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Effect of Legumes on Nitrogen Use Efficiency of Wheat in a Short Term Crop Rotation in Njoro Sub-County

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Aims: The study determined the effect of legumes in short term crop rotation (cereal – legumes cropping systems) on nitrogen use efficiency of wheat.

Study Design: A randomized complete block design (RCBD) was used in a split-split-plot arrangement replicated three times. Three factors evaluated included water harvesting (WH), crop rotation (CR) and soil fertility management (SFM). The data obtained were subjected to an analysis of variance (ANOVA) using Genstat statistical package while the mean separation was performed using least significance differences (P =.05).

Place and Duration of Study: The trial was conducted at the Kenya Agricultural and Livestock Research Organization (KALRO) fields based in Njoro for three years between 2014 and 2016 during rainy seasons.

Methodology: The treatments consisted of four pre-crops in the rotation systems (CR1 = Dolichos lablab (*L. purpureus)* as a pre-crop; CR2 = Green pea (*Pisum sativum)* as a pre-crop; potato

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(*Solanum tuberosum*) as a pre-crop; and CR4 = continuous wheat (*Triticum aestivum*), two water harvesting (WH) strategies (WH = flat beds; and WH= tied ridges) and six soil fertility management (SFM) strategies (SFM1 = untreated control; SFM2 = FYM at 5 t ha^{-1}; SFM3 = Green manure (*Leucaena trichandra*) at 2.5 t ha^{-1}; SFM4 = inorganic source at 25 kg N ha^{-1}; SFM5 = inorganic source at 50 kg N ha^{-1}; and SFM6 = Inorganic source at 75 kg N $ha^{-1)}$..

Results: The results revealed that the value of NUE significantly ($p < 0.001$) increased when *P. sativum* and *L. purpureus* preceded wheat in the short term crop rotation system. The value of NUE increased by 39% and 44%, when wheat was preceded *L. purpureus* and *P. sativum,* respectively, relative to *S. tuberosum*. Under continuous wheat, NUE value was increased by 54.17% relative to potato as a pre-crop. Overall, the contribution of legumes (*L. purpureus and P. sativum*) as precursor crops was greater than those observed with potato and wheat as pre-crops.

Keywords: Triticum aestivum; Pisum sativum; Leuceana trichandra; Lablab purpureus.

1. INTRODUCTION

Although the majority of the people leaving in the Sub – Saharan Africa (SSA) did not consider wheat as a traditional stable food crop, it has become an important food crop because of rapid population growth associated with increased urbanization and change in food preference for easy and fast foods. Despite the increase in demand for wheat products, the regional is relatively low standing at 2 tonnes ha^{-1} principally because of declining soil fertility among other abiotic stresses [1]. The growing gap between demand and supply of food in SSA requires improved agricultural practices that overcome current crop production constraints which include erratic rainfall patterns and poor soil fertility status among others [2].

In order to enhance wheat yield, there is need to address the declining soil health by adopting the use of legumes as pre-crops to help enhance N use efficiency to address sustainable wheat production. Legumes play an important role in Sub-Saharan Africa (SSA) farming systems through the provision of food, feed, fuel, income and a range of biophysical benefits, such as soil fertility enhancement and erosion control [3]. However, their full potential is not being realized because of various reasons. In one instance, it was reported that that farmers emphasize the importance of legumes in terms of their short-term benefits such as food and income rather than long-term benefits such as natural resource management and thus grain legumes are more readily identified by farmers than forage species. [4] reported that rotations with lupine (*Lupinus* spp.) and field peas (*P. sativum* L.) showed high NUE and NU_pE and in pea. Other reports have shown the inclusion of legumes in crop rotation as one of the potential ways of increasing the available N supply for cereals at low cost [5] and [6].

Accordingly, the inclusion of legumes in a cropping sequence has the potential to improve soil quality, porosity, and structure [7] and [8] and influence specific microorganism populations in the rhizosphere [9] and [10] for the benefit of the subsequent crops. The combined impact of all these factors is that post-legume cereal yields are often reported to be 40-80% greater than that achieved in cereal without N fertilizer, representing an additional 450-1000 kg of additional grain per hectare across a range of environments [11] and [12]. There is little information on the N mineralization rate in the legume-wheat rotation and how it is related to the N uptake by the wheat crop in Njoro Sub - County. In addition, this study should contribute to a better understanding of the dynamics of legumes in rain fed Sub - County in wheat cropping system, and their contribution to wheat N nutrition.

In a previous publication [13] it was reported that grain legumes fixed large amounts of N_2 and wheat yields following grain legumes were 70-110% of the yields achieved by N-fertilized wheat crops grown following oats. The objective of this study was to assess the contribution of legumes to NUE, NU_tE and the N uptake by the wheat crop following grain legumes in Njoro Sub-County.

2. MATERIALS AND METHODS

2.1 Description of the Study Site

The study was conducted for three seasons between 2014 and 2016 at the Kenya Agricultural and Livestock Research

Organization (KALRO), Njoro Centre (GPS Coordinates: Latitude -0.342644; Longitude 35.946747; Elevation of 2172m above sea level) in Njoro Sub-County (District), Kenya. The site lies within the Agro-ecological zone LH3 (AEZ LH3) with a bi-modal rainfall pattern [14] and receives an annual rainfall of about 960 mm with an average maximum and minimum temperatures of 24^{o}C and 8^{o}C, respectively [15]. The soils are well drained, deep to very deep, dark reddish brown, friable and smeary, silt clay, with humic topsoil classified as mollic Andosols [14].

