



Influence of Soybean Residue Management on Nitrate Nitrogen Accumulation and Subsequent Sorghum Yield in *Kanhaplic Haplustults* of Western Kenya

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Authors' contributions

This work was carried out in collaboration between all authors. Author SJK designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors JMRS and BMM managed the analyses of the study. Author WKN managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Crop residues are overlooked when making fertilizer recommendations, yet have potential to contribute to soil nitrogen in addition to mineral fertilizer use. A study was carried out in western Kenya to establish the contribution of soybean residues under varied management options and nitrogen fertilizer rates on nitrogen supply to subsequent sorghum crop. Six soybean residue management options were evaluated; sole sorghum, sorghum + soybean left to maturity, sorghum + soybean mulched, sorghum + soybean incorporated, sorghum + soybean *exsitu* and sorghum + soybean *exsitu* and plot tilled. Three levels of nitrogen (0 kg N ha⁻¹, 40 kg N ha⁻¹, and 80 kg N ha⁻¹) as urea were applied as top-dress and treatments arranged in randomized complete block design. Soybean left to maturity at 40 kg N ha⁻¹ indicated significant (P < 0.001) increase (56%) in soil NO₃-

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N. Removal of soybean residues resulted in significantly ($P < 0.001$) lower soil $\text{NO}_3\text{-N}$ increase while control treatment and sole sorghum indicated the lowest soil $\text{NO}_3\text{-N}$ accumulation irrespective of nitrogen fertilizer rates. Soybean left to maturity indicated significant ($P < 0.001$) increase (43%) in leaf $\text{NO}_3\text{-N}$ accumulation at 40 kg N ha^{-1} while treatments with soybean residues mulched showed 39% increase and those with residues incorporated, 25% increase. Soybean residues *ex-situ* and *ex-situ* and till indicated a decrease (-6% and -7%) in leaf $\text{NO}_3\text{-N}$ accumulation, respectively. Sole sorghum had a uniform $\text{NO}_3\text{-N}$ increase of 4% irrespective of nitrogen fertilizer rates. It was observed that *insitu* soybean residues and nitrogen fertilizer application had no significant ($P < 0.05$) influence on sorghum yield. In conclusion, soil and leaf $\text{NO}_3\text{-N}$ accumulation by soybean residues in addition to nitrogen fertilizer does not translate to optimum nor potential research sorghum yields. There is need to research on sulphur and nitrogen to establish their interactive effects on sorghum yields.

Keywords: Soybean residue management options; nitrogen fertilizer rates; nitrate accumulation and build up; subsequent sorghum yields.

1. INTRODUCTION

Soil organic nitrogen is transformed into mineral nitrogen through mineralization which is the most important process of soil nitrogen cycling [1]. Nitrogen is an essential element required for successful plant growth [2]. Inorganic nitrogen compounds exist as ammonium, nitrite and nitrate [2] and of the three, nitrate is the principal N source for plant growth irrespective of inorganic or organic N source [3]. In addition to mineral fertilizer which is the prime source of N for crops [4], legumes contribute appreciable amounts of N through symbiotic nitrogen fixation [5]. The authors [6] pointed out that cereal-legume intercropping increases the amount of nitrogen, phosphorus and potassium contents compared to mono-cropping. According to [7], legume species and several cultivars have potential to adequately contribute N for corn growth. For example, hairy vetch (*Vicia villosa*), and crimson clover (*Trifolium incarnatum*,) were found to contribute 204 kg ha^{-1} and 163 kg ha^{-1} respectively [8]. Other researchers [9] showed that soybean litter fall over the growing period of the crop contributed 8.2 to $11.8 \text{ kg N ha}^{-1}$ from N fixation while residues returned to the field after harvest had total N content of up to 30 kg N ha^{-1} .

Crop residues have been reported to play a significant role in terms of soil fertility improvement [10] and have direct roles on nutrient cycling and crop yields [11]. Leguminous residues undergoing decomposition have potential to supply adequate plant available nitrogen to the subsequent crop depending on management and soil conditions [12]. In addition, [13] were of the opinion that legume residue decomposition provides long-term supply of N for subsequent crop. The findings reported by [14] indicated that removal of crop residues

negatively impacted on soil nitrate nitrogen ($\text{NO}_3\text{-N}$) while residue covered soil showed accumulation of $\text{NO}_3\text{-N}$. Other studies [15] showed that incorporation of legume residues from velvet bean and sun hemp led to accumulation of N in the soil, high absorption by corn and ultimate increase in corn yields.

