was a significant difference in the interaction of minimum tillage and inorganic nutrients on days to tasseling. Days to tasseling were found slightly less in plots with minimum tillage and NPK+Zn+B+Mg+Ca+S (76.67 days) as compared to convention tillage and NPK+Zn+B+Mg+Ca+S (80.33 days) (Table 1). However, inorganic nutrients of NPK, NP, NK, and PK in the two tillage practices did not have any significant difference (Table 1). Effects of interaction between the inorganic nutrient application and tillage type on days to maturity were significant. The crop matured much early in the interaction between CA and NPK+Zn+B+Mg+Ca+S (144.67 days). There was no significant difference in the interaction of the two the tillage and NP, NK, PK.

Plant height and leaf area index

The effect of interaction between tillage practices and inorganic nutrients had a significant difference in the maize plant height ($p \leq 0.044$) (Table1). The plant height was highest (2.54m) in the interaction between MT and NPK+Zn+B+Mg+Ca+S. The rest of the interactions were not significantly different. The interaction between tillage and fertility had a highly significant effect $p \leq 0.013$ on the leaf area index. The highest leaf area index was recorded for interaction between minimum tillage and NPK+Zn+B+Mg+Ca+S at 8.23. There was no significant difference between NPK, NP, NK, and PK in both convention tillage and minimum tillage. However, there was a significant difference between NPK+Zn+B+Mg+Ca+S in all tillage systems.

Dry weight grains

Dry weight Stover was significant under minimum tillage and the combination of NPK+Zn+B+Mg+Ca+S nutrients ($p \leq 0.035$) (Table1). There was a significant difference between convention tillage and NPK+Zn+B+Mg+Ca+S. NPK. NP, NK, PK nutrients were not significantly different. There was a significant interaction between minimum tillage and the combination of NPK+Zn+B+Mg+Ca+S as it registered the highest weight (8.80t) and was followed by the NPK (7.93t) in minimum tillage while in CT NPK+Zn+B+Mg+Ca+S recorded 8.20 t while NPK 7.57t thus showing minimum tillage had performed better than convention tillage. However, the treatment of NP, NK, and PK in all tillage systems was not significantly different. Regarding dry weight grains, there was a significant difference when using different tillage methods and fertilizers. In the treatment in which there was NPK+Zn+B+Mg+Ca+S and minimum tillage, the performance was the best as it recorded the highest weight (4.18t) while the same treatment under CT had 3.57t. NPK and NP under minimum tillage didn't have any significant difference and also the treatment of all nutrients under convention tillage. The rest of the treatments had no significant difference while PK of the convention tillage had the lowest weight on both sides 2.77t MT and 2.53t CT respectively. There was a significant interaction between the tillage systems and inorganic nutrients.

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Interactive effects of tillage and inorganic nutrients on bean growth and yields

There was a significant effect on the interaction of tillage and inorganic nutrients on chlorophyll concentration. The chlorophyll concentration on both tillages showed an increasing trend from 15>45>75 days after emergence. However, the interaction at 75 days showed the greatest concentration of chlorophyll concentration. At 15 days, the interaction between chlorophyll and tillage showed a significant difference in a combination of minimum tillage and NPK+Zn+B+Mg+Ca+S. The combination of NPK, NK, NP, and KP did not show any significant difference under minimum tillage. NK, NP, and KP under conventional tillage showed a significant difference from the rest of the interaction but chlorophyll concentration was low. On the number of days to flowering, there was a significant effect of the interaction of tillage and inorganic nutrients. The bean that was grown on the combination of minimum tillage and NPK+Zn+B+Mg+Ca+S recorded the lowest number of days to flowering (50.33 days) (Table 2). This was significantly different from all other combinations of inorganic nutrients and the tillage method. It was closely followed by NPK under minimum tillage (52.00 days). The remaining interaction did not show any significant difference. On the number of branches of the bean plant, there was no significant effect of either the tillage system or any inorganic nutrients. Finally, there was a significant difference in the height of the bean plant. The highest height was recorded in an interaction between the minimum tillage and NPK+Zn+B+Mg+Ca+S (0.313M) (Table 2). The remaining interaction of fertility and the minimum tillage system didn't show any significant difference.

Table 2: Interactive effects of tillage type and inorganic nutrients on bean growth and yield.

