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Research article

Nutrient management options for enhancing productivity and profitability of conservation agriculture under on-farm conditions in central highlands of Kenya

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Abstract: Decline in soil fertility is one of the major constraints to sustainable crop production and profitability. To meet the increasing demand for the growing population the issue of low soil fertility needs to be addressed. An on-farm experiment was established to evaluate the effect of interaction between NPK fertilizers and minimum tillage on soil fertility, maize crop yield and on farm profit margins. The field trials were set up in a split-plot design organized in a randomized complete block design in 28 farmers' fields. Application of all the three macronutrients i.e. NPK had the highest and significant ($P < 0.0001$) yields relative to treatments, where any of the three nutrients was omitted. Maize grain yield increased by over 150% with NPK, NP and NK application in all the three cropping seasons over the control. Grain losses with the omission of a single nutrient were highest with N (2.06, 2.40 & 2.42 t ha^{-1}) followed by P (0.8, 0.59 & 0.43 t ha^{-1}) in the short rain 2014 (SR2014), long rains 2015 (LR2015) and SR2015 seasons, respectively. Conservation agriculture recorded a significant ($P < 0.0007$) increase in P over the three seasons. There was significantly higher K in the soil within the NP and PK treatments and in the conservation agriculture compared to the conventional agriculture systems. Compared with conventional tillage, the benefit to cost ratio was higher by 3 and 5% under minimum tillage during the LR2015 and SR2015 seasons, respectively. Total variable cost was 4 and 2% higher under conventional tillage compared to minimum tillage during the LR2015 and SR2015 seasons, respectively. Treatments with N and conservation agriculture were the most profitable. A combined use of conservation agriculture and all the three macro-nutrients (NPK) is the best bet for increasing, maize crop yield and associated return on investment.

Keywords: tillage; nutrient omission trials; economic returns; nutrient management

1. Introduction

Globally, the *per capita* arable land area will continue to decrease (it decreased from 0.415 ha in 1961 to 0.214 ha in 2007) while average cereal yield will need to increase by about 25% from 3.23 t ha^{-1} in 2005/07 to 4.34 t ha^{-1} by 2030 [1,2]. Currently, sub Saharan Africa (SSA) is amongst the (sub) continents with the largest gap between cereal consumption and production, whereas its projected tripling demand between 2010 and 2050 is much greater than in other regions of the world. Narrowing yield gaps from the present 20% to 50% of water-limited maize yield in 2050 requires accelerated yield increase rates of about 72% (west SSA) and 64% (east SSA) kg ha^{-1} y^{-1} [3]. The population of Kenya is estimated to double to 96 million by 2050 and so is the food demand. There is therefore a need to develop strategies for enhancing yields at a global level, at SSA level and in Kenya.

The use of improved seeds, inorganic fertilizers and good agronomic practices are the pre-requisites for enhanced crop yields [4]. It is common for continuously cultivated soils to become non-responsive soils or soils that have been degraded to an extent that the application of NPK fertilizer does not result in increased crop productivity [5]. The change from response to non-responsive soils is driven by chemical (e.g. soil acidification, micronutrient deficiencies), physical (e.g. topsoil erosion, hardpan formation), and/or biological (e.g. soil-borne pests and diseases) mechanisms [5,6].

Intensive cultivation degrades the soil structure and causes excessive break down of soil aggregates [7] resulting in soil compaction, soil erosion, increased salinization and loss of soil organic matter [8]. Consequently, the resulting loss of soil nutrients and degraded plant rooting environment results in low productivity, low crop yields and high food insecurity [9,10]. To alleviate abject poverty and foster achievement of food security, sustainable farming systems aimed at improving soil health, conserving soil water, and increasing crop production while protecting the environment are pivotal. Stakeholders have advocated for conservation agriculture as one of the panacea to problems caused by conventional agriculture in that it has the potential to redress declining soil fertility, improve crop productivity and increase profits as well as household food security [11–16]. Conservation agriculture employs the principles of; minimum mechanical soil disturbance; permanent organic soil cover with crop residues or cover crops [17] diversified crop rotations [18,19] and appropriate use of inorganic fertilizers [15]. For the conservation agriculture to address the problems related to smallholder farming systems, there is a need for identification of effective region-specific conservation agriculture options for resource-poor farmers [20].

