OPTIMIZED INORGANIC FERTILIZER APPLICATION ON SORGHUM YIELD AND NITROGEN USE EFFICIENCIES IN THE NIGERIAN SAVANNA

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TITLE PAGE

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A DISSERTATION SUBMITTED TO SCHOOL OF POST GRADUATE STUDIES, AHMADU BELLO UNIVERSITY, ZARIA IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF MASTER DEGREE IN SOIL SCIENCE

DEPARTMENT OF SOIL SCIENCE,

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NOVEMBER, 2017

DECLARATION

I declared that the work in this dissertation entitled "**OPTIMIZED INORGANIC FERTILIZER APPLICATION ON SORHGUM YIELD AND NITROGEN USE EFFICIENCIES IN THE NIGERIAN SAVANNA**" has been performed by me in the Department of Soil Science, Ahmadu Bello University Zaria. The information derived from the literature has been duly acknowledged in the text and a list of references provided. No part of this dissertation was previously presented for another degree or diploma at any other Institution.

Bakodo, Raymond Pwanogoshin ……..…… ….……

Signature Date

CERTIFICATION

This dissertation entitled "**OPTIMIZED INORGANIC FERTILIZER APPLICATION ON SORHGUM YIELD AND NITROGEN USE EFFICIENCIES IN THE NIGERIAN SAVANNA**" by Bakodo, Raymond Pwanogoshin meets the regulations governing the award of Degree of Masters of Science in Soil Science of the Ahmadu Bello University Zaria and is approved for its contribution to knowledge and literary.

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DEDICATION

I dedicate this research work to God Almighty, my creator for keeping me alive and healthy to see to the completion of this phase of my life.

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ABSTRACT

Sorghum (*sorghum bicolor* (L.) Moench) is an important staple food grain that is grown among smallholder farmers. The yield is low due to inherent low soil fertility because resource poor farmers apply little to no fertilizer to their land due to economic and social factors. The objective of the study was to provide recommendations for optimizing yield and profit from fertilizer use for financially constrained and smallholder sorghum farmers. The treatments consisted of five levels of inorganic N fertilizer (0, 30, 60, 90 and 120 kg N ha^{-1}), four levels of inorganic P fertilizer (0, 7.5, 15 and 22.5 kg P ha^{-1}) and four levels of inorganic K fertilizer (0, 10, 20 and 30 kg K ha^{-1}) and with some diagnostic nutrients. The experiments were laid out in a randomized complete block design (RCBD) replicated three times on-station and fifteen times on-farm. The experiment was carried out in 2015 on smallholder farms in Unguwar Chida, (Zamfara state), Zarewa (Kano state) and IAR experimental farm at Samaru, Kaduna state of Nigerian northern Guinea savanna.Result showed that application of 60 kg N ha^{-1},15 kg P ha^{-1} and 10 kg K ha^{-1} gave the highest grain yield (2567.3 kg ha^{-1}) at Samaru, 120 kg N ha^{-1} and 22.5 kg P ha^{-1} had the highest grain yield (2432.1 kg ha^{-1}) at Unguwar Chida, and 30 kg N ha^{-1} and 15 kg P ha^{-1} obtained highest grain yield (2181.6 kg ha^{-1}) at Zarewa. The economically optimal nitrogen rate (EONR) means were 52 to 34 kg N ha^{-1} in Unguwar Chida, 45 to 26 kg N ha^{-1} in Zarewa and 40 to 2 kg N ha^{-1} at Samaru with the fertilizer cost to grain price ratios (CPs) of 2 to 6 across the locations. Mean economically optimal phosphorus rate (EOPR) were 21 to 10 kg P ha^{-1} at Unguwar Chida, 20 to 14 kg P ha^{-1} and 7 to 5 kg P ha^{-1} in Samaru. Agronomic use efficiency decreased with increasing nitrogen rates and were 11.50, 31.10 and 10.08 kg kg^{-1} respectively at EONR. Partial factor productivity decreased with increasing nitrogen rate and were 57.91, 65.95 and 61.19 kg ha^{-1}, respectively at EONR. The optimized fertilizer recommendation per hectare for the sites studied were 78 kg N and16 kg P at Unguwar Chida, 51 kg N and 49 kg P, at Zarewa, and 72 kg N, 23 kg P at Samaru. The use of inorganic fertilizer by smallholder farmers in these regions based on this study was very profitable. Therefore, favourable formulated fertilizers blends and policies that will make available straight fertilizers and these blends available to smallholder farmer should be developed.