Tillage* Fertility	Chlorophyll at 100 days	Days to 50% tasselling	Maize height at harvest(M)	Leaf area index (LAI)	No. of days to physiological maturity	Dry weight Stover (t/ha)	Dry weight grains (t/ha)
CA* NP-K+Zn+B+Mg+-Ca+S	66.57^{a}	76.67^{e}	2.54^{a}	8.63^{a}	144.67^{d}	8.80^{a}	4.18^{a}
CT* NP-K+Zn+B+Mg+-Ca+S	59.33^{bc}	80.33^{cd}	2.42^{ab}	8.23^{ab}	149.00^{ab}	8.20^{b}	3.57^{bc}
CA* NPK	61.47^{b}	79.67^{d}	2.45^{ab}	8.23^{ab}	147.33^{bc}	7.93^{bc}	3.83^{b}
CT* NPK	60.57^{bc}	82.67^{c}	2.29^{bc}	7.80^{b}	150.33^{ab}	7.57b^{c}	3.20^{cd}
CA* NK	60.17^{bc}	82.33^{c}	2.31^{bc}	6.93^{d}	150.67^{ab}	7.53^{c}	3.37^{c}
CT* NK	59.10^{bc}	84.33^{ab}	2.14^{c}	7.10^{cd}	149.67^{ab}	6.43^{d}	2.90^{de}
CA* NP	59.90^{bc}	81.67^{c}	2.52^{a}	7.20^{bc}	148.00^{cb}	7.07^{cd}	3.67^{bc}
CT* NP	58.63^{bc}	84.33^{ab}	2.03^{d}	6.63^{d}	151.33^{ab}	6.87^{cd}	3.01^{d}
CA* PK	59.37^{bc}	83.67^{bc}	2.42^{ab}	6.97^{d}	149.00^{ab}	6.63^{d}	2.77^{de}
CT* PK	57.50^{c}	86.00^{a}	2.11^{cd}	6.57^{d}	153.33^{a}	5.83^{e}	2.60^{e}
Mean	60.26	82.17	2.32	7.43	149.33	7.286	3.315
CV (%)	3.494	1.356	4.75	5.354	1.053	2.832	5.29
LSD (0.05)	3.438	1.82	0.18	0.65	2.569	0.595	0.356
P-value	0.049	0.039	0.044	0.013	0.003	0.035	0.019

There was a significant effect on the interaction of inorganic nutrients and the tillage system on the number of seeds per pod $p \leq 0.048$, biomass weight $p \leq 0.029$, and dry weight grains $p \leq 0.019$, (Table 2). Concerning the number of seeds per pod, the interaction of the NPK+Zn+B+Mg+Ca+S and minimum tillage had a higher number of 5.40 seeds per pod closely followed by the same inorganic nutrients under conventional tillage 4.93 seeds per pod, and they were significantly different. The number of pods per plant that was recorded under the interaction of NPK+Zn+B+Mg+Ca+S and minimum to tillage was highest (5.40 pods) while the same treatment under conventional tillage had 4.93 pods respectively. The interaction between minimum tillage and NPK+Zn+B+Mg+Ca+S had the highest weight (3.17 t/ha) while the same treatment in conventional tillage had (3.06 t/ha) of dry biomass of the bean. NPK+Zn+B+Mg+Ca+S ≥ NPK did not have a significant effect in both tillages. In both interactions, PK and either tillage did record the lowest amount of biomass 0.62 t/ha in minimum tillage and 0.51 t/ha in conventional tillage. The other combination where one of the macronutrients was omitted did not have any significant difference. For the dry weight,

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NPK+Zn+B+Mg+Ca+S and minimum tillage had the highest dry weight of the grains (1.98 t/ha) while the same treatment under conventional tillage had 1.78 t/ha. NPK on both tillage systems was significantly different and registered 1.76 t/ha in minimum tillage and 1.56 t/ha in conventional tillage. The interaction of NP and NK in both tillage systems had a lower amount of dry grains. KP recorded the lowest weight 0.62 t/ha in minimum tillage and 0.51 t/ha in conventional tillage respectively.

Discussion

Interactive effects of tillage and inorganic nutrients on maize growth and yields

The high chlorophyll concentration in minimum tillage could be due to the soil residue of the maize crop that ensured adequate moisture content in the ground that can be absorbed by the plant. As a result, the nutrients received more soil water to dissolve into a solution form thus making them available for easy absorption by the plant. Residues increased soil fertility by favoring microbial activities that acted on the organic matter that in turn increased available nutrients for uptake [22]. The reason for early tasselling with the interaction between MT and NPK+Zn+B+Mg+Ca+S could be due to better root development. There was a minimal disturbance on the roots and minimized exposure of the soil to evaporation by cultivation. Further, the presence of macro and micronutrients that were applied facilitated plants' faster growth because it obtained most of the nutrients for rapid plant growth and development thus early tasselling. The other combination had no significant difference because of the stress of one of the macronutrients and adequate micronutrients thus slow growth.

