



Seasonal and Treatment Effects on Soil pH under Potato Production in Kitale, Kenya: A Randomized Block Analysis with Multiple Comparisons

Waithera Rosalia¹, Mungau Martin², Kasina Martin³, Thomas Kwambai⁴, Mary Kifuko-Koech⁵, Keziah Ndungu-Magiroi⁶, and Jane Mugwe⁷

¹Department of Mathematics and Statistics, Machakos University, Machakos, Kenya

²Kenya Agricultural and Livestock Research Organization (KALRO) FCRI – P.O. Box 450-30200, Kitale; Kenya

³Kalro Fcrc Alupe, P.O. Box 278-50400, Busia, Kenya

⁴Kenyatta University, P.O. Box 43844-001000, Nairobi, Kenya

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ABSTRACT

Soil pH is important as a measure of the soil chemical condition and will affect the availability of soil nutrients and fertilizer efficiency. This study evaluated the effects of eight fertilizer treatments on soil pH under potato production in Kitale, Trans Nzoia County, Kenya. A Randomized Complete Block Design (RCBD) experiment was applied, having 5 replications across two production seasons. The treatments consisted of farmers' practice, Baraka, Baraka + Calcipril, DAP, DAP + Calcipril, Yara, $\frac{1}{2}$ DAP + $\frac{1}{2}$ CAN + FYM, and FYM at 10 t/ha. Overall ANOVA showed significant effects of treatment ($F_{7,60} = 4.919$, $p < 0.001$), season ($F_{1,60} = 269.853$, $p < 0.001$), replication ($F_{4,60} = 86.481$, $p < 0.001$), and treatment $\times$ season interaction ($F_{7,60} = 3.224$, $p = 0.0057$). In Season 1, treatment effects on post-production soil pH were not significant ($F_{7,28} = 1.961$, $p = 0.097$), whereas replication was significant ($F_{4,28} = 36.872$, $p < 0.001$). Treatment effects were also significant during Season 2 ($F_{7,28} = 6.504$; $p < 0.001$), with FYM showing significant higher pH than some treatments. The FYM treatment was found to be significantly different from the farmer practice by Dunnett's test ($p = 0.0051$). The results indicated that fertilizer effects on soil pH also depended on production season.

Keywords: soil pH, potato production, fertilizer treatments, FYM, Calcipril, RCBD, Kitale, Kenya, Tukey HSD, Dunnett test

INTRODUCTION

Potato (*Solanum tuberosum* L.) is an important food and cash crop in Kenya and is produced in the high-potential agricultural zones where the climatic and soil conditions are appropriate. Good nutrient availability is necessary for potato production, and farmers frequently use a range of both organic and inorganic sources of nutrients for the establishment and maintenance of crop growth and productivity.

Soil pH is one of the most important soil fertility factors because it affects nutrient availability, microbial activity, and is related to some soil chemistry reactions. Soil chemical properties may change over time as a result of repeated applications of fertilizers and organic amendments. Therefore, it is necessary to assess the soil pH after various nutrient management practices in order to determine the sustainability of the different types of fertilizer strategies adopted in potato production. Recent studies in Kenya highlighted the significance of spatial variability of soils in fertilizer recommendations for potato production [1]. There is a decline in essential soil nutrients, a decrease in soil organic matter, and a decrease in crop yields due to continuous

cultivation without adequate renewal of soil nutrients [2]. Potato is a nutrient-demanding crop, and its productivity is significantly reliant upon proper use of fertilizer management practices [3]. Apart from that, poor crop management practices such as inappropriate fertilizer use and inadequate technical knowledge have been identified as significant constraints on potato productivity among the smallholder farmers in Kenya's north-western region [4].

Soil pH changes can be delayed or variable depending on fertilizer management practices. Differences may emerge between production seasons because of cumulative effects of amendments, nutrient transformations, crop uptake, rainfall, and other environmental processes. Additionally, there can be significant differences in experimental blocks due to field heterogeneity. Therefore, treatment effects need to be distinguished from variation associated with field position and seasonal conditions.

Analysis of Variance (ANOVA) was used to assess the adequacy and significance of the treatments on the pH of the Soil. Tukey's HSD and Dunnett's tests were used to test pairwise comparisons and control comparisons.

Research Objective

To assess the effects of the fertilizer treatments and experimental blocks on the pH of soils following potato cultivation in two seasons in Kitale, Kenya, with an interaction between the treatments and differences among the experimental blocks and in relation to farmers' practice.

Research Hypotheses

Null Hypothesis (H_0) : Fertilizer treatments and experimental blocks have no significant effect on soil pH after potato production across the two production seasons. ($H_0 : \tau_1 = \tau_2 = \dots = \tau_8 = 0$)

Alternative Hypothesis (H_1) : Fertilizer treatments and experimental blocks significantly affect soil pH after potato production in both production seasons. ($H_0 : \tau_1 \neq \tau_i$)

The null hypothesis used for the replication effect was that the five blocks did not differ in their mean soil pH values when the treatments were considered.