In order to increase maize yields and ensure sustainable productivity in the smallholder farms the potential effect of crop management practices like balanced nutrient application, mulching and minimum tillage on maize crop yield and household financial returns, needs to be understood. Against this background, an on-farm study was set up with an aim of determining the effect of interaction between NPK fertilizers and minimum tillage on soil fertility, maize crop yield and on farm profit margins.

2. Materials and methods

2.1. Description of the study area

The study was conducted in Runyenjes Division of Embu County. Runyenjes Division lies in agro-ecological zones; Upper Midland zone (UM2) to Lower Midland zone (LM3) on the eastern slopes of Mt. Kenya at an altitude of 1500 m.a.s.l. [22]. The area receives a bimodal rainfall with long rains (LR) lasting from mid-March to May and short rains (SR) from late October to December, hence two cropping seasons per year. The annual rainfall ranges from 930 to 1395 mm per year with mean monthly temperatures of 20 ℃ [22]. The soils are predominantly humic-nitisols which are deep weathered and with moderate to high inherent fertility [22]. The farming systems in the study area are complex and intensively managed consisting of an integration of crops, trees and livestock. Maize *(Zea mays*) is the main staple food crop and is mainly grown as an intercrop with beans (*Phaseolus vulgaris)*. The other food crops grown are bananas (*Musa* spp.), sweet potatoes (*Ipomoea batatas),* Irish potatoes (*Solanum tuberosum* L.*)*, millet (*Eleusine coracana*), yams (*Dioscorea* spp.), sorghum (*Sorghum* spp.) and cassava (*Manihot esculenta*). The cash crops include bananas (*Musa* spp.), tea (*Camellia sinensis*), coffee (*Coffea* spp.), tobacco (*Nicotiana tabacum* L.) and butternuts (*Juglans cinerea*).

2.2. Farm selection and sampling

A household field survey was conducted in July 2014 to characterize the smallholder farms in the study area. The farms were categorized in terms of farm types and sizes, main soil types, the cropping system, farm management practices as well as the socio-economic factors influencing the farming systems. Soil samples were collected using an alderman soil auger at 3 random points of the demarcated fields at a depth of 0–20 cm and composited to one sample to establish the fertility status of the soils. Results from the household survey and soil data were used to guide the selection of the farms where trials were to be established. A total of 28 farms were selected and trials established and monitored for three seasons (SR2014, LR2015 and SR2015). The trial farms were selected on the basis that they were either flat or on a gentle slope, they represented the main cropping system, had uniform soil fertility and could accommodate the 5 treatments each measuring 5 m by 5 m. The rainfall data was collected using an automatic rain-gauge.

2.3. Trial design, treatments and crop management

The trial was laid out in a split-plot design and treatments arranged in a randomized complete block design in the 28 selected farms. The trial plot size was 5 m by 5 m. Out of the 28 farms 14 farms were under conservation agriculture while the other 14 were under conventional agriculture. Conservation agriculture system entailed, minimum tillage and retention of crop residues; while the conventional agriculture system entailed, manual ploughing and weeding and no residue retention. Maize (*Zea mays* L.), Duma 23 variety which is commonly grown in the area was the test crop. Two maize seed per hole were planted at a spacing of 0.75 × 0.25 m between and within rows, respectively. Thinning was done after germination leaving one seed per hole to maintain a population of 53,000 plants ha^{-1} in accordance with the regional plant population and density recommendation. A blend of straight fertilizers {urea as a source of N, triple superphosphate (TSP) as a source of P and muriate of potash (MOP) as a source of K} were applied at the rate of 120-60-60 kg ha^{-1} (N-P_2O_5-K_2O), respectively (Table 1). Urea fertilizer was applied in 3 splits; 40 kg N ha^{-1} at planting, 40 kg N ha^{-1} at first top dressing (3 weeks after crop emergence) and 40 kg N ha^{-1} during second top dressing (5 weeks after crop emergence). Triple Super Phosphate (TSP) and Muriate of Potash (MOP) were applied at planting.

