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# ASSESSMENT OF NUTRIENT FLOWS IN MAIZE-BASED FARMING SYSTEM BY SMALLHOLDER FARMERS FOR SUSTAINABLE PRODUCTION IN IKARA, KADUNA STATE

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## ABSTRACT

Nutrient depletion is one of the major causes of decreased crop yield, and a threat to food security and sustainable crop production. NutMon- toolbox was used to determine nutrient flows and partial nutrient balances of maize-based smallholders' farming system. Data was collected using structured questionnaire from 15 randomly selected farmers, with five farmers each in three villages. Composite soil samples were also taken from each of the three plots. At crop maturity, samples of crop products and residues were randomly taken from the selected fields. Nitrogen, P and K contents in soil and crop material was used to calculate nutrient flows and partial balances. Results obtained revealed that mineral fertilizer flow, averaged 349.20kg N $yr^{-1}$ and 81.45kg K $yr^{-1}$ and were lower than 376.65kg N $yr^{-1}$ and 431.44kg K $yr^{-1}$ organic input. However, phosphorus in mineral fertilizer (55.78kg P $yr^{-1}$) was higher compared to phosphorus (51.06 kg P $ha^{-1}$ $yr^{-1}$) in organic input. Nitrogen, phosphorus and potassium for maize seeds and crop residue were all negative. The partial nutrient balances were positive 53.45kg N $ha^{-1}$ $yr^{-1}$ and 79.40kg K $ha^{-1}$ but negative 1.10kg P $ha^{-1}$ $yr^{-1}$. Harvesting of crops for food, without incorporation of crop residue into the soil, were the most important sources of nutrient mining in smallholder production system. Integrated soil fertility management practices that favour the buildup of soil organic matter and use of animal manure should be encouraged through effective extension services at Ikara, Kaduna State, Nigeria.

**Keywords:** Nutrient flows, Nutrient mining, Partial balance, Food security, Sustainable, smallholder, Maize

## INTRODUCTION

Maize (*Zea mays L.*) is an important food crop, widely grown in the Northern Guinea Savanna (Ofor & Ibeawuchi, 2009), and a source of food to more than 1.2 billion people in areas adaptable for production. Maize is also used as basal ingredients of livestock feeds in addition to other uses (Babatunde *et al.,* 2008). In Nigeria, about 4.2 million hectares were cropped to maize, which accounted for about 43% of the maize grown in West Africa and a production of 11 million metric tons in 2020 (PricewaterhouseCoopers Nigeria, 2021). Despite its importance and expansion in production area, maize yields in farmers' fields average 1 to 2 t/ha due to low and declining soil fertility, compared to the high yields of 5 to 7 t/ha reported by plant breeders in Northern Guinea Savanna (Fakorede *et al.,* 2003; Kasim *et al.,* 2014). One of the major constraints to low maize yields in the Nigerian Savanna is the inherent low fertility status of the soils, which are characterized by low activity clays and low levels of organic matter, exchangeable bases, nitrogen, phosphorus and potassium (Osundare, 2008). Maize, is known to be a high nutrient demanding crop, especially its need for nitrogen, phosphorus and potassium along with secondary elements (Ahmed *et al.*, 2009). For optimum yield, deficiencies of these essential nutrients in the Northern Guinea Savanna soils, which have high production potential, can cause poor root development and growth, thereby predisposing the plant to pest and disease attack and consequently, yield reduction (Kyoigwom *et al.,* 2011; Shehu *et al.,* 2015).

Soil fertility decline in Nigeria was estimated at an average loss of 24kg nutrient $ha^{-1}$ $year^{-1}$ (10kg N $ha^{-1}$ $year^{-1}$, 4kg $P_2O_5$ $ha^{-1}$ $year^{-1}$, 10kg $K_2O$ $ha^{-1}$ $year^{-1}$) in 1990 and 48kg nutrients/ha per year in 2000, which is an equivalent 130 kg and 310 kg fertilizer/ha per year ( Sheahan & Barrett, 2014). Nutrient depletion is the result of a net negative balance between incoming and outgoing nutrient in farm input and output accompanied by low, untimely or inefficient applications of manure or fertilizers, as well as with farm management practices that lead to leaching and erosion, which may result in a decreased capacity of land to produce crop (Van Beek *et al.*, 2008), leading to low agricultural productivity and hence a threat to food insecurity and reduced cash income (Kabirigi *et al.,* 2016). Many studies have documented soil fertility decline in Northern Nigeria (Macaulay, 2014), information on nutrient balances of smallholder farms in the Northern Guinea Savanna of Nigeria is scarce. The use of Decision Support Tool such as NutMon ((now known as MonQI) can be a valuable tool for explaining the consequences of smallholder farming system on soil fertility, provide insight into the magnitude of nutrient losses from the system and causes of such losses. The study assessed nutrient balances of maize-based system at crop activity and farm levels at Ikara.