All tests were conducted at the level of significance of 0.05.

METHODOLOGY

The experimental design and study area are described. The experimental design and the study area are described.

The field trials were carried out in Kitale, Kenya, over two potato growing seasons, March-July 2021 and September-December 2021. Eight fertilizer treatments were tested under smallholder production conditions in a Randomized Complete Block Design (RCBD) with five farms in each season as blocks. In this way, 40 experimental plots were determined to encompass each season and a total of 80 observations were made for 2 seasons. Treatment was randomly allocated within each block to minimise spatial variation of farms.

The experimental plots were 3 m long, 75 cm apart and five rows across, 30 cm apart. Eleven seed tubers were planted in each row and 55 seed tubers per plot were obtained. Potato variety tested was [insert variety]. The Kenya Agricultural and Livestock Research Organisation (KALRO) with farmers implemented fertilizer treatments. All other crop management practices were identical among treatments and were in accordance with the recommended potato production practices.

Proper spacing of potato seed, certified potato seed was planted. During the growing season the Kenya Agricultural and livestock Research Organization (KALRO) agronomy teams maintained homogeneous agronomic activities in all the plots, such as another method of weeding, pest control, and irrigation where



necessary. Scattered such deviations or field difficulties were written systematically The application of fertilizers and their treatments.

The treatments included Farmers' Practice, DAP + CAN, DAP + CAN + Calcipril, Baraka fertilizer, Baraka + Calcipril, Yara fertilizer, organic–inorganic fertilizer mixture, and farmyard manure (FYM). The application rates and fertiliser programmes are shown in Table 1. Fertilizers were adjusted for the application rates necessary and were applied at planting, top dressing or foliar application based on the treatment recommendations. Basal fertilizers were added in planting furrows and mixed with soil before sowing and FYM and Calcipril were applied as per treatment rates.

The response variable and the representation of the mixtures are discussed. The representation of the mixtures and the response variable are discussed.

Table 1: Eight distinct treatments and rates were implemented by Kenya Agricultural and Livestock Research Organisation (KALRO) with farmers

Treatment	Amount/ha
Farmers' practice	125 kg DAP/ha + 125 kg CAN/ha (55 kg N + 57.5 kg P ₂ O ₅)
DAP + CAN (Research recommendation)	DAP + CAN (200 kg N + 230 kg P ₂ O ₅)
DAP + CAN + Lime	DAP + CAN (200 kg N + 230 kg P ₂ O ₅) + Calcipril lime (250 kg/ha)
Baraka fertilizer (manufacturer recommendation)	250 kg/ha Baraka (planting) + 250 kg/ha Baraka (top dressing)
Baraka fertilizer + Calcipril	250 kg/ha Baraka (planting) + 250 kg/ha Baraka (top dressing) + Calcipril lime (250 kg/ha)
Yara fertilizer (manufacturer recommendation)	• Planting: Yara Mila Power (250 kg/ha)
	• 3 weeks after sprouting: Yara Vita Crop Boost (400 ml/20L knapsack)
	• 7 weeks after sprouting: Yara Mila Winner (250 kg/ha) + Yara Bela Sulfan (125 kg/ha)
Organic + Inorganic	1/2 (DAP + CAN) (100 kg N + 115 kg P ₂ O ₅) + Farmyard manure (5 t/ha)
Farm Yard Manure	10t/ha

Note: Fertilizer Nutrient contents: Yara Mila Power- 13-24-12+S, Mg and micronutrients, Yara Vita Crop Boost- 0-44-7.5 +6.6 MgO +4.6 Zn, Yara Mila Winner- 15-09-20-S-Mg and micronutrients, Yara bela Sulfan- 24N+6S, Baraka potato planting 13-25-15+S+CaO+MgO+Zn+B), Baraka top dress -18-0-21+S+CaO+MgO

Experimental design

Randomized Complete Block Design (RCBD) was used for the analysis of the experiment. Five replications were used, and eight different fertilizer treatments were tested with 40 observations per season.

The fertilizers used were:

Table 2: Mixture Composition of Inorganic Fertilizer, Organic Manure and Lime Across Treatments

Treatment No.	Treatment Description	Mixture Type
T1	Farmers Practice	Pure Inorganic Control
T2	Baraka Fertilizer	Pure Inorganic
T3	DAP + CAN (Recommendation)	Pure Inorganic
T4	Baraka + Calcipril	Inorganic–Lime Blend



T5	DAP + CAN + Calcipril	Inorganic–Lime Blend
T6	Yara Fertilizer Program	Pure Inorganic
T7	½ DAP + ½ CAN + FYM	Organic–Inorganic Mixture
T8	FYM (10 t/ha)	Pure Organic

The experimental design allowed the treatment effect to be assessed but with some consideration of the variation between blocks.

Response variable

The dependent variable that was studied in this experiment was the soil pH following each potato cropping season.

