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Estimating Partial Nutrient Balance using Nutmon Model in Irrigated Rice-based Farms of the Nigerian Dry Savanna

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ABSTRACT

Soil fertility decline coupled with the failure to conduct soil analysis by the farmers while generating fertilizer recommendations are among the factors that led to low yield especially in the dry Savanna of Nigeria which is characterized by a dramatic increase in population. In this study, the performance of the soils at Bunkure Local Government Area of Kano State that was under irrigation farming was estimated using the NUTMON model. This was part of the strategies for boosting agricultural production and to have adequate and sustainable rural development. The experimental findings of this study showed obviously that most of the farms in the research area received sufficient amount of fertilizer during the growing season despite the lower fertility status of the soils. Even with the continuous productivity within crop-based cropping unit, highly positive balance was obtained for N and slightly for P and K. The result as obtained from the data processing module of the NUTMON model revealed positive partial balances in kg/ha as 220.7, 26.3 and 47.8 for farms 1, 2, and 3 respectively, with the highest balance at farm 2 and the lowest at farm 3, despite the higher quantity of fertilizer (IN 1) that was applied to farm 1 of about 342 kg of Nitrogen. However, the N, P, and K were exported to the farm through the harvested grains and crop residues (OUT 1) and crop residues (OUT 2) considering partial balance. On the other hand, Phosphorus partial balance was also positive as a result revealed 55.0, 13.6 and 16.9kg/ha of Phosphorus for farms 1, 2 and 3 respectively. The K balances for farms 1, 2 and 3 in kg/ha as 68.8, 13.6 and 23.7 respectively which means farm 1 has the highest balance and farm 3 has the lowest. The result showed that the NUTMON model was a valuable tool for estimating nutrient balance and maintaining soil fertility in the study area. Reviewing fertilizer recommendation and its adherence by the farmers was recommended to have an appreciable yield in the study area.

1. Introduction

The dramatic increase in population density is one of the attributes of sub-Saharan Africa that leads to the increase in land use practices to sustain the livelihood of the population. As such, accelerated and sustainable agricultural intensification has to be adopted (Olawepo and Ibrahim 2013). Nevertheless, intensification, increased agricultural productivity and improved rural livelihoods cannot occur without investment in soil fertility. Limited use of nutrient inputs among smallholder farmers exerts pressure on soil nutrient deficiency. The estimated nutrient losses due to erosion, leaching and crop harvests are sometimes overwhelming, at over 60 – 100 kg of N, P, and K per hectare each year in Western and Eastern Africa (Stoorvogel and Smaling, 1990).
The establishment of a large-scale irrigation scheme that passes through the research area has brought new opportunities to the farmers to grow varieties of crops year in year-round (HJRBDA, 2004) which accounted for about 44.4 % of the net production in the area according to Sani *et al*. (2010).
Failure to conduct soil analysis was a limiting factor to the farmers in the research area where almost all the farmers do not have any information about the fertility status of their farms which they cultivate throughout the season. However, rice and other cereals cultivation are intensively carried out year-round in the study area. Therefore, there is an unremitting uptake of nutrients especially those that are essential for the growth of cereals. This continuous uptake of these nutrients may cause the soil to be deficient in nutrients such as N, P and K which in turn render the soils to be low regarding fertility (Shehu *et al*., 2015). On the other hand, most of the farmers are not keeping any information on the amount of nutrient flows in their farms and they also have low access to information about the new scientific developments in agriculture.

Failure of majority of the farmers in the study area to carry out soil test to know the nutritional status of their farms together with the cost of soil analysis necessitated the use of simple models like

NUTMON/MONQI that were designed to assess the nutrient flows on the farms so that they will know the appropriate amount of fertilizer they will apply to their farms to have an appreciable yield.
The significant problems caused by nutrient imbalance is the under or over application of fertilizers which in turn affect the yield and increase the cost of production.

This research is aimed at assessing the nutritional stability of soils in Bunkure Local Government Area of Kano State in order to boost crop production and achieve sustainable and judicious utilization of soils. The specific objectives of this research are as follows:
To estimate the various nutrient pools in an irrigated rice-based system.
To quantify the various nutrient flows in an irrigated-rice based system.