Table 1. Treatments description.

	Application rates (kg ha^{-1})			Omitted nutrient
Treatment	N	P_2O_5	K_2O	
PK	0	60	60	N
NK	120	0	60	P
NP	120	60	0	K
NPK	120	60	60	None
Control	0	0	0	All (N, P & K)

Dry maize stover was used as a mulching material and applied after crop emergence at the rate of 5 t ha^{-1} under conservation agriculture treatments. Weeding was done twice using hoes in conventional agriculture treatments prior to first and second N top dressing. To control the pre-annual weeds and ensure that crops were established on clean fields, a mixture of selective Dual Gold 960EC® (pre-emergence) and non-selective Weedal 480 SL (post-emergence) were sprayed two days after planting in the conservation agriculture plots. Weeding under conservation agriculture treatments was done twice by spraying 2, 4 D-Amine herbicide 21 days after emergence (DAE). The Bulldock® 0.05 GR insecticide was applied in all the treatments three weeks after the crop emergence to control maize stalk borer (*Busseola fusca*).

2.4. Data collection

2.4.1. Soil laboratory analysis

The soil samples from the field were taken to the laboratory, where they were air-dried and ground to pass through a 2 mm sieve. The soil pH in water was measured in a ratio of 1:2 soil to water using a pH meter [23]. Total nitrogen was analyzed through the Kjeldahl method [23]. Soil organic C was determined using the Walkley-Black method [24]. Soil extractable P was determined using Mehlich 1 method [25,26]. Soil K, Ca, Mg and Zn were analyzed using standard methods [27]. Table 2 shows the averages for the initial soil chemical and physical characteristics for the 28 farms.

Table 2. Initial soil characteristics of 28 farms in Runyenjes, Embu County.

Parameter	Min	Mean	Max
Sand (%)	8.3	11.0	13.8
Silt (%)	5.1	12.7	17.8
C (%)	2.4	2.8	3.3
CEC (meq/100 g)	10.2	15.17	20.4
Ca (ppm)	557	1,568	2,535
EC(S)_uS/cm	27.5	44.6	68.0
K (ppm)	166.5	456.2	697
Mg (ppm)	147	277	434
N (%)	0.1	0.2	0.3
P (ppm)	4.1	21.8	51.8
pH	4.8	5.9	6.6
Zn (ppm)	2.9	16.6	37.7

Note: Min = Minimum values of each parameter; Mean = Average of each parameter from all the farms; Max = Maximum value of each parameter.

2.4.2. Harvesting and yield determination

Maize grain yield and stover yield were harvested at physiological maturity from a 3 m by 2 m net plot. The cobs were manually separated from the stover. Cobs were then manually threshed, moisture content determined and then adjusted to 12.5% and presented in t ha^{-1}. Maize stover was cut at ground level and total above-ground fresh weight determined. The dry weight of the stover was determined after drying a sample of known fresh weight to a constant dry weight and expressed in t ha^{-1}.

2.4.3. Economic data

Data on costs of farm inputs (seeds, TSP, Urea, MOP, and herbicides) was collected through a survey of input prices from agro-input stockists in the study area. The time taken for the field operations (land preparation, planting, fertilizer application, thinning, weeding, pest control and harvesting) was taken using stopwatches and calculated as the work rate per hour. The average time taken was calculated and converted into monetary value at the rate of 0.25 USD per 8 hour working day. Maize stover was accounted for as an additional benefit and was valued at the market value of 19.61 USD ton^{-1} at harvest time (Table 3).

The partial budget procedures were used for cost-benefit analysis [28]. Net benefits were calculated by subtracting total variable costs from gross benefits for each treatment from the sale of maize grain and stover yields. Benefit to cost ratio was calculated as the ratio of net benefits to total variable cost [28].