Two measurements were analysed,

1. Soil pH after the first production season
2. Soil pH after the second production season

Baseline Soil sampling and Soil pH Determination

Soil chemical condition at the experimental field was determined by taking baseline soil pH measurements prior to application of the fertilizer treatments. Baseline soil pH measurements for individual blocks or treatment plots were not included in the data provided for this analysis. Baseline pH values were therefore not considered for statistical analysis and baseline values were not imputed.

Post -production soil pH observations were available for the two potato production seasons and constituted the response variable for the analysis performed in this study. The analysis was thus directed at the differences in soil pH after exposure to the experimental fertilization treatments.

The original experimental field records should be consulted for the exact soil sampling depth, number of cores collected per plot, compositing procedure, sample preparation, soil-to-water ratio, instrument specification and laboratory quality-control procedures. Lack of documentation in the data available in the present analysis prevents a definitive inference of these details.

The analysis was done on each season separately to assess whether the treatment effects differed across seasons.

Statistical analysis

The model of the RCBD analysis of variance was represented as:

$$Y_{ij} = \mu + \tau_i + \beta_j + \epsilon_{ij} \quad (1)$$

where:

- Y_{ij} is the actual pH level for treatment i in block j
- μ is the overall mean,;
- τ_i represents the effect of the i th fertilizer treatment;
- β_j is the effect of the j th replication;
- ϵ_{ij} is the random experimental error.

Analysis of variance at 5% significance level was used to test the treatment and replication effects.

Tukey's Honest Significant Difference (HSD) test was used for all pair wise comparisons among treatment levels when the treatment effect was statistically significant. Dunnett's multiple comparison test was also conducted using farmers' practice as the control treatment. Dunnett's test is suitable when interest lies more specifically in the comparison of one or more alternative treatments to a specific control.

RESULTS AND DISCUSSION

Analyses for soil pH after the first season

ANOVA

The results of RCBD analysis revealed that no statistically significant difference was noted in soil pH level between fertilizer and non-fertilizer treatment in the first season.

The F-statistic for the treatment effect was 1.961, which had 7 and 28 degrees of freedom, and a p-value of 0.097. The null hypothesis (equal treatment effects) was not rejected because $p > 0.05$.

Replication, however, significantly affected soil pH, with the exception of dry soil.

$$F_{4,28} = 36.872, \quad p < 0.001.$$

Table 3: RCBD ANOVA for soil pH after the first production season

Source	df	Sum of Squares	Mean Square	F-value	p-value
Treatment	7	0.314	0.0449	1.961	0.097
Replication	4	3.377	0.8444	36.872	< 0.001
Residual	28	0.641	0.0229	—	—

The ANOVA results are presented in Table 3.

The result shows that the observed differences between the fertilizer treatments in the first season were not big enough compared to the experimental variation to prove that the differences were statistically significant at the 5% level.

The large and significant replication effect suggests that significant variation exists in the soil pH from one block to another. This demonstrates the importance of accounting for spatial variation in the field through the RCBD.

Tukey HSD comparisons after the first season

The Tukey's HSD comparisons are presented in table 4

Table 4: Selected Tukey HSD pairwise comparisons of soil pH after the first production season

Comparison	Difference	95% CI	Adjusted p-value
<i>Significant comparisons</i>			
FYM (10 t/ha) – ½ DAP + ½ CAN	0.324	0.0287 to 0.6193	0.0239
FYM (10 t/ha) – Baraka	0.33	0.0347 to 0.6253	0.0204
FYM (10 t/ha) – Baraka + Calcipril	0.398	0.1027 to 0.6933	0.0031
FYM (10 t/ha) – DAP	0.582	0.2867 to 0.8773	< 0.001
FYM (10 t/ha) – DAP + Calcipril	0.426	0.1307 to 0.7213	0.0014

FYM (10 t/ha) – Farmers’ practice	0.338	0.0427 to 0.6333	0.0164
Yara – FYM (10 t/ha)	-0.362	-0.6573 to -0.0667	0.0085
<i>Selected non-significant comparisons</i>			
Baraka – ½ DAP + ½ CAN + FYM	-0.006	-0.3013 to 0.2893	1.0000
Baraka + Calcipril – Baraka	-0.068	-0.3633 to 0.2273	0.9942
DAP – Baraka	-0.252	-0.5473 to 0.0433	0.1378
DAP + Calcipril – DAP	0.156	-0.1393 to 0.4513	0.6702
Farmers’ practice – DAP	0.244	-0.0513 to 0.5393	0.1635
Yara – DAP	0.22	-0.0753 to 0.5153	0.2633
Yara – Farmers’ practice	-0.024	-0.3193 to 0.2713	1.0000

Note: Tukey’s honestly significant difference (HSD) test was used for pairwise comparisons. Comparisons with adjusted $p < 0.05$ were considered statistically significant. CI = confidence interval. The table includes all statistically significant comparisons and selected non-significant comparisons.