2.2 Treatments

2.2.1 Cropping Rotation (CR) systems

Four CR systems consisted of CR1 = Wheat (*T. aestivum* L) – Dolichos (*L. purpureus*) – Wheat (*T. aestivum* L); CR2 = Wheat (*T. aestivum* L) – Green pea (*Pisum. sativum*) – Wheat (*T. aestivum* L); CR3 = Wheat (*T. aestivum* L) – Potato (*Solanum tuberosum*) – Wheat (*T. aestivum* L); and CR4 = Continuous *Triticum aestivum* L. In the first and the final year of cropping cycle (2014 and 2016), wheat was planted in all the plots as a way of stabilizing the soil fertility in the first year and to establish the cumulative effect of soil treatments and water harvesting strategies on wheat NUE, NUpE and NUtE as well as WUE. However, in 2015, crop rotation had all the crops coming after wheat in 2014 and preceding wheat in 2016.

2.2.2 Water harvesting (WH) strategies

Two WH (WH1= Normal/Flat beds and WH2 = Tied ridges) strategies were evaluated for three seasons. In the plots occupied by *T. aestivum*, *P. sativum* and *L. purpureus,* tied ridges were constructed immediately after planting by heaping soil around the plots whereas in the plots occupied by *S. tuberosum*, tied ridges were constructed within the furrows between rows at planting. On the potato plots the tied ridges were maintained further during weeding. However, normal or flatbeds were prepared normally without raising the plots in all the test crops.

2.2.3 Soil Fertility Management (SFM) strategies

Six soil fertility management (SFM) strategies evaluated included: i) Untreated control; ii) Farm yard manure (FYM) (using dried cow dung) at 5 t ha^{-1}; iii) Green manure (GM) of an agro-forestry tree (*Leuceana trichandra*) at 2.5 t ha^{-1} on dry matter basis; iv) Inorganic N source at 25 kg N ha^{-1}; 50% below the recommended rate; v) Recommended rate of inorganic N source at 50 kg N ha^{-1} and vi) Inorganic N source at 75 kg N ha^{-1}; 50% above the recommended rate. Rock phosphate was applied blanket in all plots at 125 kg P_2O_5 ha^{-1} excluding the untreated control during planting.

The *L.trichandra* biomass was harvested every season from the Kenya Forestry Research Institute (KEFRI) at Muguga. The fresh biomass was weighed immediately and the biomass was then transported to KALRO Njoro where it was shredded using a tractor mounted shredder. Six kgs of shredded biomass was weighed in bags and spread evenly along the furrow or uniformly in plots depending on the water harvesting strategy and crops. The biomass was covered immediately after application with a thin layer of soil to avoid N volatilization.

2.3 Field Experimentation

2.3.1 Establishment of the trials

Wheat were planted on plots measuring 4.5 x 3 m consisting of 23 rows spaced at 20 cm between the rows and drilled continuously using plot seeder at a seed rate of 100 kg ha^{-1}. Potato (*Solanum tuberosum*) was planted in plots measuring 4.5 ^{x} 3 m consisting of 7 rows, spaced at 0.75 m between the rows and 0.3 m (10 plants per row) within the row. The two rows of potatoes on the extreme ends and 0.5 m on both ends of the plots served as guards and were used for destructive sampling. Similarly, *L. purpureus* and *P. sativum* were planted in the same plot size as potatoes and wheat, spaced at 50 cm between the rows and 25 cm between plants within the rows. This translated into 9 rows each consisting of 12 holes (plants). A blanket treatment of 100 kg P_2O_5 ha^{-1} rock phosphate (30% P_2O_5) fertilizer was applied at planting to all plots except the untreated ones.

Water harvesting (WH) strategies in the form of either tied or normal ridges were constructed, taking into account the test crops planting requirement in terms of seedbed. The tied ridges were constructed by hand at an interval of one metre within the normal ridges after planting the crops. In the case of normal ridges, no constructions were done hence it was normal field allowing free flow of water. The tied ridges

(TR) were destroyed during land preparation in the following season to allow free movement of machineries and also to avoid compaction of the soils. The TRs were maintained in the same position and plot throughout the study period in both seasons.

2.3.2 Experimental management

Standard crop management procedures for the control of weeds, insect pests and diseases were used. However, before seedbed preparation, roundup (glyphosate) was applied at 3 L ha^{-1} to clear the perennial weeds while Ariane (Fluroxypyr + Chlorpyrlid + MCPA total acid equivalent to 350 g/lt) was applied at 1.0 L ha^{-1} as a post-emergent herbicide from 3 leaf stage of wheat to control broadleaved weeds. Foliar diseases in wheat were controlled by Folicur in wheat while in potato and legumes and Thunder was used to control insect pests in all the crops. However, in potato and the two legumes (*L. purpureus* and *P. sativum*) weeds were controlled by hand weeding. Weed control was performed by hand weeding after two weeks from emergence while earthing the potato crop at the same time. Fungal diseases in wheat were controlled by using Folicur 250WP at 100 ml in 20 L of water whereas Ridomil at 250 gm in 20 L of water was used in potatoes and legumes while insect pests were controlled using Thunder at 50 ml in 20 L of water.

2.4 Soil Sampling and Analysis

Soil samples were collected on the top (0 -30 cm) in representative spots within the plots prior to planting and after harvest before the next season. Samples were air-dried and sieved using a 2 mm sieve after which they were subjected to chemical analysis at KALRO, Njoro Centre soil laboratory as described and [14]. Total N and available P were determined by micro Kjeldahl and molybdenum blue colorimetry methods, respectively. Exchangeable K, Ca and Mg were extracted using ammonium acetate. Organic Carbon (%) in the soil sample was oxidized by acidified dichromate at 150^0C for 30 minutes to ensure complete oxidation [16]. Soil pH was measured using a soil water ratio of 1:2.5 (w/v). The results are presented in Table 1.