2. Materials and Methods

The study was carried out at Bunkure Local Government Area of the southern part of Kano State. It is situated between latitude 11^0 42' N, and longitude 8^0 33' E. The area has been identified as an area where mechanized and intensive Irrigation activities are taking place especially the Hadejia Jama are River Basin that passes through the area.
The climate of Kano State (Bunkure inclusive) is the tropical wet and dry type denoted as ***Aw*** by Wladimir Koppen (1936) in his climate classification. The temperature is averagely warm to hot throughout the year at about 25°C+/-7 °C (Olofin and Tanko, 2002). The area has an average of 209 mm of precipitation per year which is characterized by one peak (single maximum of about 428) which is usually attained in August (Buba, 2009).
The Sudan savanna can be said to be the natural vegetation of Kano State (the study area inclusive). It is composed of a variety of trees scattered over the expanse of grassland. Distinctive trees that can be found in the area include *Azadirachta indica, Acacia albida, Parkia clappa Toniana, Mangifera indica*, etc.
The soils of the area have sandy loam textured surface, and sandy clay loam textured sub-soil (NEDECO, 1976; IAR, 1994). Malgwi (2001), classified the soils of the area as Aquic Natrustalfs and Aquic Haplustalfs using the USDA soil taxonomy and Gleyic Solonetz, Haplic Solonetz and Calcic Luvisols using the FAO classification system.
The area is predominantly underlain by older granites and younger meta-sediments of Precambrian to lower paleozoic age (McCury, 1976).

2.1 Model description

NUTMON (NUTrient MONitoring) is an integrated, multidisciplinary methodology that targets different actors in the process of managing natural resources in general and soil nutrients in particular. With the NUTMON methodology, farmers and researchers jointly analyze the environmental and financial sustainability of tropical farming systems. The NUTMON-toolbox (manual in addition to accompanying software) has been developed to integrate the assessment of nutrient stocks and flows with economic farm analyses. The NUTMON approach distinguishes two phases: the diagnostic phase and the development phase. Multidisciplinary and integration of knowledge systems are essential in both phases.

2.2 Diagnostic phase:

The diagnostic phase is carried out at the farm level as farm management decisions are taken at this level. The goal of the diagnostic phase is a participatory analysis of the current situation regarding soil nutrient depletion and economic performance. It entailed the application of the various tools in the NUTMON-toolbox, preceded by participatory techniques, such as a participatory rural appraisal (PRA) and participatory resource flow mapping.

2.3 Development phase:

The development phase that followed could be executed at two different scales. At the farm level, a process of participatory technology development was launched with the aim of identifying and developing technologies to address the problems identified in the diagnostic phase. Based on the diagnosis, farmers prioritize technologies, which are tested on-farm. For example, negative nutrient balances caused by massive outflows of erosion and leaching may call for soil and water conservation technologies. A situation where low application levels of external inputs have caused negative nutrient balances may call for changes in the marketing infrastructure to make external inputs more attractive.

2.4 NUTMON-tool box

The NUTMON-tool box consists of four modules and two data bases that together facilitate nutrient monitoring at the level of individual farmers' fields and farms as a whole.

The four modules consist of:

A set of questionnaires that collects the required farm-specific information on management, the farm environment, the farm household, soils and climate;
A data entry module that facilitates entry of the data from the questionnaires into the computer;
A background processing module that stores non-specific information on crops, crop residues, animals, inputs, and outputs;
A data processing module that calculates nutrient flows, nutrient balances and economic indicators, based on the farm-specific data from the questionnaires and general data from the background database, using calculation rules and assumptions.

The two databases are:

a background database containing non-farm-specific information on, for example, nutrient contents of crop and animal products, crop and livestock parameters, as well as calibration factors of local units of measurement;
A farm database containing farm-specific information. One farm database contains information on a set of farms that are part of one study.

2.5 Conceptual framework

Because the complexity of farms does not usually allow for quantification of all nutrient flows and stocks, a conceptual framework has been developed. The framework simplifies reality to the extent that significant nutrient flows and pools are included, and minor flows and pools are neglected. The framework consists of four major components:

Farm section units (FSUs), which are continuous farm fields;
Nutrient pools, such as crops, livestock and compost pits;
Other entities that play a role in farm management (soils, climate and markets);
Nutrient and cash flows, e.g., harvested crop products, mineraler, and labour.