2.5. Data analyses

The maize yield, soil properties and economic data was subjected to analysis of variance (ANOVA) using SAS 9.3 software [29]. Post-ANOVA analysis (polynomial contrasts) was conducted to examine the potential contribution of individual and combined nutrients on maize grain yields. For both ANOVA and post-ANOVA the treatment means were separated using Fisher's least significance difference (LSD) at 5% level of significance. Paired t-test was done on soil properties to test whether the mean value changes on soil nutrient values at initiation and termination of the experiment was significant at 5% level of significance.

Table 3. Parameters used in economic analysis.

Parameter	Actual values
Cost of Duma 43 maize seed	USD 2.06 kg^{-1}
Cost of TSP fertilizer	USD 1.62 kg^{-1}
Cost of Urea fertilizer	USD 1.07 kg^{-1}
Cost of MOP fertilizer	USD 1.24 kg^{-1}
Labour cost	USD 0.25 hr^{-1}
Cost of 2, 4 D-Amine herbicide	USD 7.35 $litre^{-1}$
Cost of Weedal 480 SL herbicide	USD 5.39 $litre^{-1}$
Cost of Dual Gold960EC herbicide	USD 24.51 $litre^{-1}$
Cost of Tremor® GR 0.05 insecticide	USD 2.45 kg^{-1}
Price of maize grains	USD 0.33 kg^{-1} (LR2015), 0.30 kg^{-1} (SR2015)
Price of maize stover	USD 19.61 ton^{-1}

Note: Exchange rate: KES 102 = 1 USD (the official rate in February 2016 at the end of the trial period).

3. Results

3.1. Rainfall trend over the experimental period

The highest rainfall was recorded during the SR2015 season (October-December 2015) while the least was recorded in the SR2014 season (October-December 2014) (Figure 1). A 12 days' drought towards the end of the SR2014 season was experienced in December. Rains were uniformly distributed during the SR2015 season.

3.2. Maize grain yields

Table 4 presents, the effect of tillage and applied nutrients on maize grain yield. Tillage effects on yield were not significant ($P < 0.05$). Cumulative yields for the three seasons, ranged from 12.9 to 15.1 t ha^{-1} for tillage practices with N included, between 7.7 and 8.2 t ha^{-1} for tillage practices with N omitted and between 4.6 and 5 t ha^{-1} for the control. All the fertilizer treatments, yielded significantly higher yields relative to the control, irrespective of the omitted nutrient ($P < 0.01$). The NPK treatments increased maize grain yields by 197, 237 and 196% over the control during the SR2014, LR2015 and SR2015 seasons, respectively (Table 4). A trend, of highest yields in nitrogen by tillage interactions was evident ($P < 0.001$). Omitting N resulted in cumulative yield penalties of more than 4 t ha^{-1} over the three seasons, irrespective of the tillage type. The yields were influenced by the amount of rainfall received across the seasons.

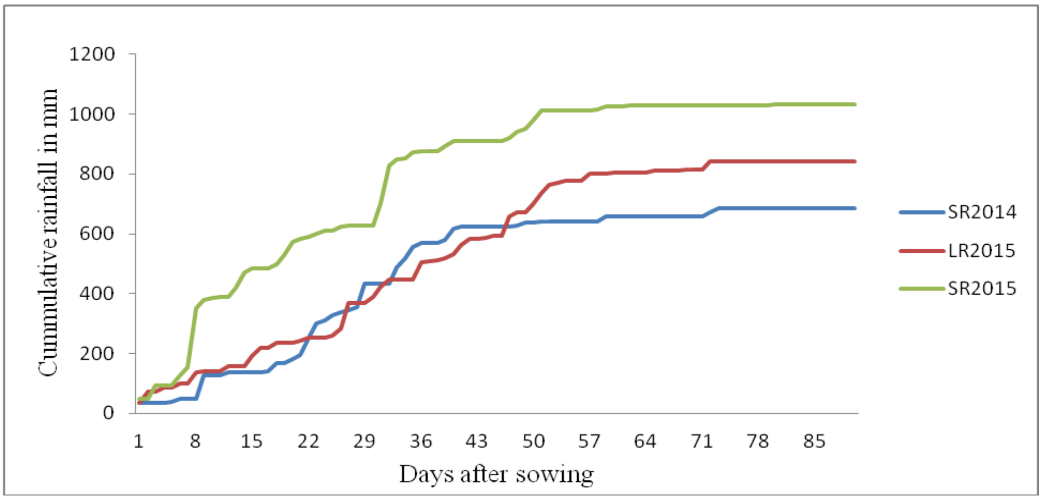

Figure 1. Cumulative rainfall trend for short rains 2014, long rains 2015 and short rains 2015 in Runyenjes, Embu County.