2.4.1 Determination of soil reaction (pH), Total N and Soil moisture

A soil suspension was prepared with distilled water keeping 1:2 soil to water ratio and the concentration of hydrogen ions in soil (pH) of suspension was measured by potentiometric method [16]. Total nitrogen (N) was determined using micro kjeldahl digestion method where organic N in presence of H_2SO_4, K_2SO_4 and $CuSO_4$ catalyst amino nitrogen of many organic materials is converted into ammonium [18]. The Ammonia was determined by titration with a standard mineral acid (dilute H_2SO_4), [19]. The colorimetric method described by [20] was used for soil organic C. Total N was also measured colorimetrically following Kjeldahl digestion [21]. Microbial biomass C and N were measured by chloroform fumigation for 12 h followed by extraction with 0.5 M K2SO4 [23]. Carbon in the extract was measured colori- metrically by the method of [22].

Soil moisture was measured in volumetric water content using a Time Domain Reflectance (TDR) meter to a depth of 16 mm at a weekly interval at four pre-determined spots in each plot of all the test crops between 8 and 10 am. The soil moisture content was monitored on a weekly basis at a depth of 160 mm at four randomly selected spots within each plot using of a Time-Domain-Reflectometry (TDR) 300 [23] soil moisture meter.

2.5 Data Collection

2.5.1 Measurements of parameters on wheat (*Triticum sativum*)

The data on number of tillers were recorded four weeks after emergence using a 1 m^2 quadrant. Using the number of seedlings per metre, the number of tillers per plant was calculated. Number of spikes was determined at physiological maturity using a $1m^{-2}$ quadrant. The quadrant was placed at two randomly selected spots within each plot.

Table 1. Initial soil values before the experimentation

Sampling depth (cm)	pH	C (%)	N (%)	P (%)
0 -15	6.25	2.39	<u>0,21</u>	<u>10.5</u>
15 – 30	5.65	2.09	<u>0.17</u>	<u>10.5</u>
Critical level	5.5 – 6.5	2 – 4	0.25	35

Underlined values indicate inadequate levels

All the plants within the quadrant were counted and the number of spikes were counted then averaged between the two quadrant samples. Wheat grain yield (12.5% moisture content) was determined by harvesting the center 18 rows by 3 m long using sickles.

2.5.2 Measurements of parameters on potato (*Solanum tuberosum*)

Above ground biomass was determined at 50% physiological maturity by sampling from the outer rows measuring a metre long. The material from crops was sun dried first and then oven dried at 70 °C until constant weight was attained and the final weight was expressed as kg m^2. Tuber yield and above ground biomass was determined by harvesting net plot consisting of 6 rows covering a length of 2 metres.

2.5.3 Determination of Nitrogen Use Efficiency (NUE) and its components, Nitrogen Uptake Efficiency (NU_pE) and Nitrogen Utilization Efficiency (NU_tE)

Nitrogen use efficiency (NUE) was determined on the basis of nitrogen utilization efficiency (NU_tE) at the end of the third season using the mean soil N and applied N across three seasons. Plant samples collected at harvest (wheat plots) were separated into grain and straw then both were oven-dried at 70°C for 48 hours up to a constant weight. Dried grain and straw samples were milled to 1 mm with Retsch mill (model:mm400) using chromium balls and the flour was thereafter put in test cells for nitrogen determination using FOSS Near Infrared (NIR) model Infratec 1241 Grain Analyzer [24]. In this study, nitrogen use efficiency (NUE) and its associated attributes were determined using various credible formulae.

For NUE of wheat, biomass and grain nitrogen content were used, hence in this study NUE was computed in accordance with [25] and [26]. But because the nitrogen content was derived from protein content, it was therefore obtained by diving the protein content (%) by a factor of 5.7 [27].

Other important associated attributes of NUE including nitrogen uptake efficiency (NU_pE) and nitrogen utilization efficiency (NU_tE) were computed using the formulae stated below:

$$\text{Nitrogen uptake efficiency } (NU_pE,\ kg\ kg^{-1}) = N_t / N_{supply} \quad [1]$$

Where N_t is total plant N uptake in kg ha^{-1} and was determined by multiplying dry weight of plant parts by N concentration of the plant samples and summing up for total uptake.

N_{supply} is the sum total of mean soil N content at sowing, mean mineralized N and N-uptake in control (0 N applied). Nitrogen (N) supply fertilizer was therefore determined according to [28] as sum of (i) mean N applied across seasons as fertilizer and (ii) mean total N uptake in control (0 N application).

In this study, NU_pE and NU_tE were also computed because of their importance in exhibiting the efficiency of the crop in obtaining N (applied and native) from the soil. NU_tE has been used as a strategy to increase NUE by [29] and it was computed using the formula below:

$$\text{Nitrogen utilization efficiency } (NU_tE,\ kg\ kg^{-1}) = G_y / N_t \quad [2]$$

Where G_y is grain yield in kg ha^{-1} and N_t is total plant N uptake in kg ha^{-1} determined by multiplying dry weight of plant parts by N concentration and summing over parts for total uptake.

$$\text{Nitrogen use efficiency } (NUE,\ kg\ kg^{-1}) = G_y / N_{supply} \quad [3]$$

Where G_y is grain yield in kg ha^{-1} and N_{supply} is the sum total of soil N content at sowing, mineralized N and N-uptake in control (0 N applied) in kg ha^{-1}.

2.6 Data Analysis

The data was subjected to an analysis of variance (ANOVA) using Genstat 15th edition statistical package [30]. The main factor was tested using error (a), sub-plot factor using error (b) while sub-sub factor using error (c). Multiple comparison of means was done using Fishers's least significant difference at 5% significance level. Trends were indicated whenever there were no statistical significance.