## METHODOLOGY

### Description of Study Area

The study was carried out at Ikara Local Government Area of Kaduna State, located in the Northern Guinea Savanna of Nigeria. Ikara covers an area of 1,614km$^2$ and 30km Northeast of the city of Zaria. Ikara lies on latitude 11°10' N and longitude 8°13' E and has an average elevation of 676 meters above sea level. It receives a mean annual rainfall of 1011±161 mm that lasts for 6 -7 months, which starts from April or May and ends in October. The area has an average temperature of 28.8°C. It is hottest in April (35.8 °C) and coolest (22.1°C) in December (Muhammad *et al.,* 2014). The soil type was classified as Typic Halpustalf (Ogunwole *et al.,* 2001). The soils are inherently low in fertility due to low organic matter and cation exchange capacity and the dominance of low activity clays (LAC) (Odunze, 2003).

### Model Description

The NutMon toolbox is a computer software, which is used for monitoring nutrient flows and stock. The software consists of a structured questionnaire, a database and two simple static models; background database (BGDB) and a farm data base (FDB). The toolbox calculates nutrient flows, balances and economic performance, using a combination of the five inputs: mineral fertilizers, manures, atmospheric deposition and sedimentation harvested crop residue, leaching, denitrification and erosion losses from monthly farm household interviews, transfer functions, and secondary data using the equation (Vlaming, *et al.,* 2001).

*Net soil nutrient balance = Σ (nutrient input) - Σ (nutrient output)*

### Sampling and Sampling Technique

Data on nutrient flows were collected by survey, using structured questionnaire by means of schedule interviews from a sample of 15 randomly selected farmers, with five (5) farmers each in 3 villages. The selected farmers gave three of their farm plots each at sites located away from homestead; this gave 45 farm plots at Ikara.

### Soil Sampling

Soil samples were taken using an Auger at 0-20cm soil depth, to obtain a maximum of 10 cores as composite sample per farm plot as one layer of the soil profile which was further sub-sampled. These gave three composite soil samples, with one from each of the three (3) farm plots per farmer and forty-five (45) soil samples. The soil samples were transported in polythene bags to the Institute for Agricultural Research, Samaru (IAR), and air dried in the laboratory, after which the soils were gently crushed with a porcelain pestle and mortar, and sieved through a 2mm sieve. The fine earth portions were stored in polythene bags for laboratory analysis.

### Laboratory Analysis

Particle size distribution was determined by Bouyoucos hydrometer method (Klute, 1986). Soil pH was determined by using the Pye Unicam pH meter. Organic carbon was determined by Walkley and Black wet oxidation method (Nelson and Sommers, 1982). Total nitrogen was determined by micro-Kjeldahl technique (Bremner, 1982). Available phosphorus was determined by Bray 1 method (Bremner and Mulvaney, 1982).

### Data Analysis

Nutrient flows, balances at crop activity were calculated, with the laboratory results obtained from soil samples and plant material using the data processing module (DPM) in the NutMon software. The model output, nutrient flows, balances and economic performance indicators were aggregated per farm for each farm component (crops and livestock). Annual nitrogen, phosphorus potassium flows, balances were expressed as average for farms. Results on nutrient flows of land use were standardized on kg per hectare basis.

## RESULTS AND DISCUSSION

### Physical and chemical characteristics of soils in the study location.

The textural class of soil on farms was found to be generally sandy loam using USDA textural triangle (Table 1.), with sand fraction being the dominant particle size, with a mean value of 53.88 at Ikara. The dominance of sand fractions, which were coarse textured, might be attributed to the parent material, developed predominantly on deeply Precambrian basement complex rocks, such as granite and sand stone (Odunze *et al.,* 2010; Shehu *et al.,* 2015). The dominance of sand fractions at Ikara suggests, these soils were prone to leaching due to the high presence of macro-pores. The soil pH in water had a mean value of 5.29 was acidic. The acidic condition of the soils could be attributed to the silica content of the underlying acid parent materials: granite, gneiss and schist, which had rendered them inherently low in bases, especially calcium and magnesium, lost by leaching (Jones and Wild, 1975). This can affect the growth of maize at Ikara, mainly due to nutritional imbalance. The organic carbon contents were low with a mean value of 0.50g $kg^{-1}$. Total nitrogen had a mean of 0.05g $kg^{-1}$ in the surface soils, was generally low when compared to the mean value of 0.58g $kg^{-1}$ of well drained soils reported by Jones (1973) for the Savanna region. The low N can be accounted for by the low organic carbon content of Savanna soils, since organic nitrogen constitutes the bulk of total nitrogen of tropical soils (Noma *et al.,* 2005).

