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ENHANCING OF NITROGEN USE EFFICIENCY AND ITS ASSOCIATED ATTRIBUTES THROUGH SHORTTERM CROP ROTATION FOR INCREASED WHEAT PRODUCTIVITY IN KENYA

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ABSTRACT

Kenya's agriculture is about 98% reainfed hence sensitive to climate change. Therefore climate smart agriculture (CSA) should be considered to help farmers mitigate against the impacts of climate change. In view of this, a three year study was conducted at the Kenya Agricultural and Livestock Research Organization (KALRO) in Njoro for three years mainly to quantify the effect of crop rotation on water use efficiency (WUE); nutrient use efficiency (NUE) and its associated components of wheat and potato in a cereal- potato cropping system. The trial consisted of three factors including (1) water harvesting (WH=No ridge and Tie ridge), (2) Crop rotation (CR) (Wheat-Dolichos-Wheat-Dolichos; Wheat-Greenpea-Wheat-Greenpea; Wheat-potato-Greenpea-Potato; Wheat-Wheat-Wheat-Wheat); and (3) Soil Fertility Management (SFM) = including four treatments such as untreated control; Calcium Ammonium Nitrate (CAN) at 25, 50 and 75 kg P_2O_5 ha^{-1}; Farm yard manure (FYM) at 5 t ha^{-1}; and Green manure (*L.eucaena triachandra*) at 2.5 mt ha^{-1}) for three seasons. The treatments were laid out in a randomized complete block design (RCBD) with split-split arrangement with three replications. Data was subjected to an analysis of variance (ANOVA) using SAS statistical package was performed. The result showed a significantly ($P \leq 0.05$) greater influence on both water (WUE) and nitrogen use efficiency (NUE) in a situation where wheat was preceded by leguminous crop (Greenpea) than the other two crop rotation systems. Organic sources of nutrients also resulted in a positive influence on the WUE and NUE of both wheat and potato however, the influence was greater in potato than wheat. In conclusion it was confirmed that cereals grown after legumes had a positive influence on NUE and its associated components. This manifested the significant contributions of the study to the CSA concept because the reliance on crop of cereals (wheat) with legumes and the use of organic sources of fertility in short cropping cycle would help to mitigate against the impacts of climate change.

Key words: Cropping systems; water use efficiency; nitrogen use efficiency present in alphabetical order

1. INTRODUCTION

The global demand for total fertilizer nutrient (N+ P_2O_5 + K_2O) demand is projected to reach 200,500,000 tonnes by the end of 2018 out of which N fertilizers accounts for about 60% (119,400,000 tonnes) (FAO Report, 2015). Of this, total N applications to cereals accounted for about 55% and among the three main cereals; wheat, rice and maize accounted for up to 17% (Heffer and Homme, 2016). Although, the amount of N used by cereals is significantly high as shown by the projections, the worldwide, nitrogen use efficiency (NUE) is more negatively correlated to the level of use. Available statistics show that NUE for cereal producrion (wheat, Triticum aestivum L.; corn,Zea mays L.; rice Oryza sativa L.; and O. glaberrima Stued.; barley Hordeum vulgare L.; sorghum Sorghum bicolor (L.) Moench; millet, Pennisetum glaucum (L.) R. Br.; oat, Avena sativa L.; and Rye, Secale cereal L.) is approximately 33%. This leaves 67% unaccounted applied N fertilizer representing a $ 15.9 billion annual loss (assuming fertilizer – soil equilibrium) (Raun and Johnson, 1999). It is important to take cognizance of the huge losses due low NUE in cereals production systems among others and think of appropriate management approaches to counter them. It has been reported that production practices that have resulted in increased NUE relative to conventional or standard practices are those that are able to counter conditions, or environments known to contribute to N loss from soil-plant systems (Raun and Johnson, 1999). Such production practices include rotations that can reduce the chances of leaching hence increasing the NUE under irrigation or high rainfall environment. For instance, increased NUE have been reported in legume – cereal rotation studies such as soybean – corn rotation that resulted in increased NUE due to its ability to reduce the amount of residual N available for leaching relative to continuous corn (Huang et al., 1996). Similarly, greater NUE values have been reported in wheat planted after legume than that for wheat following fallow or continuous wheat (Badaruddin and Meyer, 1994).