3. RESULTS AND DISCUSSION

3.1 Cumulative Effect of Crop Rotation (CR) on Nitrogen use Efficiency (NUE) of Wheat

Significantly lower NUE values were observed when wheat was preceded by potato were depressed than in any of the pre-crops (Table 2). However, the NUE values were significantly increased when green pea and dolichos preceded wheat compared to potato and wheat as pre-crops. The NUE values when dolichos and green pea preceded wheat increased by 39% and 44%, respectively, relative to potato as a pre-crop. Under continuous wheat, NUE value was increased by 54.17% relative to potato as a pre-crop. Overall, the contribution of legumes (*L. purpureus and P. sativum*) as precursor crops was greater than those observed with potato and wheat as pre-crops. With reference to the results obtained in this study, it was evident that the NUE value was significantly higher when *P. sativum* was preceded by legumes (*L. purpureus* and *P. sativum*) as compared to the other cropping systems. *L. purpureus* as a pre-crop in the rotation increased the value of NUE by 39% and 13%, relative to *S. tuberosum* and *P. sativum* as the preceding crops, respectively. However, in the case of *P. sativum* as pre-crop, the value of NUE rose by 44% and 17% above *S. tuberosum* and wheat as pre-crops, respectively. This was attributable to the fact that the inclusion of legumes in the crop rotation increased the ability of the soils to accumulate more N and the same time it influenced soil moisture accumulation.

Legumes as cover crops (pre-crops) have considerably added soil organic matter (SOM) that may hold moisture as sponge and improve microbial activities thereby playing a vital role in soil ecosystem sustainability and this has a great potential of increasing the available N supply for subsequent cereals [5][13]. The benefits due to the inclusion of legumes in a cropping sequence can also improve soil quality, porosity, and structure [31] [8] and influence specific microorganism populations in the rhizosphere [9] [10] for the benefit of the subsequent non-fixing crops. Although grain legumes grown in rotation with annual cereal crops are expected to contribute to the total pool of nitrogen in the soil and improve the yields of cereals, the anticipated N benefits of the legume may be positive or negative depending on legume species and its interaction with the environment [32]. The importance of choosing the right legume species for a specific *T. aestivum* farming system has been emphasized further by the fact that different legume species and varieties growing in the same location can differ significantly in dry matter production, nitrogen fixation and accumulation, and residue quality [33].

The superior performance of green pea is attributable to several reasons. For example [34] reported that 91% of the wheat yield benefit from a preceding pea crop due to reduced leaf disease and weed infestation, while only 9% was estimated to have derived directly from N. Furthermore, the benefits in N nutrition to wheat have been attributed to break crops simply because the healthier root system which enhances the ability to utilize existing soil N or applied N more efficiently [35]. Other researchers have also reported that planting a legume pre-crop instead of summer fallow with legume crops improved soil fertility and reduced nitrate leaching thus contributing to increased N use efficiency [36, [37] and [38].

3.2 Cumulative Effect of Crop Rotation (CR) on Nitrogen Utilization Efficiency (NU_tE)

Nitrogen utilization efficiency (NU_tE) was significantly ($p < 0.05$) influenced by the cumulative effect of crop rotation, with lower values being observed when wheat was preceded by potato than in any of the pre-crops (Table 1). The three crops (*L. purpureus, P. sativum* and *T. aestivum)* resulted in significantly greater NU_tE than *S. tuberosum* or *T. aestivum* as pre-crops. Under continuous wheat system (39.42 kg N kg N^{-1}) a significantly higher NU_tE value was obtained compared to potato as a pre-crop (29.12 kg N kg N^{-1}). This resulted to a reduction of NU_tE by 35% compared to continuous wheat.

Higher soil moisture was significantly influenced by CR with legume pre-crops resulting in greater soil moisture than potato and continuous wheat. The high soil moisture might have enhanced N uptake and utilization efficiency ultimately resulting in increased NUE because it is a product of the two components (NU_tE and NU_pE). Scientific basis of this builds on the fact that the humus content formed by the biomass from legumes could have also helped in maintaining the soil physical structure in turn enhancing better soil moisture retention. This also concurs with the findings of [39] who observed that when organic inputs are incorporated into the soil, they increase water absorption, reducing water loss as well as improving soil moisture content. Thus, an understanding of the processes associated with NUE, especially in relation to its primary components (uptake and utilization efficiency), are among the most important factors in determining strategies for the management with the aim of improving NUE [40]. Nitrogen utilization efficiency (NU_tE) reflects the ability of the plant to translocate the absorbed N (N uptakes) into grain [25]. The NU_tE response to preceding crop was similar to the corresponding response of NU_pE. In this study, preceding crops influence on wheat yield and highest NU_tE value were observed in *S. tuberosum*- *T. aestivum* rotation. This agrees with [41], who reported that increasing grain yield increased NU_tE, reported a strong relationship between NU_tE and yield.

Furthermore, [26], reported that crop rotation has marked influence on the utilization of resources. Results showed that there was a positive correlation between NU_tE and yield as well as biomass. This observation implies that the influence of NU_tE through the accumulation of above ground biomass is important and can be used to indirectly enhance NUE via nitrogen harvesting index (NHI).