According to [16], 55% of overall nitrogen applied in agricultural systems can be recovered; out of this percentage, 35% is in harvested products and 20% is in crop residues. However, crop residues are under-estimated in nutrient recycling and often overlooked when making fertilizer recommendations. Further to this, [17] reported that legumes have potential to contribute to build up of soil $\text{NO}_3\text{-N}$ to meet and/or exceed the plant nitrogen requirement during the cropping season and consequently increase yields. Findings by [18] showed that crop residues' contribution to soil nitrogen need to be considered in nitrogen fertilizer management and factored in to reduce mineral fertilizer rates. In the light of the findings and opinions of these researchers, this study sought to establish the potential of integrated soybean residue management options and nitrogen fertilizer rates on nitrogen supply to the subsequent sorghum crop and their influence on grain yield in *Kanhaplic Haplustults* of Western Kenya.

2. MATERIALS AND METHODS

2.1 Study Area

The experiment was carried out in Busia County, Emalomba area (N $00^{\circ}25'28.8''$ E $034^{\circ}15'51.9''$), Agro-ecological zone: LM 1 [19]. The site elevation is 1222 m above sea level. Table 1

Table 1. Rainfall amounts (mm) and maximum and minimum temperatures (°C) for the years 2012 and 2013

Month	Rainfall (mm)		Max. Temp (°C)		Min. Temp (°C)	
	2012	2013	2012	2013	2012	2013
Jan	7.2	47.1	30.1	28.6	12	13.9
Feb	12.1	40.7	31.3	29.9	13.8	14.1
Mar	54.2	248.0	31.0	29.6	14.3	15.1
Apr	206.6	209.0	27.2	27.1	15.5	15.4
May	261.2	172.9	26.5	27.4	14.9	14.5
June	146.0	77.2	26.5	26.8	14.5	14.5
July	105.3	24.3	25.9	26.9	14.1	13.6
Aug	79.8	190.5	26.3	26.5	13.9	13.9
Sept	197.4	268.0	26.9	27.2	13.9	14.0
Oct	332.6	196.7	27.4	27.4	14.8	14.7
Nov	166.1	174.6	27.2	27.2	14.6	14.9
Dec	215.8	68.6	27.2	27.5	14.4	14.5

Source: [20]

presents the mean monthly rainfall and temperature of the experimental site over a two year period (2012 – 2013).

The average annual precipitation of the study area ranges between 1718 – 1784 mm while the mean maximum temperatures ranged between 26.3°C and 31.3°C in comparison to mean monthly minimum temperature that vary from 12.0°C to 15.5°C. The experimental site experiences bimodal rainfall with the long rains beginning in March and the short rains in August/September. The soil is classified as *Kanhaplic Haplustults* in USDA Soil Taxonomy [21] correlating with *Haplic Cutanic Acrisols* in WRB [22].

2.2 Field Experimentation

The experimental site was prepared preceding the onset of long rains in March, 2012 and 2013. In the year 2013, a study was carried out in the previous experimental plots with respective treatments to establish the contribution of soybean residues under varied management options and nitrogen fertilizer rates on nitrogen supply to the subsequent sorghum crop and on yield. Additionally, in same year, 2013, new experimental site with similar experimental treatments as the previous experimentation in the year 2012 were prepared alongside that of the year, 2012. This was done to allow a comparison on effects of soybean residue management options and N fertilizer rates on $\text{NO}_3\text{-N}$ accumulation and build up both in the soil and sorghum leaves in the year 2012 and that of year 2013. Each experimental plot measured 3.0

m x 4.5 m with inter-plot distance of 0.5 m and 2 m between blocks. An outer allowance path of 2 m around the experimental plots was considered. Sorghum variety; KARI Mtama II, recommended to the climatic conditions of the experimental site, was sown at the spacing of 75 cm inter-rows and 15 cm between plants. Soybean variety SB 19 inoculated with Biofix® inoculants was planted in between the sorghum rows at a spacing of 10 cm. Six treatment options were considered;

- (i) sole sorghum(SS),
- (ii) sorghum + soybean left to maturity (SS + SB [maturity]),
- (iii) sorghum + soybean residue mulched (SS + SB [mulched]),
- (iv) sorghum + soybean residue incorporated (SS + SB [incorporated]),
- (v) sorghum + soybean *ex-situ* (SS + SB [*ex-situ*]), and
- (vi) sorghum + soybean *ex-situ* and plot tilled (SS + SB [*ex-situ* and plot tilled]).