Table 4. Maize grain yields response to tillage and macro-nutrients options during the SR2014, LR2015 and SR2015 seasons in Runyenjes, Embu County.

	Grain yields (t ha^{-1})			
Treatments	Seasons			
Tillage + Macro-nutrient inputs	SR2014	LR2015	SR2015	Cumulative yield
Conventional agriculture + NPK	4.11^{a}	5.25^{a}	5.78^{a}	15.14^{a}
Conservation agriculture + NPK	4.21^{a}	5.13^{a}	5.48^{ab}	14.82^{a}
Conservation agriculture + NP	4.16^{a}	4.89^{ab}	5.45^{ab}	14.50^{a}
Conventional agriculture + NP	3.69^{ab}	4.97^{a}	5.63^{a}	14.29^{a}
Conservation agriculture + NK	3.59^{ab}	4.41^{b}	4.90^{b}	12.90^{ab}
Conventional agriculture + NK	3.13^{b}	4.78^{ab}	5.40^{ab}	13.31^{a}
Conventional agriculture + PK	2.12^{c}	2.94^{c}	3.13^{c}	8.19^{b}
Conservation agriculture + PK	1.98^{cd}	2.63^{c}	3.11^{c}	7.72^{b}
Conservation agriculture + Control	1.46^{cd}	1.41^{d}	1.76^{d}	4.63^{c}
Conventional agriculture + Control	1.34^{d}	1.66^{d}	1.95^{d}	4.96^{c}
P	$\leq$0.0001	$\leq$0.0001	$\leq$0.0001	$\leq$0.0001
Macro-nutrient inputs				
NPK	4.16^{a}	5.20^{a}	5.62^{a}	14.98^{a}
NP	3.92^{a}	5.00^{ab}	5.53^{ba}	14.45a
NK	3.36^{b}	4.61^{b}	5.18^{b}	13.15^{a}
PK	2.10^{c}	2.80^{c}	3.20^{c}	8.10^{b}
Control	1.40d	1.54^{d}	1.90^{d}	4.84^{c}
P	$\leq$0.0001	$\leq$0.0001	$\leq$0.0001	$\leq$0.0001
Tillage				
Conservation agriculture	3.07^{a}	3.70^{a}	4.13^{a}	10.9^{a}
Conventional agriculture	2.88^{a}	3.86^{a}	4.47^{a}	11.2^{a}
P	0.450	0.150	0.730	0.700

Note: Same superscript letters in the same column denote no significant differences between the treatments.

The highest individual macronutrient response to maize grain yield was N followed by P and K, respectively (Table 5). Orthogonal contrast showed omission of N (NPK vs PK) had the highest significant ($P \leq 0.0001$) losses on maize grain yields of 2.06, 2.40 and 2.42 t ha^{-1} during the SR2014, LR2015 and SR2015 seasons, respectively. Omission of P (NPK vs NK) contributed a significant influence on crop yields losses with 0.8, 0.59 and 0.43 t ha^{-1} during the SR2014, LR2015 and SR2015 seasons, respectively (Table 5).

Table 5. Class Orthogonal Contrasts of NPK inputs on maize grain yields in Runyenjes for the SR2014, LR2015 and SR2015 season.