3.3 Cumulative Effect of Crop Rotation (CR) on Nitrogen Uptake Efficiency (NU_pE)

Significant ($p < 0.05$) differences were observed on N uptake efficiency (NU_pE) among the crop rotation treatments (Table 2). The NU_pE value obtained due to green pea as a pre-crop was significantly higher than those attained with dolichos and wheat as pre-crops. The highest NU_pE value (78.75 kg N ha^{-1}) was obtained when wheat was preceded by green pea while the lowest value (54.84 kg N ha^{-1}) was observed with potato as a pre-crop. The effect of greenpea as a precursor crop increased the value of NU_pE by 44% while dolichos had an increase of 31% relative to potato as a pre-crop. Continuous wheat (68.01 kg N ha^{-1}) also resulted in a significantly higher NU_pE value than potato as a pre-crop (54.84 kg N ha^{-1}). This translated to increase of NU_pE value by 19% due to wheat relative to potato as a pre-crop. The lower NU_pE of wheat following potato - wheat rotation disagrees with the observations by [42] who reported higher NU_pE value on wheat grown following potato – wheat rotation system. The relatively higher value of NU_pE observed in the continuous wheat (cereal monoculture) shows the impact of this rotation in depleting soil N.

The average NU_pE of 78.75 kg N ha^{-1} (equivalent to 1.575 kg N uptake kg^{-1} N supply) and 71.81 kg N ha^{-1} (equivalent to 1.436 kg N uptake kg^{-1} N supply) observed when wheat was grown after green pea and dolichos, respectively, were higher than the average 0.49 kg N uptake kg^{-1} N supply reported by [26]. These observations could be attributed to the fact that the study referred here was conducted under Mediterranean climate conditions as opposed to ours that was done under tropical environment. The differences therefore could be explained by the variance in soils, duration of the experiments, and different legume varieties used.

Table 2. Effect of preceding crops (Crop rotation) on nitrogen use efficiency (NUE), nitrogen utilization efficiency (NU_tE), and nitrogen uptake efficiency (NU_pE) of wheat

Pre-crop in the rotation	Crop Rotation Cycle	NUE (%)	NU_tE (kg grain kg N^{-1})	NU_pE (kg kg N^{-1})
Dolichos	W – Dol - W	61.19 a	37.73 a	71.81 b
Greenpea	W – Gp - W	-63.15 a	37.98 a	78.75 a
Potato	W – Pot - W	43.91 c	29.12 b	54.84 c
Wheat	W – W - W	54.17 b	39.42 a	68.01 b
LSD (0.05)	-	5.23	2.264	6.57
CV (%)	-	4.7	3.1	4.8

Means on the same column with the same letter are not significantly different at p < 0.05; Key: W= wheat; Dol = dolichos; Gp = green pea

3.4 Interaction Effect of Crop Rotation (CR) and Soil Fertility Management (SFM) on Nitrogen use Efficiency (NUE) of Wheat

The most competitive NUE value was obtained under organic sources of fertility as compared to the inorganic sources (Fig. 1). Farm yard manure (FYM) at 5 tonnes ha^{-1} increased the NUE of wheat by 42% while the increase due to Green manure (*L. trichandra* at 2.5 tonnes ha^{-1}) was 35%. Generally it was evident that the soils required some fertility amendment based on the observation that organic source of soil fertility amendment as well as lower rate of inorganic (25 kg N ha^{-1}) resulted in significantly higher NUE than the untreated control. The increase in NUE due to organic source of soil amendment especially FYM could be due to the fact that FYM having a low C/N ratio, decomposes fast and readily releases plant available nutrients. In doing so, FYM builds up soil organic matter (SOC) which is an important indicator of soil health, particularly with regard to soil fertility for crops. This agrees with [43] who reported increased nutrient bio-availability due to SOM (soil organic matter) decomposition, and more exchange sites for mineral nutrients increasing the soil's cation exchange capacity (CEC). Other benefits of SOC can be more pronounced on unfertilized soil, where it may provide 90% of plant available N, 80% of plant available P, and 50% of plant available S, as well as micro nutrients [44].

Inorganic source of N resulted in different effects on the NUE value. Application of inorganic fertilizer at 25 kg ha^{-1} (50% lower than recommended rate) improved NUE by 41% and depressed value were observed when rates higher that 25 kg N ha^{-1} with the least value of NUE being obtained at 75 kg N ha^{-1} (which is 50% higher than the recommended rate). This disagrees with [45] who reported that sole mineral fertilization or over application enhances the decomposition of soil organic matter (SOM), which leads to degraded soil structure and declined soil aggregation and loss of nutrients through leaching, fixation, and greenhouse gases emission.

3.5 Cumulative Interaction Effect of Crop Rotation (CR) and Soil Fertility Management (SFM) on Nitrogen Utilization Efficiency (NU_tE) of Wheat

The results showing cumulative effect of crop rotation (CR) and soil fertility management (SFM) nitrogen utilization efficiency (NU_tE) are presented in Fig. 2.

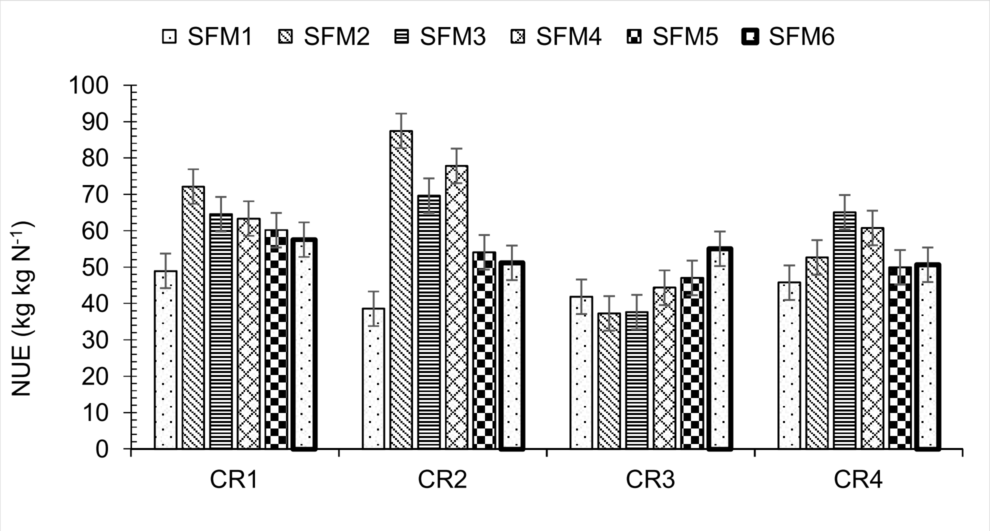

Fig. 1. Interaction effect of crop rotation (Pre-crop) and soil fertility management (SFM) on nitrogen use efficiency (NUE) of wheat