Triple super phosphate ($\text{Ca}(\text{H}_2\text{PO}_4)_2 \cdot \text{H}_2\text{O}$) was applied uniformly to all the treatments during planting by broadcasting and mixing with soil at rate of 20 kg P ha^{-1} . Three levels of nitrogen (0 kg N ha^{-1} = N_0 , 40 kg N ha^{-1} = N_{40} , and 80 kg N ha^{-1} = N_{80}) as urea ($\text{CO}(\text{NH}_2)_2$) was applied 42 days after emergence to sorghum plants as a top dress. The treatments were arranged in a randomized complete block design with three replications. Soybean residue management options as described in the treatments were carried out before pod formation by soybeans. A schematic lay-out of the field experiment was as given below and was replicated in three blocks;

1 SS + N ₄₀	2 SS + SB (maturity) + N ₈₀	3 SS + SB (<i>exsitu</i> and plot tilled) + N ₄₀	4 SS + SB (incorporated) + N ₀	5 SS + SB (mulched) + N ₄₀	6 SS + SB (<i>exsitu</i>) + N ₀
12 SS + SB (incorporated) + N ₄₀	11 SS + SB (<i>exsitu</i> and plot tilled) + N ₈₀	10 SS + SB (maturity) + N ₀	9 SS + SB (<i>exsitu</i>) + N ₄₀	8 SS + N ₀	7 SS + SB (mulched) + N ₈₀
13 SS + SB (<i>exsitu</i>) + N ₈₀	14 SS + SB (mulched) + N ₀	15 SS + N ₈₀	16 SS + SB (incorporated) + N ₈₀	17 SS + SB (<i>exsitu</i> and plot tilled) + N ₀	18 SS + SB (maturity) + N ₄₀

2.3 Determination of On-site Soil and Leaf Nitrate Nitrogen

Supply of mineralized N was investigated over a sequence of dates as recommended by [23] using extractable inorganic soil- and leaf- nitrate-nitrogen and quantified by direct measurement in the field [24,25]. Three soil samples from every plot were collected by augering at 0 - 15 cm and each time putting in sealed plastic bags. The respective samples were then mixed thoroughly to obtain a representative sample for determination of soil NO₃-N concentrations. The composite soil samples in sealed plastic bags were placed in cooler box to protect them from heat. Soil solution of each composite was extracted by mixing soil with water at the ratio of 1:5 (10 g of soil + 50 ml of water) and 10 ml of calcium chloride was added. The sample was thoroughly shaken for 2 minutes until all the soil clumps had thoroughly dispersed. The sample was left to sit until a clear zone of solution formed at the top of the tube. The ISE meter was calibrated with two standard solutions for NO₃-N which was included in the kit. Using a dropper, 2 - 3 drops of the clear solution was put on the meter sensor. Once the meter reading stabilized (after 30 - 40 seconds) the value for NO₃-N concentration was recorded. Determination of soil NO₃-N concentrations was performed in duplicate for each treatment and the average recorded.

Leaf nitrate nitrogen was determined by selecting randomly, appropriate sizes from recently matured leaves of the sorghum plant on a fortnight interval. From each experimental plot, three sorghum leaf blades were selected, placed in sealed plastic bags and put in cooler boxes until

leaf samples from all experimental plots had been collected. At the end of the sample collection, the leaves were rinsed with distilled water and blot-dried with a paper towel. Direct sunlight/high temperatures were avoided during meter reading. With a sharp knife and on a cutting board, leaf blades were chopped and put in a plastic bag. The samples were then punched using a hand hammer to extract the juice. The corner of the bag bottom was cut to puncture the plastic bag then squeezed to collect the juice. The juice was then dropped to the nitrate meter sensor (about 0.3 ml) to cover the sensor. The measurement values were then read off and recorded once the meter reading stabilized. Leaf NO₃-N concentrations were determined in duplicate for each treatment and the average recorded. Concentrations of NO₃-N in the soil and leaf was evaluated over time during the growing period from 20 days after emergence at an interval of 2 weeks up to physiological maturity of sorghum plants to monitor the trends of both soil and leaf nitrate nitrogen. Prior to harvest, an area of 2 x 2 m was demarcated for measurement of crop yields.