The overall treatment ANOVA was not significant at the 5% level, and therefore, there were no statistically significant differences between the treatments based on the Tukey comparisons.

The Tukey adjusted p -values were all greater than 0.05. The smallest p -value was 0.1195 for Yara versus Baraka, both of which were still statistically insignificant at the 5% level.

For example, the difference between Baraka and ½ DAP + ½ CAN + FYM was 0.224, with a 95% confidence interval from -0.0890 to 0.5370 and an adjusted p -value of 0.3082.

Likewise, the difference between Yara and Baraka was -0.274, with a 95% confidence interval of -0.5870 to 0.0390, followed by an adjusted p -value of 0.1195.

Therefore, there is no statistical evidence that any two of the fertilizer treatments caused a different soil pH after multiple comparisons during the first season.

Dunnett’s comparisons after the first season

The Dunnett’s comparisons are provided after the first season. Dunnett’s comparisons are given after first season.

The multiple comparison test was carried out with the total farmers’ practice as the reference treatment.

Table 5: Dunnett comparisons with farmers’ practice after the first production season

Comparison with farmers’ practice	Estimate	t -value	Adjusted p -value	Significance
½ DAP + ½ CAN + FYM	-0.096	-1.003	0.852	NS
Baraka	0.128	1.337	0.633	NS
Baraka + Calcipril	-0.064	-0.669	0.976	NS
DAP	-0.11	-1.149	0.763	NS
DAP + Calcipril	0.074	0.773	0.951	NS
FYM (10 t ha ⁻¹)	0	0	1	NS
Yara	-0.146	-1.525	0.503	NS

Note: NS = not significant at $\alpha = 0.05$.

However, none of the seven alternative treatments were significantly different from farmers’ practice after adjusting for multiple comparisons.

The adjusted p-values were between 0.503 and 1.000 for Yara and FYM at 10 t/ha respectively.

No Dunnett comparisons are significant, which is consistent with the lack of significant overall treatment effect in the first-season ANOVA.

Soil pH analyses after the second production season

Analysis of variance for season two

The ANOVA results are shown in Table 6.

Table 6: RCBD ANOVA for soil pH after the second production season

Source	df	Sum of Squares	Mean Square	F-value	p-value
Treatment	7	0.928	0.1325	6.504	< 0.001
Replication	4	4.257	1.0642	52.217	< 0.001
Residual	28	0.571	0.0204	—	—

Fertilizer treatment had a statistically significant effect on soil pH after the second season, unlike in the first season. There was a significant difference in the treatment effect: $F_{7,28} = 6.504$, $p < 0.001$. Thus, the null hypothesis of identical treatment effects was rejected. Replication was also highly significant: $F_{4,28} = 52.217$, $p < 0.001$. The treatment sum of squares increased from 0.314 in the first season to 0.928 in the second season, while the treatment mean square increased from 0.0449 to 0.1325.

This indicates that differences among fertilizer treatments became more pronounced in the second season.

Tukey HSD comparisons after the second season

The significant treatment ANOVA was followed by Tukey's HSD test. Some of the comparisons between the pairs were significant. Soil pH was significantly higher for FYM at 10 t/ha compared to:

- 1/2 DAP + 1/2 CAN + FYM;
- Baraka;
- DAP;
- DAP + Calcipril; and
- farmers' practice.

For instance, when comparing FYM (10t ha⁻¹) with DAP, the difference was 0.582; the 95% confidence interval was 0.2867 to 0.8773 and the adjusted p-value was 0.000014.

The difference between FYM and DAP + Calcipril was 0.426 with a 95% confidence interval of 0.1307 to 0.7213, and the adjusted p-value was 0.00136.

The difference between FYM and farmers' practice was also very large (0.338) and the p value obtained is adjusted (0.01642).

The results of the comparisons reveal the consistent trend that the soil pH after FYM treatment was higher than some of the other treatments after the second production season.

The comparisons show a consistent pattern in which the FYM treatment was associated with higher soil pH than several of the other treatments following the second production season.

Table 7: Selected Tukey HSD pairwise comparisons of soil pH after the second production season

Comparison	Difference	95% CI	Adjusted <i>p</i> -value
<i>Significant comparisons</i>			
FYM (10 t ha ⁻¹) – ½ DAP + ½ CAN + FYM	0.324	0.0287 to 0.6193	0.0239
FYM (10 t ha ⁻¹) – Baraka	0.33	0.0347 to 0.6253	0.0204
FYM (10 t ha ⁻¹) – Baraka + Cal-cipril	0.398	0.1027 to 0.6933	0.0031
FYM (10 t ha ⁻¹) – DAP	0.582	0.2867 to 0.8773	< 0.001
FYM (10 t ha ⁻¹) – DAP + Cal-cipril	0.426	0.1307 to 0.7213	0.0014
FYM (10 t ha ⁻¹) – Farmers' practice	0.338	0.0427 to 0.6333	0.0164
Yara – FYM (10 t ha ⁻¹)	-0.362	-0.6573 to -0.0667	0.0085
<i>Selected non-significant comparisons</i>			
Baraka – ½ DAP + ½ CAN + FYM	-0.006	-0.3013 to 0.2893	1.0000
DAP – 1/2 DAP + 1/2 CAN +FYM	-0.258	-0.5533 to 0.0373	0.1208
Baraka + Calcipril – Baraka	-0.068	-0.3633 to 0.2273	0.9942
DAP + Calcipril – DAP	0.156	-0.1393 to 0.4513	0.6702
Farmers' practice – DAP	0.244	-0.0513 to 0.5393	0.1635
Yara – DAP	0.22	-0.0753 to 0.5153	0.2633
Yara – Farmers' practice	-0.024	-0.3193 to 0.2713	1.0000