Key: SFM1 = untreated control; SFM2 = Farm yard manure (FYM) at 5 tonnes/ha; SFM3 = green manure (L. trichandra); SFM4 = inorganic N source at 25 kg N/ha; SFM5 = inorganic source at 50 kg N/ha; SFM6 = inorganic source at 75 kg N/ha

Significant interactions effect of crop rotation (CR) and soil fertility management (SFM) were observed on NU_tE of wheat. The interaction between soil fertility management (SFM) strategies and *L. purpureus, P. sativum* or *T. aestivum* as pre-crops significantly ($p < 0.05$) influenced NU_tE. Wheat planted in untreated control (SFM1) plots following potato as a pre-crop, significantly reduced the NU_tE value (by 26% and 32%) compared to *L. purpureus* and *P. sativum* as pre-crops, respectively. However wheat fertilized with inorganic fertilizer (SFM5) at 50 kg N ha^{-1}) in plots that were previously occupied by dolichso and green pea resulted in increased NU_tE value by 14% and 12%, respectively. It was evident that planting wheat with the recommended rate of inorganic fertilizer (50kg N ha^{-1}) in plots that were previously occupied by legumes (*L. purpureus* and *P. sativum*) increased the utilization efficiency of the recovered N (uptake).

Wheat grown with the highest rate of inorganic fertilizer (75 kg N ha^{-1}) after potato increased NU_tE value compared to the lower rate of inorganic N fertilizer and organic sources of fertilizer. It was clearly evident that under low rates of inorganic fertilizers with legumes as pre-crops the ability of wheat to utilize either the inherent or applied N was more enhanced. Since legumes are able to fix symbiotically atmospheric N_2, they require minimal or even no inputs of N fertilizers. Thus, with legumes as pre-crops application beyond 50 kg N ha^{-1} instead depressed the ability of wheat to utilize applied or inherent soil N (reduced NU_tE). This could be attributed to the fact that higher N rates suppressed the effectiveness of soil microorganisms to fix N.

Thus it is important to adopt a crop management system that has the potential to enhance NU_tE of wheat in order to reduce loss of N through leaching. In view of this, a sustainable soil fertility management system should be designed by choosing crops that have the ability to either recycle or replenish nutrients through biomass or atmospheric N fixation. For example in the case of this study, no significant effect was observed on NU_tE when wheat was grown in plots previously occupied by potato irrespective of the SFM strategies evaluated. However, the value of NU_tE improved with application of the highest (75 kg N ha^{-1}) rate of inorganic fertilizer.

Low rates of inorganic fertilizers with legumes as pre-crops increased the ability of wheat to utilize either the inherent or applied N. Since legumes are able to fix symbiotically atmospheric N_2, they require minimal or even no inputs of N fertilizers. Thus, with legumes as pre-crops, an application of inorganic fertilizer beyond 50 kg N ha^{-1} instead depressed the ability of wheat to utilize applied or inherent soil N (reduced NU_tE). This was further explained by the fact that most crops especially potato and some horticultural ones deplete soil nutrients during their growth cycle and some of these nutrients leave the farm as harvested products. The findings of this study disagree with [46], who reported increased NUE, NU_tE and NU_pE wheat grown after potato. The variance between the two studies could be because they were conducted in contrasting environments. It was therefore important to note that growing wheat after potato in the tropical environment like with high rainfall may require increased rates of inorganic fertilizer on the preceding grain legume.

3.6 Interaction Effect of Crop Rotation (Pre-crop) and Soil Fertility Management (SFM) on Nitrogen Uptake Efficiency (NU_pE) of Wheat

The interaction of crop rotation (CR) and soil fertility management (SFM) on NU_pE as presented in Fig. 3 demonstrated a significant ($p < 0.05$) effect on NU_pE. There was no significant differences observed on the value of NU_pE due to the interaction between the use of green manure and various pre-crop systems. This translated into an increase in the value of wheat NU_pE by 43% when wheat crop was planted with green manure at 2.5 t ha^{-1} and preceded by green manure relative to when wheat was fertilized with green manure and preceded by potato.

Among the SFM strategies evaluated, a significantly greater NU_pE value was observed with an application of Farm Yard Manure (FYM) at the rate of 5 t ha^{-1} than the untreated control. Use of organic sources such as FYM at 5 t ha^{-1} and green manure (*L. trichandra* at 2.5 t ha^{-1}) increased the value of NU_pE values by 80% and 70.86%, respectively, while the lowest rate (25 kg N ha^{-1}) of inorganic source of N increased the value of NU_pE by 75.15%. These findings disagreed with the findings of [47] who reported lower N uptake efficiency from organic sources than those obtained from inorganic N source because the study used manure from beef animal (its manure contains 0.57% N)