Efficiency in uptake (NU_pE) and utilization of N in the production of grain requires that those management processes associated with absorption, translocation, assimilation and redistribution of N operate effectively. The relativity of this contribution of some of the management processes to NUE, NU_pE and NU_tE is not fully understood and may vary according to environments and N supply (Moll *et al*., 1981). In this paper, the objective was to quantify the contribution of crop rotation on Nitrogen use efficiency (NUE) and its associated components including Efficiency in uptake (NU_pE) and Nitrogen utilization efficiency (NU_tE).

2. MATERIAL 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 (S 00.34344; E 035.94711; Elevation 2172 m above sea level). The site lies within the Agro-ecological zone LH3 (AEZ LH3) with a bi-modal rainfall pattern (Jaetzold and Schmidt, 2009) 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 (NPBRC, Njoro Meteorological station No.9035021, 1999). The soils are well drained, deep to very deep, dark reddish brown, friable and smeary, silt clay, with humic topsoil classified as mollic Andosols (Jaetzold and Schmidt, 2009).

2.2. Rainfall during the experimental season

During the season in 2014, total rainfall was 301.9 mm which was about 36% of the annual rainfall. In the last two years of the study (2015 and 2016), the seasonal rainfall were 464.4 mm and 248.9 mm, respectively (Table 1). These represented 47.6% and 23.8% of the annual rainfall in 2015 and 2016, respectively. Considering that the minimum amount of rainfall for wheat is about 550 mm, for potato is about 600 mm, Dolichos is 450 mm and greenpea is 425 mm (FAO Report, 2012, http://www.fao.org/docrep/S2022E/s2022e02.htm).

Table 1: Rainfall (mm) during the seasons, annual rainfall (mm) and the percentage of seasonal rainfall against the annual rainfall between 2014 and 2016

Seasonal Rainfall	**2014**	**2015**	**2016**
Season's rainfall (mm)	301.9	464.4	248.9
Annual rainfall (mm)	848.4	976.7	1048.1
Seasonal rainfall as % of the annual rainfall (mm)	35.58	47.55	23.75

2.3. TRIAL PROTOCOLS:

2.3.1. Cropping systems

Four crops were planted in three year rotation cycle and these included Wheat (*Triticum aestivum* L.) (Variety=Duma), Dolichos lablab (*Lablab purpureum*) (Variety = DL1002), Green peas (*Pisum sativum*) and Potato (*Solanum tuberosum*) (Variety = Shangi). In the first year of cropping cycle (2014) wheat was planted in all the plots as a way of standardizing the soil fertility. In the progressive seasons from 2015, crop rotation cycles followed the programme outlined in Table 2.

Table 2: Summary of the Crop Rotation (CR) used during the study between 2014 - 2016

Rotation Cycle	2014	2015	2016
CR1	Wheat	Dolichos	Wheat
CR2	Wheat	Greenpea	Wheat
CR3	Wheat	Potato	Wheat
CR4	Wheat	Wheat	Wheat

Key: CR = Crop Rotation

2.4. EXPERIMENTAL DESIGN

The experiment was laid out in a complete randomized block design with a split-split plot arrangement and the treatments were replicated three times. Crop rotation (CR) (consisting of 4 levels) was assigned as the main plot (Factor A), water harvesting (WH) (consisting of 2 levels) as the sub-plot (Factor B) while soil fertility management (SFM) (consisted of 6 levels) was assigned as the sub-sub-plot (Factor C). Hence the field trial consisted of a total of 48 combinations within the three replications resulting into a total of 144 cases. However, the results presented in this paper are derived from the crop rotation factor. In this paper the discussion is centred on the crop yield in the third season because the effect of CR is cumulative.