The boundaries of the farm coincide with the physical borders. The lower boundary is the depth to which leached nutrients are assumed to be lost from the system, as defined in the leaching transfer function.

The farm concept differentiated the farm in farm section units (FSUs) into:

Primary production units (PPUs) which is a crop activity consisting of one or various crops grown deliberately in one field within the farm.
Redistribution units (RUs) which is a location within the farm where nutrients are collected or accumulated and from where nutrients are redistributed, e.g., stables, corrals, fish ponds, compost pits, and latrines.
Secondary production units (SPUs) which are a group of animals of the same breed/species managed by the farmer.

2.6 Quantifying nutrient flows

The flows are quantified using four methods: (i) asking the farmer; (ii) using transfer functions; (iii) livestock mode; and (iv) Assumptions. All nutrient flows are determined in kilograms of nutrient per hectare per year.

2.7 On-farm nutrient flows

IN 1 (mineral fertilizer) is determined by asking the farmer and combining the applied quantities with the nutrient contents from the background database.

IN 2 (organic inputs) is determined by asking the farmer and combining the applied quantities with the nutrient contents from the background database.

IN3 (atmospheric deposition) is determined using three transfer functions:

N: IN3 = 0.14 × P

P: IN3 = 0.023 × P

K: IN3 = 0.092 × P

where P = annual precipitation (mm/year).

IN 4 (BNF) consists of two parts: symbiotic and non-symbiotic N fixation. Non-symbiotic N fixation is determined using the mean annual precipitation P:

IN 4 = 2 + (P - 1 350) × 0.005

The symbiotic N fixation is assumed to be a crop-specific percentage of the total N uptake of leguminous species (annual or perennial). The total N uptake is defined as the sum of the amounts of N in the crop product and the crop residues.

IN 5 (sedimentation) is the amount of irrigation multiplied by the nutrient content of the irrigation water.

OUT 1 (farm products) is obtained from the questionnaires and is multiplied by the nutrient content of the crops from the background database.

OUT 2= (other organic outputs)

OUT 3= leaching

OUT 4 = Gaseous losses

OUT 5 = (erosion) is calculated using the USLE.

OUT6 (human excreta)

However, in partial nutrient balance, only two inflows and outflows (IN1, IN2, OUT1, and OUT2) are taken into consideration.

2.8 Sample collection:

The samples were collected from three farms at different locations of the site at a depth of 25 cm with a trowel using simple random sampling, and the composite sample was obtained from each farm, it was then dried under ambient condition, and then the sample was crushed using agate mortar and sieved through 1.7 mm sieve and subjected to laboratory analysis.

2.9 Laboratory analysis

The following laboratory analysis were conducted at Centre for Dryland Agriculture (C.D.A) and Soil Science Laboratories of Bayero University Kano.

Total Nitrogen:

Total nitrogen was obtained using the regular macro Kjeldahl method, 10 grams of each soil samples were weighed into digestion tubes, 20 ml of distilled water was added, and the flask was swirled for few minutes then it was allowed to stand for 30 minutes. 10 gram of catalyst (potassium sulphate) then 30 ml of concentrated sulphuric acid was added, the mixture was then heated for about five (5) hours on the digestion block at the digestion chamber until the solution cleared. The samples were then transferred into another clean bottle and cooled slowly, distilled water was added to mark (100 ml).10 ml of Boric Acid solution was added and then followed by 2 drops of indicator and then placed under condenser of distillation apparatus.10 ml of sodium hydroxide with 10 ml of the sample was added to the distillation tube, 50 ml of distillate when it turns green to light green. The mixture was titrated with hydrogen chloride, the colour change at the end point was from green to pink, and then the percentage of nitrogen in the soil was computed.

Available Phosphorus was determined using bray-I method (Bray and Kurtz, 1945). 10 grams of soil samples was centrifuged for about 15 minutes. Reagent A of 200 ml and 1.6 grams of ascorbic acid were mixed to become reagent B.3ml of centrifuged samples with distilled water was made up to the mark of 25 ml. A standard P solution was prepared with an interval of 0.5, 1.0, 2.0 and 2.5ppm and the readings were taken using an atomic absorption spectrophotometer (AAS).