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CHAPTER ONE

1.0 INTRODUCTION

Sorghum (*Sorghum bicolar* (L.) Moench) is an important staple food grain among many smallholder farmers of the Nigerian savanna (Ofor *et al*., 2009). It occupies about 44% of the total land area devoted to cereals in Nigeria (Ajeibe *et al*., 2010). The land area put into cultivation of sorghum in Nigeria is 6.7 million hectares (FMARD, 2012b).

Decline in yield has been identified as major constraint to sorghum production. Average yield is estimated at 0.6-1.7 tons per hectare against potential yield of 4.0-5.0 tons per hectare of sorghum (FMARD, 2012b). The yield gap is attributed to poor inherent soil fertility and low fertilizer use. (Vanlauwe and Giller, 2006). Smallholder farmers apply little to no fertilizer to their land due to socioeconomic factors including timely access to fertilizer (SSA-CP, 2005). Improper types of fertilizers, ineffective extension system and inappropriate fertilizer recommendation which limit the efficiency of fertilizer use reduce farmer's income and increase poverty and food insecurity in the Northern Guinea Savanna of Nigeria (SSA-CP, 2005).

Nitrogen use efficiency (NUE) is important in developing fertilizer recommendations for profitability and environmental sustainability (Kaizzi *et al*., 2012). Low nitrogen use efficiency in crop production is due to excess application of N. Deficiency of phosphorus (P) and other essential nutrients limit crop growth due to biotic and abiotic factors (Bekuda *et al*., 2007; Kaizzi *et al*., 2012). Several attempts to provide fertilizer recommendations to smallholder farmers often lead to inappropriate fertilizer rates that lower the NUE of crops.

1.1 Justification of the Study

Current fertilizer recommendations are aimed at maximizing yield rather than profit. The fertilizer rate needed to maximize net returns is a function of fertilizer cost relative to

grain prices as the fertilizer prices increase relative to the prices, the economic optimal rate (EOR) is expected to decrease. Therefore, they need to maximize net returns for a given amount of money they have to invest in fertilizer which can be maximized by identifying the right combinations of nutrient, and application rate that will give highest value to cost ratio (VCR).

1.3 Objective of the Study

The general objective of this study was to provide recommendations for optimizing crop yield and profit from fertilizer use for financially constraint and small holder sorghum farmers in the northern guinea savanna zone of Nigeria. The specific objectives are:

1. To evaluate the yield response of sorghum to N, P and potassium (K) at the selected sites in the Northern Guinea Savanna of Nigeria.
2. To determine the economically optimal nutrient rate for N, P and K and the corresponding value to cost ratio (VCR) at different fertilizer cost to grain price ratio.
3. To determine the N use efficiency (NUE) of sorghum at the selected sites in the Northern Guinea Savanna of Nigeria.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Sorghum Consumption

Sorghum is the fifth most important cereal crop in the world; only rice, wheat, maize and potatoes are more highly consumed than sorghum (Dahlberg *et al*., 2011) and it is the most important cereal crop in Nigeria (Ofor *et al*., 2009). While the total food consumption of all cereals has risen greatly in the past three and a half decade, the global food consumption of sorghum has remained stagnant among smallholder farmers (FAO, 1995). The consumption trend of sorghum is very similar to global pattern of production since most of the grain is consumed in sub Saharan Africa while developed countries used it as animal feed (Mason, 2010). Poor resource farmers rely on sorghum as a source of energy (Godwin and Gary, 2000). Sorghum stands to contribute more to food supplies and food security in Nigeria and around the globe that are in dire need (AATF, 2011).

2.2 Sorghum Production

Sorghum production is estimated at 6.2 million tons with a decrease of 2% from 6.3 million tons in 2014 (USDA, 2014). The bulk of sorghum is grown in northern guinea savanna (Aba *et al*., 2005), it is the third cereal in terms of quantity of production in Nigeria (USDA, 2014) and it occupies about 44% of the total land area devoted to cereals in Nigeria (Ajeibe *et al*., 2010). The land area put into cultivation of sorghum in Nigeria has been 6.5million hectares (FMARD, 2012b).