2.4 Statistical Data Analysis

Data on concentrations of NO₃-N in the soil and leaf as well as sorghum yields were subjected to analysis of variance using GenStat software version 13.2 [26]. To test the differences between different soybean residue management options and N fertilizer rates, the means were analyzed using Tukey's Test at 95 per cent of significance level (P < 0.05). Pearson Correlation Coefficient (r) was used to show correlation between leaf nitrates and period of sampling during growing period of sorghum.

3. RESULTS AND DISCUSSION

3.1 Accumulation of Soil NO₃-N as Influenced by Soybean Residue Management Options and N Fertilizer Rates in Year 2012 and 2013

Accumulation of soil NO₃-N with respect to soil depth (0 – 15 cm) as influenced by soybean residue management options and nitrogen fertilizer rates is presented in Table 2. A comparison of soil NO₃-N accumulation with respect to years of study showed significant ($P < 0.001$) difference between treatments. A significant ($P < 0.001$) difference was noted in treatments with soybean left to maturity at fertilizer application rates of 0 kg N ha⁻¹, 40 kg N ha⁻¹ and 80 kg N ha⁻¹ that indicated 28%, 56% and 38% soil NO₃-N, respectively, in the year 2013 as compared to 2012.

At 40 kg N ha⁻¹, treatments with soybean residues mulched or incorporated indicated an increase in soil NO₃-N but were not significantly different and the concentration levels were lower than that of soybean residues left to maturity. In the year 2013, fertilizer N at 40 kg N ha⁻¹ with soybean left to maturity and soybean residues mulched at 80 kg N ha⁻¹ had significant difference ($P < 0.001$).

A comparison of nitrogen fertilizer application at 80 kg N ha⁻¹ in the year 2012 and 2013 indicated significant ($P < 0.001$) difference in soil NO₃-N accumulation between the treatments (i.e. soybean left to maturity, soybean residues mulched and soybean residues incorporated). The findings indicate the role soybean litter and residue incorporation play in nutrient cycling and in particular NO₃-N accumulation for use by the subsequent crop.

The study findings are supported by [9] who demonstrated the contribution of soybean litter to soil N buildup. The findings are further in agreement with the findings of [27] who reported an increase in NO₃-N with residues incorporated and N application at 40 kg ha⁻¹. The results also agree with [15] who showed that crop residues contribute to NO₃-N accumulation and soil N improvement.

In comparison with *in-situ* soybean residue management, the experiments with soybean residues removed showed significantly ($P < 0.001$) lower soil NO₃-N accumulation in response to nitrogen fertilizer application. The control experiment with sole sorghum indicated

still lower soil NO₃-N accumulation. The findings are in agreement with those pointed out by [14] and [6] indicating negative implications of residue removal on soil N improvement and signifying that intercropping cereals and legumes improves soil fertility.

3.2 Accumulation of Leaf NO₃-N as Influenced by Soybean Residue Management Options and N Fertilizer Rates during the Year 2012 and 2013

Leaf NO₃-N accumulation evaluated followed similar patterns of increase with increase in nitrogen fertilizer application in the year 2012 (Fig. 1a)

In the year 2013 (Fig. 1b), there were significant ($P < 0.001$) differences in NO₃-N accumulation with soybean left to maturity, indicating 43% increase from the previous NO₃-N concentrations when N was supplied at 40 kg ha⁻¹. Treatments with soybean residues mulched resulted in 39% increase while those with residues incorporated had 25% increase in NO₃-N accumulation at 40 kg ha⁻¹. Treatments with soybean residues removed, removed and tilled and sole sorghum recorded increase of 17%, 2% and 4%, respectively.

The control treatments (0 kg N ha⁻¹) with soybean left to maturity showed 18% increase in leaf NO₃-N accumulation in comparison with that of the previous year while soybean residues mulched and incorporated each indicated an increase of 13%. In contrast, the control treatments with soybean residues ex-situ and ex-situ and till indicated a negative influence of residue removal on NO₃-N accumulation (-6% and -7%, respectively). Percentage change in leaf NO₃-N concentration in sole sorghum in the year 2013 in comparison with the observed levels in the year 2012 indicated a uniform increase of 4% irrespective of nitrogen fertilizer rates.