Note: Tukey's honestly significant difference (HSD) test was used for pairwise comparisons. Comparisons with adjusted *p* < 0.05 were considered statistically significant. CI = confidence interval. The table presents all significant comparisons and selected non-significant comparisons to illustrate the overall pattern of treatment differences.

Dunnnett comparisons after the second season

Table 8 Shows results for Season 2

Table 8: Dunnnett comparisons with farmers' practice after the second season

Comparison with farmers' practice	Estimate	<i>t</i> -value	Adjusted <i>p</i> -value	Significance
½ DAP + ½ CAN + FYM	0.014	0.155	1	NS
Baraka	0.008	0.089	1	NS
Baraka + Calcipril	-0.06	-0.665	0.977	NS
DAP	-0.244	-2.702	0.0598	NS
DAP + Calcipril	-0.088	-0.975	0.8676	NS
FYM (10 t/ha)	0.338	3.744	0.0051	Significant
Yara	-0.024	-0.266	0.9999	NS

Note: NS = not significant at $\alpha = 0.05$.

The Dunnnett's test was used to compare each fertilizer treatment to farmers' practice.

From the results it was found that fertilizer of FYM 10 t/ha was significantly different from farmers practice.

$$\tau^{\wedge} = 0.338, \quad t = 3.744, \quad p_{adj} = 0.00507.$$



The pH of the soil under FYM was higher than that under farmers' practice with the positive estimate showing a difference of about 0.338 pH units, based on the treatment comparison.

The DAP treatment resulted in a negative difference when compared with the farmers' practice:

$$\tau^{\wedge} = -0.244,$$

However, its adjusted p-value was 0.05979. Therefore, it did not reach the conventional 5% significance level, although it was close to the threshold.

No significant difference was observed between the remaining treatments and farmers' practice.

Effect of Treatment and Season on Soil pH

ANOVA Analysis

The analysis of variance (ANOVA) was conducted to determine the effects of treatment, season, replication and the interaction of replication $\times$ treatment on soil pH. The results Summary of ANOVA are shown in Table 9.

Table 9: Analysis of variance for the effects of treatment, season and replication on soil pH.

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	7	0.75	0.107	4.919	0.000195***
Season	1	5.881	5.881	269.853	$< 2 \times 10^{-16}$ ***
Replication	4	7.539	1.885	86.481	$< 2 \times 10^{-16}$ ***
Treatment:Season	7	0.492	0.07	3.224	0.005736**
Residuals	60	1.308	0.022		

Note: *** $p < 0.001$; ** $p < 0.01$.

Treatment was found to have a statistically significant effect. significant effect on soil pH ($F_{7,60} = 4.919$, $p = 0.000195$), indicating that the different fertilizer and soil amendment treatments resulted in varied soil pH reactions. Season also had a very significant effect on soil pH ($F_{1,60} = 269.853$, $p < 0.001$), indicating here was no significant difference in soil pH between the two seasons.

Soil pH was significantly affected by replication. ($F_{4,60} = 86.481$, $p < 0.001$), indicating that there was considerable Variations between experimental replicates. This variation may be due to differences in the experimental units or spatial variability in soil properties. The treatment $\times$ season interaction was also statistically significant. significant ($F_{7,60} = 3.224$, $p = 0.005736$). This significant interaction indicates that the response of soil pH to the different treatments was not consistent between the two seasons. Therefore, the impact of treatment was found to be evaluated by season only.

Estimated Marginal Means of Soil pH

Soil pH was significantly different among the (estimate marginal means) treatments between two seasons (Table 10). In Season 1, estimated soil pH values ranged from 4.69 under Yara to 4.96 under Baraka. Farmers practice and FYM applied at 10 t/ha both had an estimated mean pH of 4.83. DAP had an estimated mean pH of 4.72, while the combination of $\frac{1}{2}$ DAP + $\frac{1}{2}$ CAN + FYM resulted in a mean pH of 4.74. DAP + Calcipril had a mean pH of 4.91, whereas Baraka + Calcipril resulted in a mean of 4.77. Season 2 soil pH values were typically lower than the values in Season 1. highest estimated mean was found for DAP (4.92). The highest was in the case of FYM at 10 t/ha (4.61). The remaining treatments had estimated means ranging from 4.18 to 4.29. The reduction in soil pH from Season 1 to Season 2 was evident for most treatments and provides a

possible explanation for the highly significant seasonal effect observed in the ANOVA. Estimated Marginal Means for the soil pH values are reported below.