2.3 Constraints to Sorghum Production in Nigeria

Soils of the Nigerian savanna are predominantly Alfisols with associated well-drained Inceptisols and Entisols. These soils are characteristically low in organic matter, cation exchange capacity (CEC), N and P and are large coarse textured (USDA Soil survey staff, 1975). In this agroecological zone the bulk of sorghum produced are in soil with

low organic matter content due to high rate of chemical and biological actions as well as the abundance of micro organic activity (Ismaila *et al*., 2010). The declining fertility of Nigerian savanna soils because of soil nutrient mining is a major cause of decreased sorghum yield and per capita food production (Ismaila *et al*., 2010). Low yield levels have been experienced with local cultivar of sorghum (Ismaila *et al*., 2010). Weeds are the most underestimated pests in tropical agriculture. Uncontrolled weed in sorghum farms could lead to 100% yield drop as weeds compete with plants for nutrients, space, light and even water (Ismaila *et al*., 2010). Striga is among the most important weed of sorghum in Nigerian savanna. Striga cause devastating impact on sorghum in Nigeria (Ismaila *et al*., 2010). Ismaila *et al*. (2010) reported that weeds also increase production costs in most cereal fields and sorghum yield are often reduced drastically because of delayed weeding due to competition for labour at the early growth stage. Ismaila *et al*. (2010) reported that in Nigeria low yield of sorghum is ascribed to increased cost of production, lack of fertilizers and labour.

2.4 Fertilizer Use in Nigeria

Inorganic fertilizer consumption in Nigeria is estimated at 13 kg/ha (FMARD, 2010), just above the average for the sub-Sahara Africa (Liverpool-tasie *et al*., 2010). Numerous reports by researchers explained the gap of substantial increase in fertilizer use in Nigeria. The cost of inorganic fertilizer use per kilogram applied is often two to six times higher in Sub Sahara Africa than United States due to higher transportation costs, market inefficiencies, importation cost and other expense (Vlek, 1990; Sanchez, 2002). The lack of credit and incentives commonly makes conditions even worse for poor resource farmers (Heisey and Mwangi, 1996).

2.5 Fertilizer Profitability

Inorganic fertilizer use is considered low but is profitable (Liverpool-tasie *et al*., 2015). Currently farmers engage themselves into cultivation of crop for business in order to invest and make profit (Nagy and Edun, 2002). Yield response to applied nutrient and cost of inorganic fertilizer relative to the price of economic yield are major constraints that decide nutrient application rate needed to maximize net returns which is known as economical optimal rate (EOR) (Sawyer and Nafziger, 2005). Yield response to fertilizer, high price of inorganic fertilizer and low grain prices in Nigeria often lead to low net returns to inorganic fertilizer use (Vlek, 1990; Sanchez, 2002). Profitability of inorganic fertilizer investment was reduced by the factors that increase fertilizer cost such as transportation. In contrast, those attribute that raise the market values of economic yield are expected to increase the profitability of fertilizer (Yanggen *et al*., 1998). Nagy and Edun (2002) reported that improve seed varieties postulate a high probability of being a profitable investment for farmers.

Profitability, as measured by value cost ratio (VCR) mainly depends on three factors: crop price, fertilizer price and response of the crop to fertilizer application. Response rate is a parameter that changes from farmer to farmer and soil to soil. With farmer who has better farming skills or those with higher potential of using fertilizer more effectively obtain higher response (Dittoh *et al*., 2013).

In Northern Guinea Savanna of Nigeria, sorghum had a large yield increase with 30 kg/ha of applied nutrient and hence high economic optimal rate (Tarfa *et al*., 2017). This region had been observed to have negative response to nitrogen application. This observed trend could be attributed to increasing soil acidity, micronutrient depletion, decreased cation exchange capacity, exchangeable cations and upset cationic balance (Yusuf *et al*., 2008).