The late maturity can be explained by the unavailability of one of the macronutrients and adequate micronutrients thus slow growth input in all treatments except for PK which lacked N that facilitates vegetative growth [23]. The availability of balanced nutrition increased photosynthesis while minimum tillage increased the water holding capacity of the soil thus early maturity [24]. The leaf length can be explained by the enriched nutrient that led to the vigorous growth of the crop regarding gain in plant height and a higher number of functional leaves per plant. Nitrogen application increased cell division, cell elongation, nucleus formation as well as green foliage. An increase in leaf length may also be due to prolonged vegetative growth, which might have increased the leaf length. Shorter plants under N, P, and K deficiency might have been due to their effects on cell elongation, photosynthesis, water uptake as well as cell division [25-27]. Further, MT had more water holding capacity and little root disturbance thus explaining the high plant height. The leaf canopy and leaf expansion were improved in plants by giving optimum nitrogenous fertilizers and other macronutrients and secondary ones [28]. Leaf expansion was illustrated regarding leaf length and breadth though the numbers of leaves not affected nutrient application and tillage system.

The higher dry weight of cobs obtained in all treatments that had N might be due to a sufficient supply of nitrogen to the crop because nitrogen being an essential constituent of plant tissue is involved in cell division and cell elongation. Moreover, higher leaf area index values noticed in balanced nutrition mean the production of more photosynthates leading to an increase in grain number and weight of cobs. Additionally, the probable reason for the lesser dry weight of cobs was N deficiency in PK combination which reduced biomass production traits of the plant which could be primarily related to the dry weight of cob. The grain yield was significantly affected by inorganic nutrients. The different nutrient combinations significantly increased with N and the micronutrients the grain yield. The increase in grain yield reflects the better growth and development of the plants due to balanced and more availability of nutrients, which was associated with increased root growth due to which the plants explore more soil nutrients and moisture throughout the growing period [29].

Interactive effects of tillage methods and inorganic nutrients on bean growth and yields

Fertilizer input is vital for the growth of any crop. As such, the bean plant was highly affected by the type of inorganic nutrients supplied. The number of seeds in the pod where there was balanced can be attributed to the accumulation of required nutrients by the plant. This increased the size of pods thus giving room to accommodate more seeds. Further, since P is responsible for seed formation, it ensured that a maximum of the seeds was formed in the balanced nutrition. Further, micronutrients like Ca and Zn help in the metabolism of the plant thus health growth [30]. NPK closely followed it but the lack of micronutrients led to fewer seeds than CT. Finally, the rest of the nutrients where the deficiency of one of the macronutrients led to having fewer seeds. In addition, the number of pods was not significantly different in all nutrition. A long and short plant could have the same number of pods despite that their sizes could differ. This shows that nutrition did not affect the number of pods except this can be attributed to the genotypic characterization of the seed variety. Finally, nutrition had a direct impact on the dry weight of the grains. Balanced nutrition had the highest weight. This means the bean grew well thus gaining weight compared to the rest of the treatments [31].

The high performance of the bean in the interaction between minimum tillage and NPK+Zn+B+Mg+Ca+S could be explained by moisture availability due to the mulch, which reduced evapotranspiration, especially during the dry season during the growth cycle of the bean plant. In addition, the presence of macro and micronutrients, which are key to the growth of the bean, accelerated its growth and development. The moisture available ensured the applied fertilizer nutrients were in available forms for the plant uptake. In conventional tillage, the absence of residues and continuous cultivation led to the loss of soil water through evaporation, which made most of the bean plants wither before

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maturity. The other interactions of NPK, PK, NK, and NP with either conventional or minimum tillage may not have performed well because of the deficiency of one of the macronutrients and the absence of some of the micronutrients. However, the overall performance of the bean crop was not well because of the low rainfall distribution.

Conclusion

To overcome the challenge of land degradation and increase crop performance in Embu County, there is the need to embrace minimum tillage and use of NPK+Zn+B+Mg+Ca+S nutrients for enhancing soil fertility and improving crop yield for better productivity of maize and beans. Further, the use of inorganic fertilizers should be considered a driver of successful Minimum tillage practices in Embu County.

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