The results on leaf NO₃-N accumulation with respect to some soybean residues management options (soybean left to maturity, mulched or incorporated) are in agreement with report by [28] who pointed out that mineralization of soil organic matter always provides a surplus of nitrate to the plant. Other findings [29] also showed an increase in plant N when rice was grown in rotation with winged bean, attributing the increase to addition of above ground plant parts and below ground plant residues of legumes.

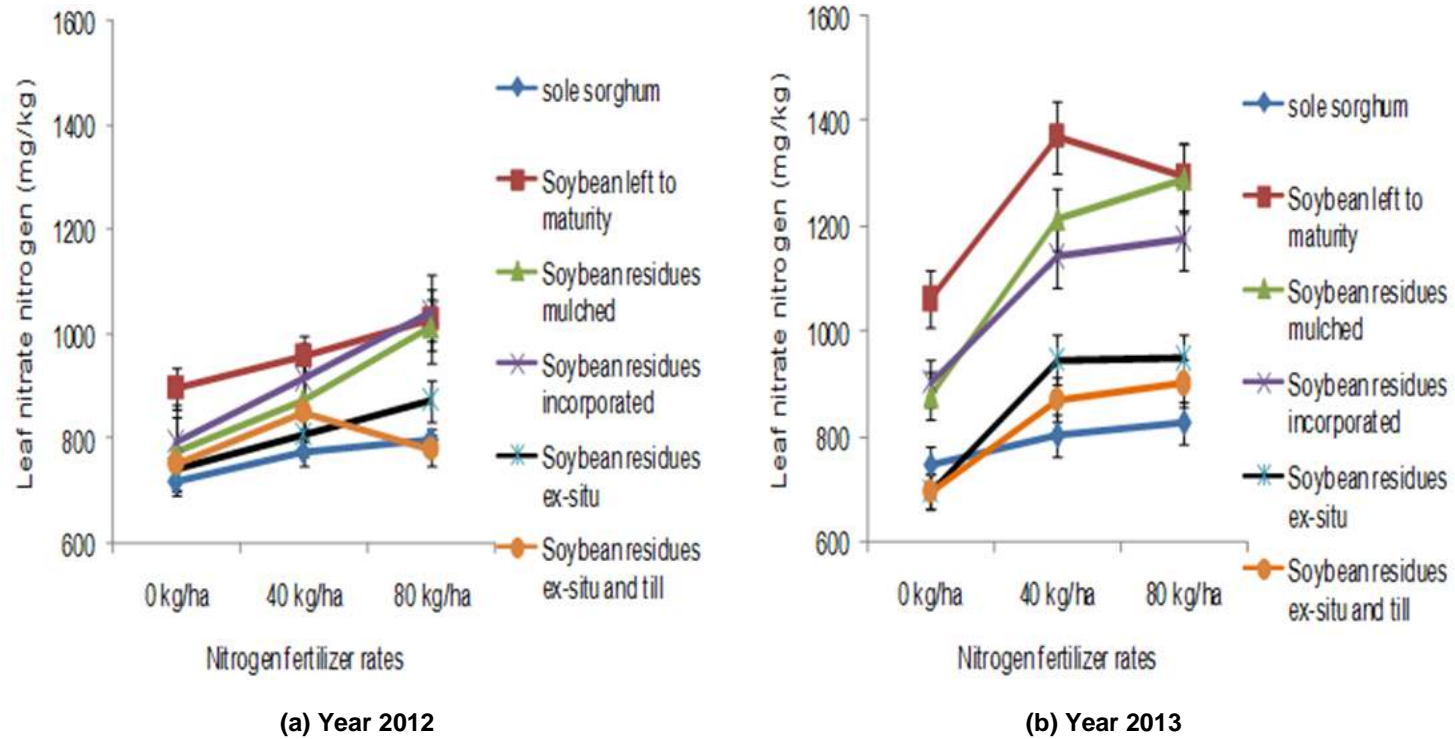


Fig. 1. Comparison of leaf NO₃-N accumulation in the year 2012 and 2013

Table 2. Accumulation and build-up of soil NO₃-N as influenced by soybean residue management options and N fertilizer rates