2.6 Nitrogen and its Role on Sorghum Nutrition

Nitrogen is the most important nutrient element for crop growth and sorghum is well known to respond to N fertilization (Uchino *et al*., 2013). Nitrogen is also a crucial component of plant nutrition and its deficiency limits productivity of crops more than any other element (Mahama *et al*, 2014). However, inadequate supply of nitrogen causes stunted growth; chlorosis, poor seeds and early maturity are as nitrogen deficiency symptoms (Silva and Uchida, 2000). Hence, application of fertilizer nitrogen results in concentration in plant tissue that usually increase grain and higher dry matter yield (Silva and Uchida, 2000). Increases in sorghum grain yield were mainly associated with improving panicle number, grain number per panicle and grain weight (Buah *et al*., 2012). Higher N levels lead to higher leaf chloropyll index for sorghum during anthesis (Addy *et al*., 2010; Mahama *et al*., 2014). If grain N demand exceeds total soil N uptake an accelerated translocation of N from stems and leaves can occur leading to complete filling and increased grain yield (Tribio and Tribio-Blonde, 2002). Applied N not taken up by the crop or immobized in soil organic N pools that include both microbial biomass and soil organic matter is vulnerable to losses from volatilization, denitrification and leaching (Cassman *et al*., 2002). The response of grain sorghum to nitrogen is high and nitrogen fertilization is a major factor determining grain yield in sorghum; similarly inorganic nitrogen application positively affect grain yield, biomass and a thousand grain weight (Lehmann *et al*., 1999).

2.7 Phosphorus and its Role on Sorghum Nutrition

Phosphorus participates in nearly all metabolic processes in plants. Phosphorus plays a key role in storage and transfer of energy required in the plant metabolism. It is involved in the transfer of genetic information. It participates in the process of photosynthesis. It is required to maintain membrane stability necessary for uptake of water and nutrients, and

its regulates the formation and translocation of sugars and starches (Carrow *et al*., 2001). Photosynthesis can be reduced by P deficiency, P deficient leaves become dark green due to an increase in chlorophyll concentration associated with reduced leaf expansion with a reddish and purplish color at the middle. Older leaves may turn more dark green than upper younger leaves (Carrow *et al*., 2001; Chinchilla, 2010). When P toxicity is present, younger leaves show interveinal chlorosis, necrosis and tip die back, marginal leaf scorch and shedding of older leaves (Westermann, 2005; Chinchilla, 2010).

Increase in soil available P have been attributed to P release from the inorganic P that is sustained by the organic material (Anetor and Omueti, 2014). In addition, P is another essential nutrient required to increase plant yield. Consequently, the lack of P is as important as the lack of N in limiting plant performance. Phosphorus application is important which directly contribute to the quality and quantity of sorghum production (Roy and Khandarkar, 2010). However, based on a study by Oseni (2009) 20-40 kg P/ha is recommended for sorghum production in northern Guinea savanna of Nigeria. This author observed P fertilizer application to increase sorghum straw yield but not grain yield.

2.8 Phosphorus Uptake

Phosphorus is absorbed by plants as orthophosphate ions in either the monovalent ($H_2PO_4^-$) or divalent form (HPO_4^{2-}) (Vance *et al*., 2003; Chinchilla, 2010). The dominant P ion is dependent on the soil solution pH. Below a pH of 7.2, the main species is $H_2PO_4^-$ whereas above that pH HPO_4^{2-} is the main P ions in solution. Maximum P uptake rates in higher plants takes place at a solution pH of between 5 and 6 during which $H_2PO_4^-$ is the dominant specie (Schactman *et al*., 1998; Chinchilla, 2010).

2.9 Potassium and its Role on Sorghum Nutrition

Potassium is the third essential plant nutrient element limiting plant growth and consequently reducing crop yield. It is probably the plant nutrient exhibiting the widest variations in its content in the savanna soil of northern Nigeria (FMARD, 2012). Among plant nutrient, K is very closely associated with crop quality. It is required for good crop growth and quality, plant health, tolerance to various stresses and seed quality.

Optimum K fertilizer rate for sorghum is found to be 20 to 40 K/ha on low fertility soils in the northern Guinea savanna (FMARD, 2012).

2.10 Sulphur and its Role on Sorghum Nutrition

Sulphur is one of the essential elements needed for the proper growth and development of plants. It is immobile in plants and a constituent of protein (Chibuike *et al*., 2012). The deficiency of sulphur in the savanna soils of Sub Sahara Africa has been attributed to annual burning of grassland vegetation and low organic matter content (Isitekhale *et al*., 2013). Deficiency of sulphur is due to continuous use of sulphur free fertilizer, high sulphur requiring crops and high yielding crop varieties (Isitekhale *et al*., 2013). Schonhof *et al*. (2007) stated that there is a severe sulphur deficiency in the Nigeria guinea savanna and insufficient availability of sulphur to crop plants not only declines their growth and yields but also deteriorate grain quality. Lack of little or no recycling crop residues causes low organic matter contents in soils (Khan and Joergensen, 2006; Isitekhale *et al*., 2013). Soil characteristics particularly the texture, clay minerals, pH and organic matter may influence the content of plant available S by controlling the retention and leaching ability of highly mobile SO_4^{2-}-S in soils (Isitekhale *et al*., 2013). Biswas (2003) reported that SO_4^{2-} retention capacity of sulphur in soils decreases with increasing soil pH and becomes almost negligible at pH values above 6.5. The oxidation of elemental sulphur to sulphate results in acidification of the soil. The acid produced from