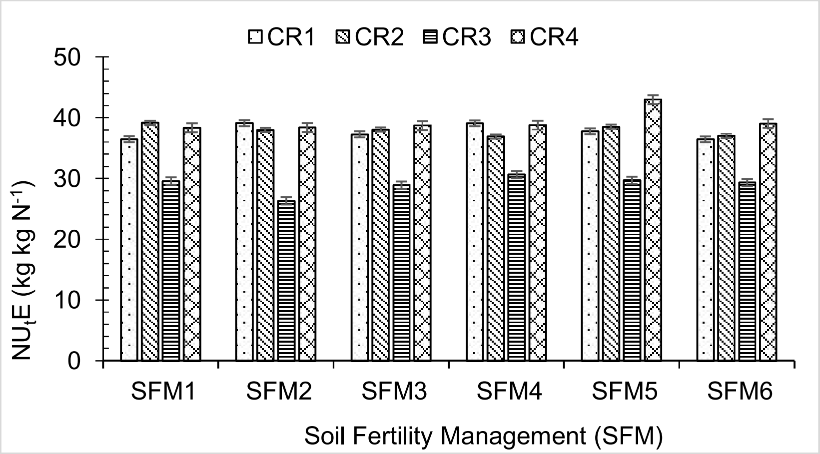

Fig. 2. Interaction effect of crop rotation (Pre-crop) and soil fertility management (SFM) on nitrogen utilization efficiency (NU$_t$E) of wheat

Key: CR1 = Wheat – dolichos – wheat; CR2 = wheat – Green pea – wheat; CR3 = wheat – potato – wheat; CR4 = wheat – wheat – wheat; SFM1 = untreated control; SFM2 = Farm yard manure (FYM) at 5 tonnes/ha; SFM3 = green manure (L. trichandra); SFM4 = inorganic N source at 25 kg N/ha; SFM5 = inorganic source at 50 kg N/ha; SFM6 = inorganic source at 75 kg N/ha

while in the current study the cattle manure (contains 0.52% N) was used. This variation is further explained by [48], who reported that nutrient value of animal manures is more variable because it is influenced by the animal's diet. He further attributed the differences in animal manure to those factors that can vary seasonally on and among farms, and regions or on a larger geographic scale.

Interaction of CR and various SFM strategies had significantly influenced NU$_p$E. The use of FYM as an amendment on plots previously occupied by green pea and dolichos gave higher NU$_p$E values than under potato as well as wheat as pre-crops. Similarly, higher value of NU$_p$E was observed due when the lowest rate of inorganic fertilizer source (25 kg N ha^{-1}) was applied on plots that were previously occupied by green pea than dolichos as well as potato and wheat. These results explained the importance of legumes as pre-crops as their inclusion in the crop rotation systems helped to increase the ability of the subsequent wheat crop to uptake more N as compared to the higher rates of inorganic N. This is supported by [49], who reported in a review article that legumes due to their ability to fix the atmospheric nitrogen, they release in the soil high-quality organic matter and facilitate soil nutrients' circulation and water retention as well. It also evident from the result that the benefit of legumes on NU$_p$E in the rotation system was more enhanced by using FYM as a soil amendment on plots that were previously occupied by green as well dolichos than potato and wheat as pre-crops. Farmyard manure (FYM) is one of the more valuable organic fertilizers maintaining soil fertility in the systems of alternative agriculture.

The importance of FYM in helping to enhance availability of N could be associated with its role in enhancing the availability of phosphorous which an important element in the fixation of atmospheric N. Furthermore, this is supported by [50], who reported increased availability of phosphorous due to application of FYM. The strategy of using legumes in rotation with wheat in the humid tropics for enhanced soil-N supply, and pest, disease, and weeds-break effects should therefore be encouraged [32]. In conclusion the introduction of legumes in wheat-based cropping is a viable strategy for the reduction of inorganic fertilizer use for the resource poor small and medium scale farmers in Africa and particularly in Njoro sub-county where this study was conducted.

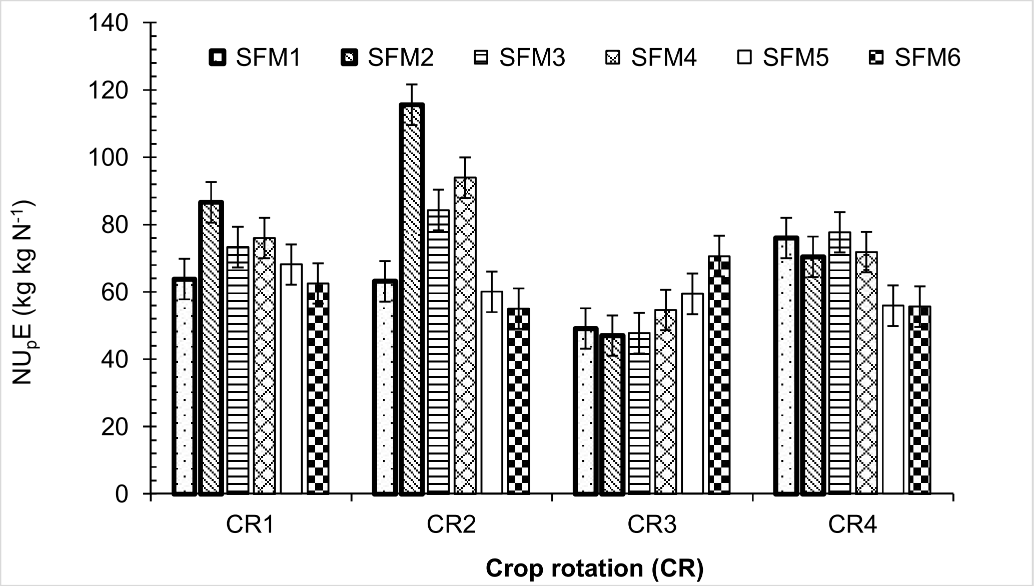

Fig. 3. Interaction effect of crop rotation (Pre-crop) and soil fertility management (SFM) on nitrogen uptake efficiency (NU$_p$E) of wheat