	SR2014	LR2015	SR2015
Contrast	EST	EST	EST
NPK vs NP	0.24 (≤0.329)	0.20 (≤0.27)	0.09 (≤0.67)
NPK vs NK	0.8 (≤0.0048)	0.59 (≤0.084)	0.43 (≤0.045)
NPK vs PK	2.06 (≤0.0001)	2.40 (≤0.0001)	2.42 (≤0.0001)
NPK vs Control	2.76 (≤0.0001)	3.66 (≤0.0001)	3.7 (≤0.0001)
NP vs Control	2.4 (≤0.0001)	3.46 (≤0.0001)	3.61 (≤0.0001)
NK vs Control	1.96 (≤0.0001)	3.15 (≤0.0001)	3.26 (≤0.0001)
PK vs Control	0.74 (≤0.00087)	1.28 (≤0.0001)	1.28 (≤0.0001)

Note: Contrast = Class orthogonal statements; EST = Estimate of grain yields in t ha^{-1}, values in bracket indicate the P value.

3.3. Soil nutrients changes

There was no observable tillage effect on total soil N during the study period. Total nitrogen decreased significantly by 13, 17, 14 and 9% in NPK, NP, NK and PK fertilizer inputs, respectively over the study period (Table 6). The soil P level increased significantly in the conservation agriculture treatments but not in the conventional agriculture treatments ($P \leq 0.05$). The nutrient management practices had no effect on the soil P level. Extractable K was significantly ($P \leq 0.05$) higher under conventional agriculture than conservation agriculture at the start of the experiments but not after the three cropping seasons. A significant positive change ($P \leq 0.05$) of extractable K was observed in PK treatments after the three cropping seasons (Table 6).

3.4. Cost benefit analysis

Conservation agriculture had significantly lower total variable costs compared to the conventional agriculture. The net benefits and benefit-to-cost ratio were significantly higher under N inclusion treatments (NPK, NP, and NK) compared to N omission treatments (PK and control) (Table 7). On average, N inclusion treatment generated over 40% higher net benefits, compared to N omission treatments irrespective of the tillage practice in each of the two seasons. The benefit-cost ratio (BCR) was significantly ($P \leq 0.05$) higher under conservation agriculture than conventional agriculture.

Table 6. Effects of tillage system on soil percentage N, P and K change between the SR2014 and SR2015 in Runyenjes Sub-County, Embu County.

Treatment	N (%)		Change	P value	P (ppm)				K (ppm)			
	SR14	SR15			SR14	SR15	Change	P value	SR14	SR15	Change	P value
NPK	0.23^{a}	0.20^{b}	−0.03	<0.0001	16.93^{a}	20.24a	3.31	0.400	45.93^{a}	48.00^{a}	2.07	0.160
NP	0.24^{a}	0.20^{b}	−0.04	<0.0001	18.12^{a}	21.67^{a}	3.55	0.210	44.33^{a}	49.03^{a}	4.7	0.070
NK	0.22^{a}	0.19^{b}	−0.03	<0.0001	17.82^{a}	24.62^{a}	6.8	0.051	44.74^{a}	47.65^{a}	2.91	0.150
PK	0.22^{a}	0.20^{b}	−0.02	<0.0001	18.28^{a}	20.76^{a}	2.48	0.340	43.70^{a}	49.11^{a}	5.41	0.050
Control	0.24^{a}	0.24^{a}	−0.002	0.6888	18.81^{a}	18.81^{a}	0.002	0.998	44.72^{a}	44.71^{a}	0.0005	0.998
P	0.9	0.044			0.96	0.53			0.9	0.8		
Conservation agriculture	0.23^{a}	0.21^{a}	−0.02	<0.0001	14.31^{b}	19.01^{b}	4.19	<0.0007	41.87^{b}	45.23^{a}	14.29	<0.0001
Conventional agriculture	0.24^{a}	0.21^{a}	−0.03	<0.0001	23.32^{a}	25.04^{a}	0.62	0.670	47.57^{a}	50.19^{a}	13.24	<0.0001
P value	0.530	0.053			<0.0001	0.009			0.046	0.052		
Till*FI	0.980	0.900			0.780	0.620			0.960	0.540		

Note: Till*FI = interaction between tillage and fertilizer inputs; P = ANOVA P value, P value = t-test P value. Same superscripts letters in the same column denote no significant differences between the treatments.

Table 7. Economic analysis of nutrient management options under conservation and conventional agriculture systems in Runyenjes Sub-County, Embu County.