The exchangeable potassium was obtained using neutral ammonium acetate leaching method. 10grams of soil samples were weighed with 50 ml of ammonium acetate, and the solution was placed in a mechanical shaker for 30 minutes. The suspension was filtered and made level 50 ml. The exchangeable potassium was determined using flame emission spectrophotometer.

The particle size was determined using hydrometer method (Bouyouces, 1951) 50 grams of the samples were measured into a bottle, and 50 ml of Calgon solution with 100 ml of distilled water was added to the bottle. The suspension was shaken vigorously using a mechanical shaker for 30 minutes, afterward it was transferred into a 1-litre capacity measuring cylinder and then placed on a table and the plunger was used to stir the mixture. The hydrometer was inserted for measurement first reading was taken in about 40 seconds, and the second in about 3 hours the temperature was recorded in both the two times. The particle size was calculated and the textural class was also determined using soil textural triangle

Table 1 Agronomic and Nutrient Management Information of the Farms in the Study area

Material	INPUT Quantity (kg/ha)	OUTPUT Quantity (kg/ha)
Farm 1		
Rice (Seed)	42.86	-
Rice (Grain)	-	4642.86
Rice (stem/leaves)	-	64.29
Farmyard manure	4285.71	-
Fertilizer (Urea)	428.57	-
Fertilizer (NPK)	428.57	-
Farm 2		
Seed (seed)	52.63	-
Rice (Grain)	-	3684.21
Farmyard manure	0	-
Fertilizer (Urea)	175.44	-
Fertilizer (NPK)	84.21	-
Farm 3		
Rice (Seed)	50	-
Rice (Grain)	-	2500
Farmyard manure	2000	-
Fertilizer (Urea)	125	-
Fertilizer (NPK)	166.67	-
Average:		
Rice (Seed)	48.50	-

3.1 Physical and Chemical Characteristics of the Soils in the Study area:

The soils in the research area as shown in Table 2a was generally sandy loam with an average bulk density of 1.54 g/cm^3 and a mean percentage of sand, silt and clay as 70.67 %, 22.11 %, and 8.23 % respectively. Farm 2 has the highest clay percentage of 15.56 % while the other farms have nearly equal percentage of 4.56 %.

On the other hand, the average total N, available P, and exchangeable K in the research area as shown in Table 3 is 0.097 %, 14.240 mg/kg, and 0.366 cmol/kg respectively. Thus, the soil has shallow Nitrogen content, moderate phosphorus and low of potassium. In a nutshell, Farm 1 was found to have the highest nutritional status while Farm 2 has the lowest. The average pH level of the Farms is 7.12 with Farm 3 has the lowest value of

Table 2a Physical Properties of Soils in the Study area

Farms	BULK DENSITY (g/cm^3)	% SAND	% SILT	% CLAY	TEXTURAL CLASS
Farm 1	1.52	72.00	23.44	4.56	sandy loam
Farm 2	1.62	66.00	21.44	15.56	sandy loam
Farm 3	1.48	74.00	21.44	4.56	sandy loam

Table 2b. Chemical properties of the soils in the study area:

Farms	*NITROGEN (%)*	*PHOSPORUS (mg/kg)*	*POTASSIUM (cmol/kg)*	*pH*
Farm 1	0.109	23.403	0.151	7.75
Farm 2	0.073	6.686	0.087	7.86
Farm 3	0.109	12.630	0.076	5.75

3.2 Partial balance at primary production unit as simulated with NUTMON model

Table 3 shows partial balance at the primary production unit (crop activity unit) which is rice based. After the data was modeled in the toolbox and the balance (the sum of all inputs minus the sum of all outputs) was obtained from the data processing module of the model, the mean N, P and K balances in kg/ha is 98.27, 28.5 and 35.37 respectively. The balance was found

Table 3. NUTMON tool box generated nutrient balances for the irrigated rice based farms in Bunkure Kano state