2.5. EXPERIMENTAL ESTABLISHMENT AND MANAGEMENT

Potato 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. Wheat (*Triticum aestivum)* and Dolichos lablab (*Lablab purpureus*) crops occupied the same plot size as Potato but maintained their respective spacing. Wheat plots consisted 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}. Similarly, *L. purpureus* was planted in the same plot size as potatoes, 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).

Rock phosphate (28 – 30% P_2O_5) fertilizer was applied at planting at the rate of 100 kg P_2O_5. Weed control started pre-seedbed preparation by applying Roundup (Glyphosate) at 3 litres per hectare and this was followed by an application of Ariane (Fluroxypyr + Chlorpyrlid + MCPA total acid equivalent to 350 g/lt) at 1.0 L ha^{-1} from 3 leaf stage. Diseases were controlled by Folicur in Wheat and in potato and legumes and Thunder were used to control insect pests in all the crops.

2.6. DATA COLLECTION

Various data sets were recorded at different times depending on the type of data needed. The procedures used to collect various data sets are described in the sub-sections below:

2.6.1. Determination of Soil Moisture Content

The soil moisture content was monitored on a weekly basis at a depth of 160 mm in four randomly selected spots within each plot using a Time-Domain-Reflectometry (TDR) 300 (TRIME-PICO) soil moisture meter. This equipment measured percentage soil moisture content, temperature (^oC) and electrical conductivity (dS/m) with an accuracy of ±1 pico-second of a radar travel time.

2.6.2. Soil Analysis for Micro and macro nutrients

The soil samples were analyzed for micro and macronutrients at KALRO Njoro soil laboratory following the methods of Okalebo *et al*, (2002) and (Bremner and Keeney, 1965). Organic Carbon (%) in the soil sample was oxidized by acidified dichromate at 150^0C for 30 minutes to ensure complete oxidation (Anderson and Ingram, 1993).

2.6.3. Determination of Nitrogen Use Efficiency and its associated attributes

In this study the definition adopted is according to Moll *et al*., (1982) that states Nitrogen use efficiency (NUE) as the grain production per unit of N available in the soil. NUE is G_y/N_s in which G_y is grain yield and N_s is N supply expressed in the same units (kgs of N). In addition, two associated components of N use efficiency including: (1) the efficiency of absorption (uptake-NU_pE), and (2) the efficiency with which the N absorbed is utilized to produce grain (utilization- NU_tE). These were expressed as follows: uptake efficiency (NUpE) = N_t / N_s, and utilization efficiency ((NU_tE) = G_y/N_t, where 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.

2.6.4. Agronomic data collection

Several data sets were recorded on the test crops: Wheat (*Triticum aestivum* L), Potato (*Solanum tuberosum*), Dolichos lablab (*L. purpurea*) and Green pea (*Pisum sativum*, L.). The parameters recorded included the germination percentage of wheat, potato, Lablab and green pea. Other data recorded included biomass at harvesting, number of pods/plant (Lablab), number of seeds/pod and nitrogen concentration on wheat grain and straw were determined based on procedures described in this article. However, wheat grain yield (12.5% moisture content) was determined by harvesting the center 18 rows by 3 m long using sickles. Yield data was also recorded on both wheat and potatoes.

2.7. DATA ANALYSIS

The data was managed in an excel software and subjected to heterogeneity analysis to prepare the data for analysis. The data was then subjected to an analysis of variance (ANOVA) using Genstat (GENSTAT, 15th release, Rothamstead, UK) statistical package. The means were separated using Least significance differences (Lsd) at α=0.05.