	Economic analysis (ha^{-1}) in $US					
Treatments	LR2015			SR2015		
Tillage + Macro-nutrient Input	TVC	NB	BCR	TVC	NB	BCR
Conservation + NPK	555^{b}	1823^{a}	3.28^{abcd}	552^{b}	1655^{ab}	3.02^{ab}
Conventional + NPK	576^{a}	1892^{a}	3.27^{abcd}	574^{a}	1831^{a}	3.19^{ab}
Conservation + NP	480^{d}	1794^{a}	3.73^{a}	477^{d}	1697^{ab}	3.53^{a}
Conventional + NP	498^{c}	1802^{a}	3.62^{ab}	492^{c}	1651^{ab}	3.35^{a}
Conservation + NK	454^{f}	1729^{a}	3.80^{a}	446^{e}	1439^{b}	3.20^{ab}
Conventional + NK	467^{e}	1588^{a}	3.39^{abc}	468^{d}	1614^{ab}	3.44^{a}
Conservation + PK	381^{h}	1120^{b}	2.93^{bcd}	378^{g}	987^{c}	2.60^{bc}
Conventional + PK	396^{g}	1027^{b}	2.58^{d}	395^{f}	980^{c}	2.48^{bc}
Conservation + Control	175^{j}	488^{c}	2.77^{cd}	177^{i}	535^{d}	2.98^{ab}
Conventional + Control	192^{i}	496^{c}	2.57^{d}	190^{h}	407^{d}	2.15^{c}
P	<0.0001	<0.0001	<0.003	<0.0001	<0.0001	<0.0033
Macro-nutrient input						
NPK	565^{a}	1758^{a}	3.28a	566a	1855a	3.10ab
NP	488^{b}	1647^{a}	3.68^{a}	479b	1797^{a}	3.42a
NK	460^{c}	1508^{a}	3.61^{a}	460^{c}	1665^{a}	3.27a
PK	388^{d}	1038^{b}	2.77^{b}	394^{d}	1078^{b}	2.61bc
Control	183^{e}	460^{c}	2.68^{b}	184e	491^{c}	2.51c
P	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0034
Tillage						
Conservation agriculture	409^{b}	1391^{a}	3.30^{a}	412^{b}	1357^{a}	3.07^{a}
Conventional agriculture	426^{a}	1361^{a}	3.19^{b}	419^{a}	1230^{a}	2.92^{b}
P	<0.041	<0.85	<0.038	<0.047	<0.069	<0.050

Note: TVC = Total variable cost; NB = Net benefit; BCR = Benefit Cost Ratio; Same superscripts letters in the same column denote no significant differences between the treatments.

During the LR2015 and SR2015 seasons, application of inorganic fertilizer led to a significant ($P \leq 0.0001$) increase of net benefits of 282 and 266% with NPK, 278 and 239% with NP, 258 and 120% with NK & 228 and 126% with PK over control, respectively. Benefit to cost ratio was increased by 26 and 24% with NP application, 25 and 23% with NK application and 18 and 12% with NPK application during the LR2015 and SR2015 seasons, respectively. Results showed that investing in NPK, NP and NK fertilizers, could yield 3-fold higher net return above the control under the two tillage systems.

4. Discussion

Significantly higher yields in NPK treatments as compared to controls over the study period indicate the importance of balanced nutrition on crop performance. The N, P and K are the major limiting nutrients in the area and their application is essential to obtain optimal yields. Several authors have reported more than double the yields with application of NPK over the control [16,30–32]. In our present study, omission of N (PK and control) affected yields more severely than omission of other nutrients. Overall P was the second most important nutrient affecting the maize yield. This is in agreement with the expected trend, since overall nitrogen is the most limiting nutrient in crop production, followed by P. Most fields tend to have N deficiencies due to high losses and uptake of nitrogen by the growing crops. P deficiencies are also evident in the area due to high P fixation in these acidic soils. The average pH of these soils was 5.87 with the pH across the farms varying between 4.84 and 6.60.