Soybean residue management option	Year 2012			Year 2013		
	Fertilizer rate (kg N Ha ⁻¹)			Fertilizer rate (kg N Ha ⁻¹)		
	0	40	80	0	40	80
Sole sorghum	25.08	26.28	27.08	28.23	29.75	30.70
Soybean left to maturity	28.01	30.64	32.15	34.88	41.08	39.18
Soybean residues mulched	28.08	29.73	31.94	31.14	38.10	40.79
Soybean residues incorporated	27.04	29.45	31.78	32.37	37.68	38.27
Soybean residues <i>ex-situ</i>	26.04	27.64	29.61	28.36	34.41	34.68
Soybean residues <i>ex-situ</i> + till	26.28	26.45	27.27	28.23	32.49	34.55
P value	0.001			0.001		
LSD _(0.05)	0.18			0.67		

The authors [6] were of the opinion that cereal-legume intercropping increases the amount of nitrogen, phosphorus and potassium contents compared with mono-cropping and this has been demonstrated by the findings of this study in relation to nitrogen. Removal of soybean residues indicated a negative effect on leaf NO₃-N accumulation and these findings are in agreement with [14] who observed that crop residue removal negatively impacted on soil NO₃-N, which has direct relation with leaf NO₃-N as shown in Fig. 2.

3.3 Accumulation of Soil- and Leaf - NO₃-N with Respect to Days after Emergence in the Year 2012 and 2013

The relationship between soil and leaf NO₃-N accumulation during the sorghum growing season indicates a similar pattern of increase in both years as shown in Fig. 2. In the year 2013, there was a significant (P < 0.001) increase in NO₃-N accumulation than in the year 2012. This was attributed to soybean residue mineralization and subsequent plant absorption resulting in NO₃-N accumulation in the sorghum leaves [28,29]. The results are supported by [13,15] and [7] who showed that legume species have potential to adequately contribute N for corn growth.

3.4 Relationship between Days after Emergence and Leaf NO₃-N Accumulation in the Year 2012 and 2013

When leaf NO₃-N accumulation is plotted versus the data sampling period in the year 2012 and 2013 (Fig. 3) a polynomial increase was noted, with the previous year indicating lower increase. The regression equation further indicated that the highest leaf NO₃-N accumulation occurred

between 60 - 70 days. The results suggest the need to apply mineral fertilizer much earlier (approximately 30 - 35 days) after emergence to meet N demand during vegetative stage and not late in the season.

The findings of the study agree with [4] who indicated that mineral fertilizer is prime in N supply and report by [7] and [29] on the important role legume residues play in soil N contribution. Researchers [30] also pointed out positive contribution of legumes on wheat N uptake, maturity and yield.

3.5 Sorghum Yield Response to NO₃-N Accumulation as Influenced by Soybean Residue Management Options and N Fertilizer Rates

The response of sorghum yields with respect to NO₃-N accumulation as influenced by soybean residue management options and N fertilizer rates are presented in Fig. 4.

From the data values, percentage increase of sorghum yields in the year 2013 up from the yields of the year 2012 in reference to soybean management options and nitrogen fertilizer rates is presented in Table 3.

The data derived indicated that the preceding soybean residues and nitrogen fertilizer application had significant (P < 0.05) influence on yield increase of sorghum in the year 2013 in comparison to year 2012. The increase in yield in the year 2013 suggests carry over soil NO₃-N from decomposing soybean residues and probably below ground biomass in the case of treatments with residues removed. The results on yield are in agreement with report by [29] who observed an increase in rice grain yield due to influence of legume residues and N fertilizer application.

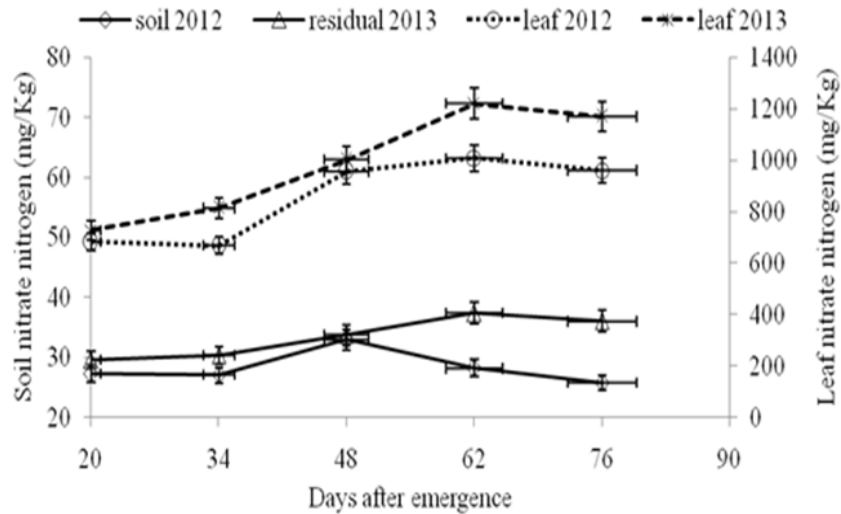


Fig. 2. Relationship between soil and leaf NO₃-N accumulation during sorghum growing season