3. RESULTS

3.1. Effect of rotation on yield

The results presented on Table 3 represent the effect of crop rotation (CR) on crop yield between 2014 and 2016. Crop rotation (CR) had significantly ($P \leq 0.05$) greater effect on the grain yield in all the seasons except in the first season (2014). Thus in the third season (2016), the wheat yield in the crop rotation coded as CR1 (Wheat-Dolichos-Wheat) and that coded as CR2 (Wheat-Green pea-Wheat) were significantly ($p \leq 0.05$) greater than under rotation phase coded as CR3 (Wheat – Potato - Wheat) and CR4 (Wheat – Wheat - Wheat).

Table 3: Means for the effect of crop rotation on grain yield (Kg ha^{-1}) of selected crops for three seasons.

Crop Rotation phase	Season1 (2014)	Season2 (2015)	Season3 (2016)
Wheat^1-Dolichos^2-Wheat^3	548a	638d	1603a
Wheat^1-Greenpea^2-Wheat^3	606a	3026b	1439ab
Wheat^1-Potato^2-Wheat^3	605a	4483a	834c
Wheat^1-Wheat^2-Wheat^3	640a	1204c	1400b
LSD ($p \leq 0.05$)	195.4	556.6	179.3
CV (%)	52.3	36.5	16.6

^{1},^{2}, and ^{3}= represent crops in seasons 1,2 and 3, respectively; means followed by the same letter within the column are not significantly different $p \geq 0.05$.

3.2. Effect of rotation on Nitrogen Use Efficiencies (%)

The results presented on Table 4 represent the effect of crop rotation (CR) on Nitrogen use efficiency (NUE). Due to the fact that effects of CR on most of the crop attributes are cumulative in nature, the discussions are therefore centred on the results of third season (2016). In this season two crop rotation phases including CR1 (Wheat-Dolichos-Wheat) and CR2 (Wheat-Green pea-Wheat) resulted in significantly $P \leq 0.05$) higher NUE (61.2 and 63.2 kg kg^{-1}, respectively) value than CR3 (Wheat-Potato-Greenpea) and CR4 (Wheat-Wheat-Wheat) with NUE values of 43.9 and 54.2 kg kg^{-1}, respectively. The two rotation phases (CR1 and CR2) had legumes in the second season (2015) preceding wheat. Thus the positive influence of C1 and CR3 phases was due to the contribution of legume.

Table 4: Means for the effect of crop rotation on Nitrogen use efficiency (NUE) of on selected crops between 2014 and 2016.

Phase of Crop rotation	Season1 (2014)	Season2 (2015)	Season3 (2016)
Wheat[1]-Dolichos[2]-Wheat[3]	8.9a	11.9d	61.2a
Wheat[1]-Greenpea[2]-Wheat[3]	13.3a	52.9b	63.2a
Wheat[1]-Potato[2]-Wheat[3]	13.1a	91.1a	43.9c
Wheat[1]-Wheat[2]-Wheat[3]	10.6a	19.6c	54.2b
LSD ($p \leq 0.05$)	4.051	1.92	5.23
CV (%)	53.4	42.4	21.7

[1],[2], and [3]= represent crops in seasons 1,2 and 3, respectively; means followed by the same letter within the column are not significantly different $p \geq 0.05$.

3.3. Effect of crop rotation on Nitrogen Uptake efficiency (NU_pE) (kg kg^{-1})

The results on the influence of crop rotation (CR) on nitrogen uptake efficiency are presented on Table 5. As is the trend that has been adopted, results discussed on this part of the paper are those observed in the third season (2016) because of the cumulative nature of CR contribution. The NU_pE of wheat in the final season (2016), wheat after leguminous crop (Greenpea) in the CR phase of CR2 (Wheat-Greenpea-Wheat) resulted in significantly ($p \leq 0.05$) greater NU_pE value than all the other rotation cycles. Similarly, an increase in yields observed in the CR 1 (Wheat-Greenpea-Wheat) where Dolichos preceded wheat yields compared to CR3 and CR4 where potato and wheat preceded, respectively. Generally it was observed that the ability of the crop to recover N increased with the inclusion of legume in the preceding phase of rotation.