Nutrients	**Inputs (kg)**		**Outputs (kg)**		**Partial balance**	**Partial balance**
Flows	**IN**	**IN 2**	**OUT 1**	**OUT 2**	**(kg)**	**(kg/ha)**
Farm 1						
Nitrogen	342.0	69.6	101.8	0.8	309.0	220.7
Phosphorus	90.0	16.9	29.8	0.1	76.9	55.0
Potassium	90.0	38.6	29.8	2.5	96.3	68.8
Farm 2						
Nitrogen	72.0	0.3	329.0	0.0	39.4	26.3
Phosphorus	30.0	0.1	9.6	0.0	20.5	13.6
Potassium	30.0	0.1	9.6	0.0	20.5	13.6
Farm 3						
Nitrogen	46.5	5.7	23.5	0.0	28.7	47.8
Phosphorus	15.0	2.0	6.9	0.0	10.2	16.9
Potassium	15.0	6.1	6.9	0.0	14.2	23.7
Average						
Nitrogen	153.5	75.6	151.3	0.27	125.47	98.27
Phosphorus	45.0	6.33	15.43	0.03	35.87	28.5
Potassium	45.0	14.93	15.43	0.83	43.67	35.37

3.3 N, P and K balances at the crop production unit:

Figure 1 shows the Nitrogen balance at the crop production unit which is rice based at all the farms. The result as obtained from the data processing module of the NUTMON model revealed the positive partial balances in kg/ha as 220.7, 26.3 and 47.8 for Farms 1, 2, and 3 respectively with the highest balance at Farm 2 and the lowest at Farm 3 despite the higher quantity of fertilizer

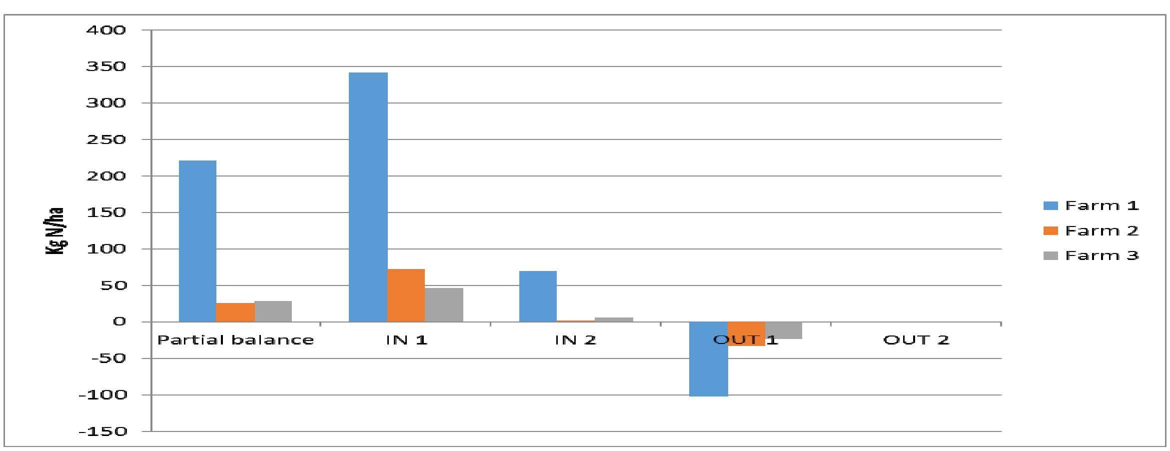

Figure 1: Nitrogen balance of the three farms as generated by the data processing module of the NUTMON model.

(IN 1) that was applied to Farm 1 of about 342 kg of Nitrogen. However, the N was exported to the farm through the harvested grains and crop residues (OUT 1) and crop residues.

On the other hand, Phosphorus partial balance was also positive as the result revealed 55.0, 13.6 and 16.9 kg/ha of Potassium for Farms 1, 2 and 3 respectively (figure 2).Thus, the balance is higher in Farm 1 while Farm 3 has the lowest balance .The P was supplied to the farms both through the fertilizers (IN 1) and farm yard manure (IN 2) while it was exported through the harvested products (OUT 1) and the crop residues especially in Farm 1, however, Farm 2 was not supplied with