In this study omission of K did not significantly influence the yields. Although K is also a macro nutrient, in most regions its supply from the soil is adequate. However, continued crop cultivation with application of only N and P supplying fertilizers, like; DAP, NPK 23:23:0, UREA and CAN by over 80% of the farmers [33] has led to continued harvesting of K by growing crops resulting often in low supply of K [30]. The results agree with [34] who reported maize grain yields decrease of 84% due to no fertilization, 77% due to N omission, 78% due to P omission and 26% due to K omission. Besides, [35] reported grain yields decrease under maize wheat rotation that followed the order NPK > NP > NK > N > Control. This trend was also reported [36] in a study that evaluated the effects of inorganic fertilizer application on grain yield, nutrient use efficiency and economic returns of maize in western Kenya.

The significant increase in extractable P on the conservation agriculture relative to conventional agriculture was probably due to addition of P through decomposition of mulching material under conservation agriculture system. Crop residues are an important source of P in the farms. Higher P levels under conservation agriculture than conventional agriculture has been reported [37,38] due to limited mixing of soil with fertilizer P [39] in the minimum tillage systems therefore reducing the surface contact for P fixation.

The higher K increase under conservation agriculture could either be as a result of additional input of K in soils through decomposition of crop residues applied as mulch. Previous studies have reported accumulation of most of the K that is taken up by plants in the stover [40]. In addition, high K under conservation agriculture could be attributed to minimum tillage which has been found to enhance K levels in the soil because of reduced losses through leaching as a result of minimal soil disturbance. For instance, [41] reported 1.65 and 1.43 times higher K in 0–5 cm and 5–20 cm soil layer in no-till when compared to conventional agriculture system, respectively. The significantly higher K increase in the NP and PK treatments could be associated with the positive synergistic interaction of N and K on nutrient uptake [42,43]. The K uptake in this case was reduced in the absence of either N or K. [44] reported that the uptake of K is strongly influenced by other elements such as N explaining the higher amounts of K in the PK treatment due to low K uptake.

Compared with conservation agriculture, higher total variable cost (TVC) was recorded under conventional agriculture in both LR2015 and SR2015 seasons. Use of herbicides under conservation agriculture could have contributed to the reduced TVC owing to the high labor cost of manual digging and weeding in the conventional agriculture [10,16,45]. The mulching under conservation agriculture could be another added advantage for reduced cost of production as it has been found to reduce weeding labour cost as well as weed density [46]. [16] reported that maize-bean rotation was KE 22,718 cheaper under no-till with crop residue retention than under conventional agriculture with no crop residue retention in Embu and Kirinyaga Counties.

Higher net benefits were recorded under conservation agriculture than conventional agriculture in both LR2015 and SR2015 seasons. This could be associated to the lower production costs under conservation agriculture than conventional agriculture. Similarly, [47] reported higher maize net returns under conservation agriculture (permanent beds) compared to conventional agriculture. Higher net benefits as a result of fertilizer application could be attributed to higher yields recorded in both seasons over the control.

The BCR was significantly higher under conservation agriculture than conventional agriculture while NPK, NP and NK treatments had signficantly higher BCR than PK over the two seasons. This could be attributed to the lower cost of production under conservation agriculture. This concurs to [48,49] who stated that N and P should be the basis of optimizing fertilizer use for maximum crop yield and profitability. The omission of N (PK) led to a lower BCR compared to control and this could be as a result of high cost of P and K fertilizers (high TVC), and relatively low maize grain and stover yields (low net benefits). The general low BCR due to the omission of N observed in this research corroborates well with those reported by other studies [35].

5. Conclusions

There were beneficial effects of applying a combination of all the three macronutrients (NPK) relative to applying any of three nutrients singly or omitting any of the three nutrients from the combination under both conservation agriculture and conventional agriculture. Rainfall variability in amount and distribution greatly affected maize yields across the seasons. Grain loses were higher with the omission of N and P affirming the importance of N and P in crop production. Treatments with N offered the most profitable options while conservation agriculture was more economical compared to conventional agriculture. There is therefore need to continue promoting the use of NPK fertilizers and conservation agriculture among the farmers for enhanced crop productivity and profitability.

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Conflict of interest

No potential conflict of interest.

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