Table 10: Estimated marginal means of soil pH by treatment and season.

Season	Treatment	Mean pH	Lower 95% CL	Upper 95% CL
Season 1	Farmers practice	4.83	4.7	4.97
	1/2 DAP+1/2 CAN+FYM	4.74	4.61	4.87
	Baraka	4.96	4.83	5.09
	Baraka + Calcipril	4.77	4.64	4.9
	DAP	4.72	4.59	4.86
	DAP + Calcipril	4.91	4.78	5.04
	FYM (10 t/ha)	4.83	4.7	4.97
	Yara	4.69	4.56	4.82
Season 2	Farmers practice	4.27	4.14	4.4
	1/2 DAP+1/2 CAN+FYM	4.29	4.15	4.42
	Baraka	4.28	4.15	4.41
	Baraka + Calcipril	4.21	4.08	4.34
	DAP	4.03	3.9	4.16
	DAP + Calcipril	4.18	4.05	4.32
	FYM (10 t/ha)	4.61	4.48	4.74
	Yara	4.25	4.12	4.38

Note: CL = confidence limit. Values are estimated marginal means averaged over the levels of replication. Confidence intervals are based on a 95% confidence level.

Comparison of Treatments Within Seasons

Because the treatment $\times$ season interaction was significant, pairwise comparisons were performed separately within each season using Tukey's adjustment for multiple comparisons. The results will be displayed as Table 11. In Season 1, none of the selected treatment comparisons was statistically significant after Tukey adjustment. For example, the difference between Baraka and Yara was 0.274 pH units, but the adjusted p -value was 0.0835. Similarly, the difference between Baraka and DAP was 0.238 pH units ($p = 0.1955$). These results indicate that, despite numerical differences among treatment means in Season 1, the differences were not large relative to the experimental variability to be statistically significant after adjustment for multiple comparisons.

Table 11: Selected Tukey-adjusted pairwise comparisons of treatment effects on soil pH within seasons.

Season	Comparison	Estimate	SE	t-ratio	p-value	Sig.
Season 1	Baraka – Yara	0.274	0.0934	2.935	0.0835	NS
Season 1	Baraka – DAP	0.238	0.0934	2.549	0.1955	NS
Season 1	Farmers practice – Yara	0.146	0.0934	1.564	0.7694	NS
Season 1	Farmers practice – Baraka	-0.128	0.0934	-1.371	0.8666	NS
Season 2	Farmers practice – FYM (10 t/ha)	-0.338	0.0934	-3.62	0.0132	*
Season 2	1/2 DAP+1/2 CAN+FYM – FYM (10 t/ha)	-0.324	0.0934	-3.47	0.0204	*
Season 2	Baraka – FYM (10 t/ha)	-0.33	0.0934	-3.535	0.017	*
Season 2	Baraka + Calcipril – FYM (10 t/ha)	-0.398	0.0934	-4.263	0.0018	**
Season 2	DAP – FYM (10 t/ha)	-0.582	0.0934	-6.234	<0.0001	***



Season 2	DAP + Calcipril – FYM (10 t/ha)	-0.426	0.0934	-4.563	0.0006	***
Season 2	FYM (10 t/ha) – Yara	0.362	0.0934	3.877	0.0061	**

Note: NS = not significant; * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$. P-values were adjusted using Tukey's method for comparing a family of eight estimates.

The trend was reversed in Season 2, FYM applied at 10 t/ha had significantly different soil pH values from several of the other treatments. The difference between Farmers practice and FYM (10 t/ha) was -0.338 pH units ($p = 0.0132$), while the difference between $1/2$ DAP + $1/2$ CAN + FYM and FYM (10 t/ha) was -0.324 pH units ($p = 0.0204$). Baraka also differed significantly from FYM (10 t/ha) (-0.330 , $p = 0.0170$).

The difference between Baraka + Calcipril and FYM (10 t/ha) was -0.398 pH units ($p = 0.0018$). The difference between DAP and FYM (10 t/ha) was -0.582 pH units ($p < 0.0001$), while the difference between DAP + Calcipril and FYM (10 t/ha) was -0.426 pH units ($p = 0.0006$). FYM (10 t/ha) also differed significantly from Yara (0.362 pH units, $p = 0.0061$).

The results show that the impact of the treatments increased in pronounced in Season 2. In particular, FYM (10 t/ha) kept relative to the relatively high level. The soil pH of some of the other treatments was higher. The findings are which was similar to the large treatment $\times$ season interaction. Identified in the ANOVA and shown to be significant the response of soil pH to the treatment was dependent on the season.