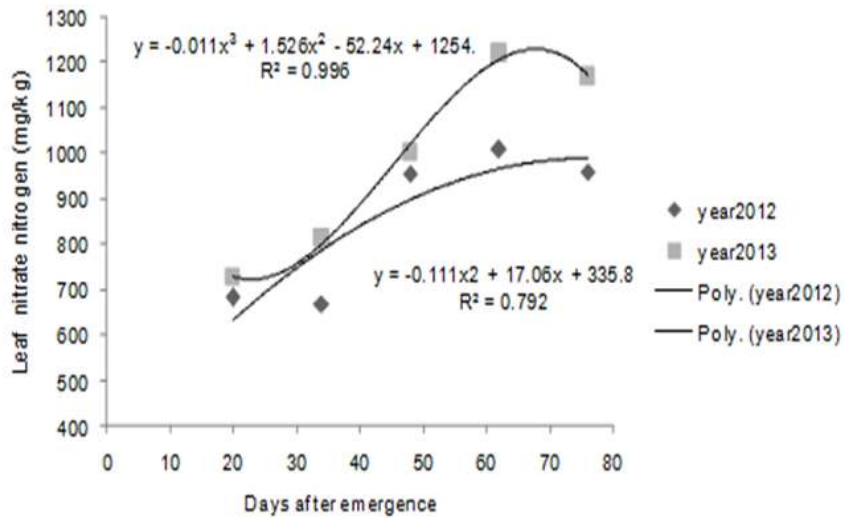


Fig. 3. Regression equation of the relationship between sampling times over the growing seasons (2012 and 2013) and leaf NO₃-N accumulation

Table 3. Percentage change in sorghum yield between 2012 and 2013 growing seasons

Soybean residues management option	Nitrogen fertilizer rates		
	0 kg/ha	40 kg/ha	80 kg/ha
Sole sorghum	-0.3	4	2
Soybean residues left to maturity	9	10	13
Soybean residues mulched	10	14	12
Soybean residues incorporated	7	5	7
Soybean residues <i>ex-situ</i>	-2	6	11
Soybean residues <i>ex-situ</i> + till	-2	6	5