Key: CR1 = Wheat – dolichos – wheat; CR2 = wheat – Green pea – wheat; CR3 = wheat – potato – wheat; CR4 = wheat – wheat – wheat; SFM1 = untreated control; SFM2 = Farm yard manure (FYM) at 5 tonnes/ha; SFM3 = green manure (L. trichandra); SFM4 = inorganic N source at 25 kg N/ha; SFM5 = inorganic source at 50 kg N/ha; SFM6 = inorganic source at 75 kg N/ha

Table 3. Cumulative effect of pre-crops in the short crop rotation (CR) on yield and biomass

Pre-crop effect in the rotation	**Yield (Kg ha^{-1})**	**Biomass (kg ha^{-1})**
CR1=Dolichos	1603 a	6035 a
CR2=Greenpea	1439 ab	6283 a
CR3=Potato	834 c	426 b
CR4=Wheat	1400 b	5536 a
LSD (0.05)	179.3	909.5
Cv (%)	6.8	10

Means followed by the same letter(s) in the same column are not significantly different at $p < 0.05$

3.7 Effect of Pre-crops in the Short Crop Rotation (CR) on Yield and Biomass

Wheat grain and biomass yields were significantly ($p < 0.05$) influenced by the effect of crop rotation (CR) as presented in Table 3. Significantly ($p < 0.05$) higher yield and biomass were obtained when wheat was preceded by *L. purpureus* and *P. sativum* in the short crop rotation (CR) cycle than when wheat was preceded by potato and wheat. *L. purpureus* and *P. sativum* as pre-crops led to significantly higher yield and biomass than when potato was the precursor crop. Wheat yield was increased by 92% and 73% due to *Dolichos* and green pea as pre-crops, respectively, relative to potato while wheat following either *L. purpureus* or *P. sativum* increased biomass by 93% relative to potato as a pre-crop. Within the grain legumes, superior contribution was observed on dolichos compared to green pea as a pre-crop. While the wheat grain yield gain due to the two legumes (dolichos and green pea) as pre-crops superseded those attained with wheat and potato as pre-crops. These results concurred with observations by [51], who reported increased wheat yield between 3.5–4 tonnes ha^{-1} following grain legumes, pea, and vetch silage crops compared with continuous wheat yield. Thus, potato as a pre-crop to wheat resulted in significantly lower yield. The contribution of legumes as a preceding crop to cereals, is significantly important and therefore should be considered under short crop rotation systems to enhance wheat yield and biomass at low cost.

The observed benefit due to the legumes as pre-crops could be attributable to the contribution of legumes by way of N fixation and increase of soil organic matter that might have held the fixed N thereby reducing the leaching threats. Legumes fix the atmospheric N through symbiotic associations and through this process half of the entire N used in agriculture production system is delivered [52]. This is apart from the residual N left in the soil for the succeeding non-legume crops [53]. This underlines the great potential of legume crops for use in soil restoration, stabilization and yield enhancers. For example highlighted that wheat (*T. aestivum*) yield substantially higher following alfalfa, and milk vetch than grass. This enhancement is explained by the contribution of both nitrate sparing by the legume species and mineralization of the N-rich residues.

A part from wheat yield, biomass was also influenced significantly ($p < 0.05$) by crop rotation (CR). Higher wheat biomass was obtained when wheat was preceded by dolichos, green pea and even after continuous wheat than potato. Among the legumes pre-crops, d*olichos* and green pea led to significantly higher biomass than when potato was the precursor crop. The increase in biomass value following either dolichos or green pea was about 90% relative to potato as a pre-crop. The contribution of legumes as a preceding crop to cereals in the accumulation of biomass could be attributed to the fact that grain legumes are excellent pre-crops for cereals. However, their atmospheric N fix ability depends on species of the legume. These results also agree with [54] who observed excellent contribution to the crop density (biomass) of the subsequent crops through high nitrogen residues left by legume after harvest as residual soil mineral N (SMN) as well as in organic crop residues. The outcome of this study is further explained by [24], who observed higher Cation Exchange Capacity (CEC) on plots that were previously cropped to legumes compared with plots previously occupied by maize and fallow plots and attributed the observation to the leaf litter droppings, which more or less served as mulch and later decomposed to add nutrient to the soil.

In conclusion, planting legumes as pre-crops to cereals (wheat) has great advantage in enhancing grain yield and biomass accumulation. It is also important to note that among the two legumes evaluated in this study showed different abilities in the enhancement of wheat yield and above ground biomass. Although *L. purpureus* had resulted in higher grain yield and biomass as compared to green pea, due to its reduced performance in high rainfall areas provides an opportunity for the latter to be recommended as a pre-crop to wheat. For maximum benefit of green pea as a pre-crop, it should be planted during the short rain season while wheat should follow in the prospective long rainy season.

4. CONCLUSION AND RECOMMENDATION

Nitrogen use efficiency (NUE), grain yield and biomass were significantly influenced when wheat grown after leguminous crops either *L. purpureus* or *P.sativum.* The increase was more enhanced when wheat when FYM was used to fertilize wheat planted on plots previously occupied by either *L. purpureus* or *P.sativum.* Of the legumes evaluated, combination of *P.sativum* as a pre-crop and FYM at 5 tone ha^{-1} significantly increased the value of NUE. Even with the lowest inorganic N (25 kg N ha^{-1}) and *P.sativum* as a pre-crop, a significantly high NUE value was achieved. This confirms the positive contribution of *P.sativum* in the enhancement of NUE which is attributed to its ability to fix greater amount of N from the atmosphere. *Thus there is a greater economic benefit accruing from the use of P.sativum* due to enhanced NUE and its associated components such as NU_tE and NU_pE.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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