Table 5: Means for the effect of crop rotation on Nitrogen uptake efficiency (kg kg^{-1}) for three seasons.

Phase of Crop rotation	Season1 (2014)	Season2 (2015)	Season3 (2016)
Wheat[1]-Dolichos[2]-Wheat[3]	21.2a	28.3c	71.8b
Wheat[1]-Greenpea[2]-Wheat[3]	31.0a	77.7a	78.8a
Wheat[1]-Potato[2]-Wheat[3]	30.7a	73.9a	54.8c
Wheat[1]-Wheat[2]-Wheat[3]	24.7a	43.8b	68.0b
LSD ($p \leq 0.05$)	10.32	6.91	6.57
CV (%)	53.8	25.2	22.4

[1],[2], and [3]= represent crops in seasons 1,2 and 3, respectively; means followed by the same letter within the column are not significantly different $p \geq 0.05$.

3.4. Effect of crop rotation on Nitrogen utilization efficiency (NU_tE)

The results describing the effects of crop rotation (CR) on nitrogen utilization efficiency (NU_tE) are presented in Table 6. The results showed significant different among the in seasons 2015 and 2015. The NU_tE of wheat in the first season (2014) was not significantly influenced by different rotation phases. However, the influence of crop rotation on NU_tE was significantly different between rotations within all the seasons except in the first season (2014). The results had shown a great variability of NU_tE across years and there was no predictable trend. In the final season (2016) the results showed that wheat grown after leguminous crops CR1 (Wheat-**Dolichos**-Wheat) and CR2 (Wheat-**Greenpea-**Wheat); and those following continuous wheat (CR4=Wheat-Wheat-Wheat) were not statistically different ($P \geq 0.05$). The trend on the contribution of legume of CR on NU_tE conforms to those observed on NUE and NU_pE.

Table 6: Effect of Crop Rotation (CR) on Nitrogen utilization efficiency (kg kg^{-1}) of selected crops between 2014 and 2016.

Phase of Crop rotation	Season1 (2014)	Season2 (2015)	Season3 (2016)
Wheat[1]-Dolichos[2]-Wheat[3]	42.9a	42.5c	37.7a
Wheat[1]-Greenpea[2]-Wheat[3]	43.7a	69.8b	38.0a
Wheat[1]-Potato[2]-Wheat[3]	42.8a	131.2a	29.1b
Wheat[1]-Wheat[2]-Wheat[3]	42.9a	40.9c	39.4a
LSD ($p \leq 0.05$)	2.299	17.94	4.958
CV(%)	9.5	38.8	12.2

[1],[2], and [3]= represent crops in seasons 1,2 and 3, respectively; means followed by the same letter within the column are not significantly different $p \geq 0.05$.

4. DISCUSSIONS

4.1. Effect of rotation on yield

The significant influence of Crop rotation (CR) on the wheat grain yield in all the seasons except in the first season (2014). Thus in the third season (2016), the wheat yield in the rotation cycle where wheat preceded leguminous crops of Dolichos in 2015 and Green pea in 2016 was greater than under situation where potato preceded wheat and under continuous wheat. This is attributable to the contribution of green Dolichos and Green pea preceding, respectively, in the second season (2015). Earlier studies have shown that grain yields of rice grown after high yielding legume crops such as bitter lupine (*Lupinus mutabilis*) and Persian clover (*Trifolium resupinatum*) were almost twice as high as those of the control treatment (rice after wheat) (Schulza et al., 1999). Other studies have reported significant increase in relative yield gap on wheat due to yearly continuous wheat cropping (Ernst et al., 2016). This fact is in conformity with the fact that the future food security will continue to rely on N fertilizer inputs, but cropping systems must be included to achieve yield potential (that is needed to close the yield gap) while minimizing trade-offs in air, water and soil quality (Tittonell and Giller, 2013; George, 2014). It therefore showed that the contribution in crop rotation was significant irrespective of the type of legume. In designing a climate smart strategy, a consideration for the inclusion of legume in the cropping system should be made so as to enhance the response to the effects of climate change.