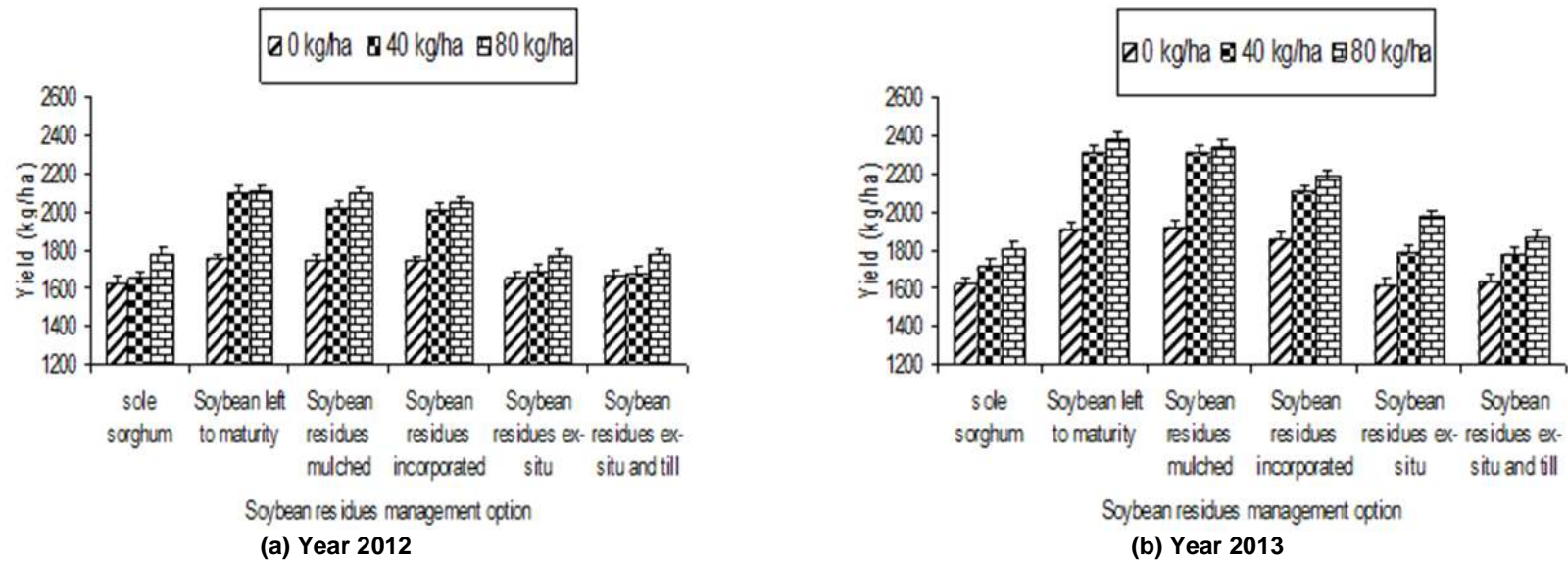


Fig. 4. Effects of soybean residue management options and nitrogen fertilizer rates on sorghum yields in the year 2012 and 2013

The results further indicate that in the year 2012, there was no significant difference in sorghum yields between soybean left to maturity, soybean residues mulched and soybean residues incorporated at 40 and 80 kg N ha⁻¹. However, in the year 2013, soybean left to maturity and soybean residues mulched had no significant difference in sorghum yield at 40 kg N ha⁻¹ or 80 kg N ha⁻¹ but indicated significantly higher yield than when soybean residues were incorporated. The results are supported by [9,15,27] who emphasized the potential contribution of soybean litter, mulch or incorporation of residues to soil N build up.

From the results obtained, the need for N fertilizer application cannot be over emphasized. The removal of residues from the field and sole sorghum cropping with no nitrogen fertilizer application showed a significant ($P < 0.001$) decrease in sorghum grain yield (lower than the previous yields). The results point out the need to supply inorganic nitrogen during the cropping season to meet the nutrient crop demand in the *Kanhaplic Haplustults* of Western Kenya.

Though there is appreciable accumulation of soil and leaf NO₃-N with respect to soybean residue management and nitrogen fertilizer rates to meet the crop N demand as reported by [17], it does not translate to research potential sorghum yields of 4 000 – 5 000 kg ha⁻¹ [31]. It is, thus, speculated that other plant essential nutrients inter-related with nitrogen could have influenced the obtained sorghum grain yield. For example, [32,33] indicated that there is a strong relationship between sulphur (S) and nitrogen (N) nutrition. The authors reported that the assimilatory pathways of S and N are functionally convergent i.e. sulphur is an essential component of enzymes involved in the metabolism of nitrogen (nitrate and nitrite reductase) and that the availability of one of the elements regulates the other.

4. CONCLUSIONS

From the results of the study, it can be concluded that:

- Fertilizer N application at 40 kg N ha⁻¹ with soybean residues left to maturity has the potential to accumulate soil and leaf NO₃-N accumulation for use during the growing season of grain sorghum.
- N fertilizer application at 40 kg N ha⁻¹ with sorghum soybean left to maturity increases

soil N by 56% but does not lead to optimal sorghum yields in the *Kanhaplic Haplustults* of Western Kenya, Busia County.

- Previous soybean residue removal and sole cropping in the year 2012 had negative influence on soil and leaf NO₃-N accumulation in the year 2013.

5. RECOMMENDATIONS

In the perspective of the above conclusions, the following recommendations are made:

- Growing of grain sorghum intercropped with soybean left to maturity in combination with nitrogen fertilizer application at 40 kg ha⁻¹ improves soil NO₃-N and is recommended be adopted to build up soil nitrogen, in the long term.
- Removal of soybean residues from the field should be discouraged as this has a negative influence on soil nitrate nitrogen and yields of grain sorghum.
- Further research on sulphur is recommended to be carried out in order to establish whether the nutrient element is limiting in the studied soils in order to optimize sorghum grain yields.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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