Multiple Comparisons

The combined ANOVA revealed a significant treatment $\times$ season interaction; so treatment com-parisons were made separately within each of the production seasons. The estimated marginal means were then determined for each treatment for each season and reported with 95% confidence intervals.

Tukey's Honestly Significant Difference (HSD) procedure was used for all-pairwise comparisons among the eight fertilizer treatments within each season. Tukey's procedure is used to control the family-wise error rate when the objective is to identify which treatment means differ from one another for all treatment comparisons.

The purpose of Dunnett's multiple comparison procedure was different and more specific: compar-ison of each fertilizer treatment with farmers' practice (T1), which was set a priori as the control or reference treatment. Therefore Dunnett's procedure is appropriate for determining significant differences between each alternative fertilizer programme and the farmers' practice and control for the multiplicity of these control vs. treatment comparisons.

Therefore, Tukey's HSD and Dunnett's test were not considered as conflicting methods. Tukey's HSD was used to determine if any pair of fertilizer treatments differed and Dunnett's test was used to determine if each alternative treatment differed from farmer's practice.

Assessment of Model Assumptions

The assumptions underlying the analysis of variance were assessed using diagnostic plots, including the normal Q–Q plot of the model residuals. The Q–Q plot was used to assess whether the residuals were approximately normally distributed. When the normality assumption is made, the residual points should be approximately aligned along the line that is theoretically straight, but with only small deviations at the tails.

Figure 1 presents the normal Q–Q plot of the residuals from the fitted model. The points should be evaluated for any systemics errors from the reference line especially at the bottom and top of the distribution. When they are reasonably close to the reference line, the assumption of normally distributed residuals is deemed to be satisfied. Experimental data may deviate somewhat from the line of best fit and this is not necessarily a sign of a significant deviation from the normality assumption.

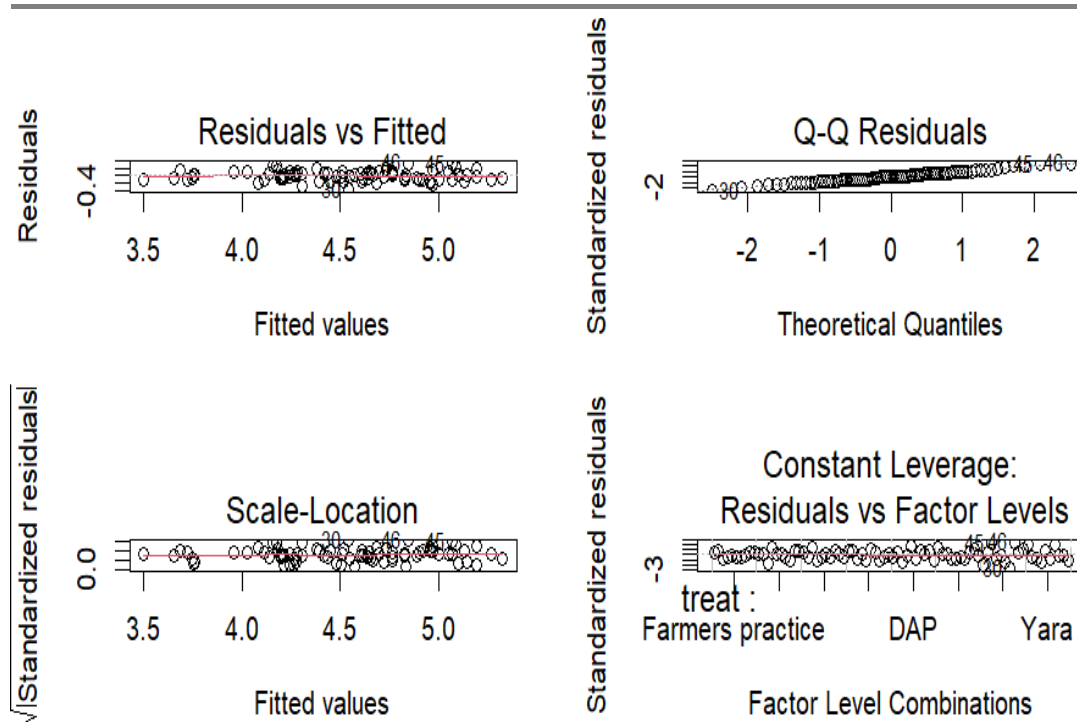


Figure 1: Normal Q–Q plot of residuals from the fitted soil pH model.

The Q–Q plot should be interpreted together with the other model diagnostic plots and the experimental design. The presence of a few points off the line is not sufficient to conclude that the ANOVA assumptions have been violated. If the points are more or less linear and do not show any systematic pattern, the residual normality assumption is deemed to be reasonable.

RESULTS AND DISCUSSION

The results showed that fertilizer and soil amendment treatments, cropping season, and their interaction influenced soil pH. The overall ANOVA suggested that treatments and seasons were significant and replication too was highly significant, indicating that there was a significant difference between the experimental units. The significant treatment $\times$ season interaction indicated that treatment effects varied between seasons, making season-specific interpretation appropriate.