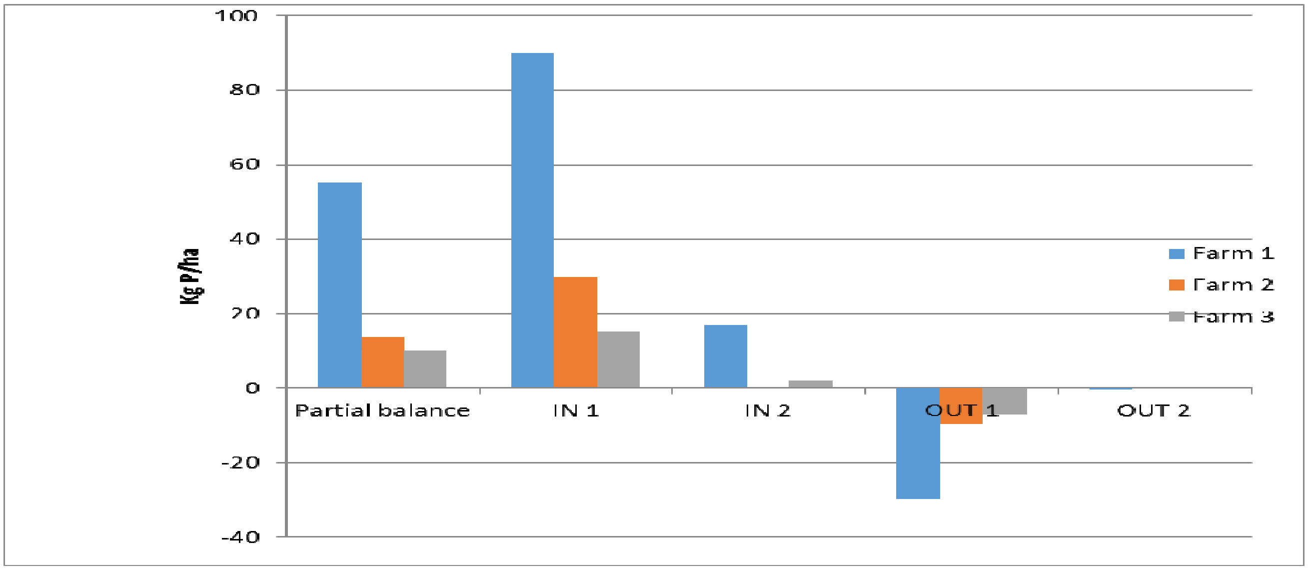

Figure 2: Phosphorus balance of the three farms as generated by the data processing module of the NUTMON model.