4.2. Effect of rotation on Nitrogen Use Efficiencies (NUE) (%)

Due to the fact that effects of CR on most of the crop attributes are cumulative in nature, the discussions in this paper are centred on the results of third season (2016). Two crop rotation phases including where wheat was preceded by a legume (Dolichos and Green pea) resulted in significantly ($p \leq 0.05$) higher NUE (61.2 and 63.2 kg kg^{-1}, respectively) value than in situations where the preceding crop was Potato and under continuous wheat with NUE values of 43.9 and 54.2 kg kg^{-1}, respectively. The values of NUE had shown a great variability across years and there was no predictable trend. This in conformity with the observation by Fiez *et al*. (1994); Guttierrez-Bean and Thomas (1998) that reported that fertilizer use efficiency as a function of available moisture. This has been supported by the fact that crop response to nitrogen fertilizer varied significantly from year and the magnitude of response to N is difficult to predict from year to the next Johnson and Raun, 2003). Climate smart agriculture, (CSA) among other things, focusses on maintaining and enhancing the productivity and resilience of natural and agricultural ecosystem functions (Steenwerth et al., 2014). Thus in this study the inclusion of legumes eg Dolichos and Green pea conformed to the principles of climate smart because this ensured greater NUE under circumstances where the response of N under low moisture may be constrained.

4.3. Effect of crop rotation on Nitrogen Uptake efficiency (NU_pE) (kg kg^{-1})

The Nitrogen Uptake efficiency (NU_pE) of wheat after leguminous crop (Greenpea) in the CR phase where wheat was grown after Greenpea resulted in significantly ($p \leq 0.05$) greater NU_pE value than all the other rotation cycles. Similarly, an increase in NU_pE observed in the CR where wheat was preceded by a legume (Greenpea) in the second season and Dolichos in the third season compared to where potato and wheat preceded, respectively. Generally it was observed that the ability of the crop to recover N increased with the inclusion of legume in the preceding phase of rotation. In this study NUE followed a trend consistent with NU_pE and agrees with the findings of Guodong *et al*. (2012) in which increased NUE significantly and enhanced N uptake and utilization efficiencies of corn and wheat, as a result of minimized N loss. In practice the scientific basis of nitrogen uptake must be understood to accurately enhance the process. In this study, the inclusion of the legumes in the rotation resulted in increased NU_pE in wheat because of legumes' contribution to soil health as opposed to continuous wheat rotation. The enhanced N uptake of N by wheat is an attribute showing climate smartness of the strategy.

4.4. Effect of crop rotation on Nitrogen utilization efficiency (NU_tE)

Significant difference NU_tE of wheat was observed after the first year of cropping. The results had shown a great variability of NU_tE across years and there was no predictable trend as well. In the final season (2016) the results showed that wheat grown after leguminous crops Dolichos as in the second season and Greenpea in the third season. NU_tE those rotational phases following continuous wheat (CR4=Wheat-Wheat-Wheat) were not statistically different ($P \geq 0.05$). The trend on the contribution of legume of CR on NU_tE conforms to those observed on NUE and NU_pE by Prochazkova et al., 2003.

5. CONCLUSION AND RECOMMENDATIONS

The best hope for reducing fertilizer needs lies in finding more efficient crop management. It is also notable from the results of this study that although rotations between cereals and legumes had marginal positive influence on NUE and its associated components, a more economical benefit would be more achievable with a combination of crop rotation and N supply. The results obtained in this study did not show full benefit of crop rotation because a three year cycle was not long enough to exhaustively provide conclusive information. It is therefore recommended that a further investigation be performed. However, in conclusion it was confirmed that cereals grown after legumes had a positive influence on NUE and its associated components.

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