Estimated marginal means showed that soil pH was generally higher in the first season than in the second season. During the first season, treatment differences were not statistically significant at the 5% level. Although the treatment means differed numerically, the Tukey-adjusted pairwise comparisons showed no significant differences. This suggests that the treatment effects during the first production cycle were not large enough to be distinguished from experimental variation.

Treatment differences were larger in the second season. Tukey-adjusted comparisons showed that FYM at 10 t/ha differed significantly from all the other treatments. FYM recorded the highest soil pH (4.61), while DAP recorded the lowest (4.03). The Dunnett comparison also showed that FYM at 10 t/ha differed significantly from farmers' practice ($\square = 0.0051$). DAP differed numerically from farmers' practice, but the difference was not statistically significant ($\square = 0.0598$).

The significant replication effect indicates that variation among experimental units also contributed to differences in soil pH. Generally, the results showed that the effects of fertilizer and soil amendments on soil pH were different from one season to the next, and there was greater pH difference to the treatments in the second season. Therefore, both treatment type and season should be considered when evaluating changes in soil acidity.

CONCLUSION

The study demonstrated that the effects of fertilizer and soil amendment treatments on soil pH varied between production seasons. The overall analysis revealed significant treatment, season, replication and treatment $\times$ season interaction. This suggests that both the fertilizer or amendment type and the seasonal conditions as well as the variation between experimental units affected soil pH.

In the first production season, the soil was not significantly different by the fertilization treatment ($F_{7,28} = 1.961$, $p = 0.097$). Both Tukey HSD and Dunnett's tests did not find any statistically significant differences, although there were some differences in the numbers. The treatment effects were more significant in the second season, however, as shown by the soil pH which for this season was significantly influenced by fertilizer treatment ($F_{7,28} = 6.504$, $p < 0.001$). Soil pH was highest for FYM and significant difference between it and farmers practice and some mineral fertilizer treatments applied at 10 t/ha. The Dunnett test further revealed significant difference between FYM 10 t/ha and farmers' practice ($p_{adj} = 0.0051$).

Hence, the results suggested that FYM application at 10 t/ha resulted in higher soil pH in the second production season, under the soil conditions of the present study. The results do not, however, provide detailed information on the specific chemical mechanisms involved in this response. The replication effect was also significant, indicating that there was a substantial variation in pH due to field level variability.

Overall, the study shows that when managing soil pH, the type of fertilizer or amendment as well as the growing season need to be taken into account. Soil pH response to treatments may be underestimated by relying on data from a single season of production.

RECOMMENDATIONS

Based on the results of the study, the following recommendations are made:

1. Use of FYM at 10 t/ha should be considered by farmers and agricultural practitioners as one of the soil amendment options to maintain or boost the basicity of the soil, especially in situations when soil acidity is a concern. However, nutrient requirements and soil and crop management practices should be taken into consideration alongside suitability.
2. Fertilizer and soil amendment effects on soil pH should be evaluated over several production seasons. The lack of significant treatment differences in the first season compared with the significant differences in the second season indicates that a single-season assessment may not adequately capture changes in soil pH.
3. Regular soil testing should be encouraged before and during fertilizer and amendment application. Monitoring soil pH over time would help farmers determine whether the selected nutrient management practices are maintaining soil pH within a suitable range for potato production.
4. Further studies should investigate the long-term effects of FYM and mineral fertilizer combinations on soil pH over more production seasons. Such studies should also include other soil chemical properties, such as exchangeable acidity, exchangeable aluminium, organic carbon, and available nutrients, to help explain the mechanisms responsible for changes in soil pH.
5. Future experiments should maintain adequate replication and consider spatial variation within experimental fields. The significant replication effect observed in this study demonstrates the importance of accounting for field variability when evaluating fertilizer and soil amendment effects.
6. Further research should also examine the economic implications of using FYM at 10 t/ha, including availability, transportation, application costs, and crop yield responses. This would help determine the practical suitability of the treatment under farmers' production conditions.

LIMITATIONS OF THE STUDY

1. Soil pH was evaluated separately for the two production seasons. The results do not therefore reflect a formal test of the treatment-by-season interaction, but only treatment effects for each season.



2. Additionally, the soil pH was analyzed. Other soil characteristics such as soil organic carbon, available phosphorus, exchangeable bases, and other nutrient indicators could also give clues to the mechanism of the treatment effects observed.
3. Thus, it is concluded that this study is evidence of the effect of the fertilizer treatments under the experimental conditions and not the effect under all potato growing conditions in Kenya.

DATA AVAILABILITY

The data analysed in this study were obtained from the experimental field dataset for potato production at Kitale, Trans Nzoia County, Kenya. The analysis presented in this manuscript is based on the treatment, replication and soil pH observations collected during the two production seasons.

CONFLICT OF INTEREST

The author declares no conflict of interest associated with this study.

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