**Table 1**: Physical and chemical properties and Standard Deviation (±) of soil (0-20cm) at Ikara.

| Characteristic | |
|---|---|
| Sand % | 53.88 (5.1) |
| Silt % | 15.83 (3.28) |
| Clay % | 30.29 (3.92) |
| Textural Class | Sandy loam |
| pH$H_2O$ | 5.29 (0.17) |
| pH$CaCl_2$ | 4.11 (0.41) |
| Org. C (g $kg^{-1}$) | 0.50 (0.33) |
| Total N (g $kg^{-1}$) | 0.05 (0.32) |
| Total P (g $kg^{-1}$) | 0.05 (0.021) |
| Total K (g $kg^{-1}$) | 0.16 (0.05) |

### Nutrient flows and Partial balances

Nutrient flows (Table. 2) at farm level with mineral fertilizer averaged, with a value of 345.20kg N $yr^{-1}$, and 81.45 $kg^{-1}$ K $yr^{-1}$ were lower than average contributions from applied organic input, with exception of phosphorus with a value of 55.78 $kg^{-1}$ P $yr^{-1}$ from mineral fertilizer, was higher when compared to input from organic fertilizer. Nitrogen output with crop products (OUT1) was high, with a mean value of 544.0 $kg^{-1}$ $yr^{-1}$ compared to crop residue (OUT2) of 1.99kg N $yr^{-1}$. Partial nitrogen and potassium farm balances were both positive, but negative with a value of 1.10kg P $ha^{-1}$ $yr^{-1}$ at Ikara.

The positive partial nitrogen and potassium balances indicates the possibility of reuse of nutrients within farming systems (Kabirigi *et al.,* 2016). This collaborates the finding of Van Beek *et al.* (2008) that the reuse of nutrients within the farm, which occurs when nutrients pass through several farm compartments before they leave the farm via marketable products, would lead to sustainable food production in nutrient limited production systems.

The negative phosphorus partial balance could be attributed to most of the P being accumulated in maize grain (OUT1) and crop residue (OUT2), which removed from the field at harvest. The quantity of this nutrient applied via mineral fertilizers and organic fertilizer in these systems was sub-optimal, as farming systems of smallholder farmers were depleting soil of P nutrient stock. According to Pedrol *et al.* (1997) this can result in 100% removal of P accumulated by crops for human nutrition. In addition, the low application of fertilizers and poor cultivation practices by farmers in the area could have decreased soil fertility by reducing in soil organic matter (SOM).

**Table 2**: Nitrogen, phosphorus and potassium (kg$^{-1}$ ha$^{-1}$ year$^{-1}$) flows and farm balances at Ikara in 2013.

| Characteristics | N | P | K |
|---|---|---|---|
| IN1 (Mineral fertilizer) | 349.20 | 55.78 | 81.45 |
| IN2a (Organic fertilizer) | 376.65 | 51.06 | 431.44 |
| IN2b (Ext grazing) | 3.44 | 0.86 | 10.03 |
| OUT1 (Maize seed) | -544.00 | -129.66 | -181.53 |
| OUT2 (Maize crop residue) | -1.03 | 0.00 | -1.18 |
| Partial balance (kg ha$^{-1}$ yr$^{-1}$) | 53.45 | -1.10 | 79.40 |

Flows were aggregated before averaging across PPUs at Ikara (2013 Monitoring year).
Partial balance ($\sum$IN1+IN2 - $\sum$OUT1 +OUT2).

The increasing occurrence of acidified soils could also have been responsible for the negative phosphorus at Ikara. While grain harvest is a desirable outcome, soil erosion is environmentally dangerous, since P-enriched topsoil, when eroded, can lead to loss of P from the farm and cause eutrophication of surface waters. However, Brouwer & Powell (1995) reported that loss of P by leaching is rare, except in very sandy soils, such as those in the Sahel.

## Conclusion and Recommendation

The positive Nitrogen partial balance of 53.45kg ha$^{-1}$ yr$^{-1}$ and potassium 79.40kg ha$^{-1}$ yr$^{-1}$ was due to the application of mineral fertilizers, while the negative phosphorus partial balance of 1.10kg ha$^{-1}$ yr$^{-1}$ were mainly a consequence of nutrient export and the inability of farmers at the study site to recycle crop residue for soil fertility maintenance. Integrated soil fertility management practices that favour the buildup of soil organic matter and use of animal manure should be encouraged through effective extension services. To effectively tackle the problem of nutrient depletion and boost maize production at Ikara.

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