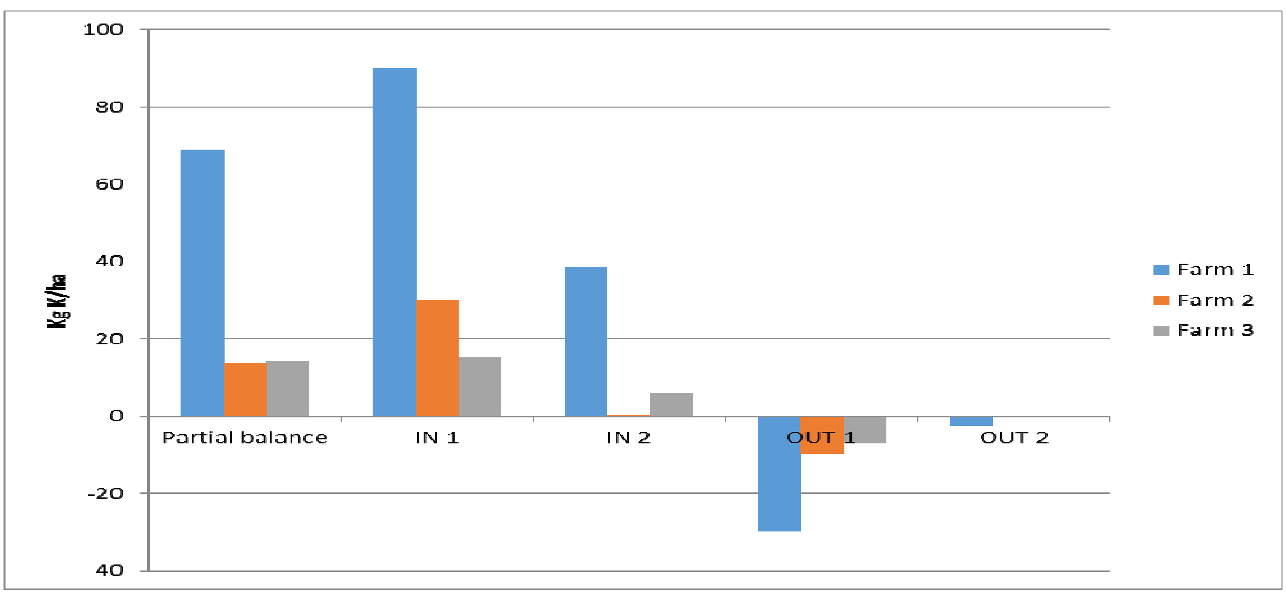

Figure 3: Potassium balance of the three farms as generated by the data processing module of the NUTMON model.

4. Discussion

The average seed rate used by the farmers in the research area was found to be 48.50 kg/ha which is less than the recommended seed rate of 80-100 kg/ha as suggested by WARDA (2008) for optimum yield, this led to low plant density and in turn low yield at the farms. It was found that Farm 1 was supplied with some amount of farmyard manure which is a source of managing and renovating soil fertility, even though the quantity of manure supplied by the farmers in the research area was usually less sufficient as found in a similar observation by Shehu *et al*. (2005).The amount of N, P and K supplied to the farms on average was about 142 kg N, 34 kg P_2O_5 and 34 K_2O per hectare which is not in agreement with the recommended rate of100 - 120 kg N, 60 kg P_2O_5 and 60 K_2O per hectare as suggested by WARDA (2008). The average yield of the farms that were found to be 3.6 t/ha agreed with the reported yield of rice in Nigeria WARDA (2008) but still less than the world average of 4.36 t/ha as reported by FAOSTAT (2012).

The textural class of the soils in the research area is generally sandy loam with a high percentage of sand which is in accordance with the finding of Adamu *et al*. (2014). This enhanced leaching of soil nutrients due to its incapacity to hold water and nutrients. A similar observation was made by Lawan (2015). The average bulk density of 1.54 g/cm ^{3} was found in the experimental area which is high especially at Farm 2; this affected the morphology of a plant as suggested incomparable research by Lawan (2015).

However, the research revealed that the soil has very low Nitrogen and potassium content which agreed with the findings of Shehu (2015) and Adamu *et al*. (2014), phosphorus was found to be in the medium fertility class as also reported by Lawan (2015). The average pH level of the soils is 7.12 which is neutral, but Farm 2 was found to be in a strongly acidity class as in a related observation by Lawan (2015).

The mean Partial balance at the primary production unit for N, P and K balances in all the three farms was positive similar to what was found in a research conducted at Tamil Nadu state of India where positive partial balance found for N and P and negative for K (Surendran *et al*., 2006) as was also reported by Ehabe *et al*. (2010) where positive partial balance was also obtained at the primary production units. This showed that the quantity of nutrients supplied to the farms through fertilizer and manure that was imported to the farms is more than what was taken out of the farms through harvest produce and crop residues. Leaching, run-off and gaseous losses which are neglected in partial balance are the possible outflows that contributed to the nutrient losses. The leached nutrients may pollute the site that they were deposited, interfere with fish industries and increase the cost of production.

5. Conclusion and Recommendation

Conclusively, nutrient monitoring with NUTMON toolbox at different spatial scales (*viz*., micro (crop activity) and meso (farm) levels were conducted, and a high to slightly positive balance was obtained which calls for strict adherence of the farmers to fertilizer recommendations. NUTMON Toolbox serves as a tool to identify the depletion of nutrients and to suggest the management options. With respect to increasing population densities, it was suggested that more than proper soil management would be required to sustain food security. While Soil Scientists and farmers can redefine their management strategies like fertilizer recommendations, policy-makers are requested to address also the demographic and economic causes of soil degradation. Sufficient amount of organic manure should be applied to improve the levels of nitrogen, phosphorus and potassium in the soil and soil water holding capacity. Low tillage practices should be promoted in order to reduce the loss of organic matter. Constant monitoring of fertility status of the soils should be carried out regularly.

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