the oxidation process helps in reducing the alkalinity of soils (Cox and Koenig, 2010). However, Wortmann *et al*. (2013) stated that sandy soils that are low in organic matter may need adequate supply of sulphur for optimum grain sorghum production.

2.11 Zinc and its Role on Sorghum Nutrition

Zinc (Zn) is one of the important elements of plant growth and development. It also plays essential metabolic roles in the plant. It participates in chlorophyll synthesis and protects chlorophyll from decomposition and it influences nitrogen association (Alekhina and Kharitonashvill, 2005; Mirshekali *et al*., 2012). However, high zinc concentration like other heavy metals are toxic to plants (Zhao *et al*., 2003) although its toxicity in crops is far less widespread than its deficiency (Mirshehali *et al*., 2012). Zinc toxicity symptoms include reduced yields and stunted growth; Fe deficiency induced chlorosis through reduction in chlorophyll synthesis and chloroplast degradation and interference with P, Mg and Mn uptake (Mirshehali *et al*., 2012).

2.12 Fertilizer Recommendation

Inorganic fertilizers are formulated chemical nutrients that are applied to soil or plant tissues to supply nutrient essential for plant growth and development. To alleviate nutrient constraints the use of inorganic fertilizer is indispensably important for crop production in Sub Saharan Africa (Sanginga and Woomer, 2009). Smallholder farmers use little fertilizer due to inefficiencies across the fertilizer value chain meaning that fertilizer is not available in outlets close to the farmer at the time when needed, procurement cost, and the high opportunity cost for the money spent on fertilizer is not available for other urgent needs. However, existing recommendations do not allow farmers to maximize net returns on their investment (Kaizzi *et al.*, 2012).

2.13 Asymptotic Curvilinear Response Function

The curvilinear response function to fertilizer use is a basic tool that relates the amount of crop that can be produced in relation to the amount of fertilizer and other inputs applied (FAO, 2004). The crop response to applied nutrients increase yield gradually with increased rate of application until a maximum yield is reach, beyond which an increased application rate does not result in increased yield. At low rates of application, the response is steep with relatively great change in yield per unit of nutrient applied (Kaizzi *et al*., 2013) (Figure 2.1). The change in yield per unit of nutrient applied diminishes as the maximum or plateau yield is approached. Once the plateau is reached, additional nutrient application does not result in additional yield. The economic optimal nutrient rates are described in three stages. The first stage describes the nutrient application rate to achieve a targeted percentage. Similarly, the second stage describes the nutrient application rate required to maximize net returns to applied fertilizer per hectare. This rate is in many instances called the Economically Optimal rate (EOR) (Dobermann *et al*., 2011) and is a function of the ratio of fertilizer cost relative to grain price (C: P). Hitherto, the EOR is lower than the yield maximizing rate. An addition in C: P leads to a decline in EOR. The rate of greatest return to fertilizer use is acheived where addition in fertilizer cost balances the value of the yield increment. More addition in fertilizer use becomes less even though yield continues to increase until the yield plateau is reached. The third stage describes the situation when C: P and resource limited farmers are taken into account, the nutrient application rate needed to make large return on resource limited investment in fertilizer use can be calculated (Kaizzi *et al*., 2013). The value-cost ratio (VCR) or the ratio of net profit relative to cost of fertilizer is used as an index for making such recommendation. Smallholder farmers commonly lack the financial resources to apply fertilizer at EORs and would require a VCR>2 (>100% net

profit) within a period of 6-12 months to find a recommendation that is adoptable. Given their limited access to money, financially constrained farmers need to consider the VCRs of fertilizer rates which are a function of application rates and C: P. The highest VCR occurs at the lowest portion of the response curve where crop response to nutrient application is highest (where the shape of the curve is steepest due to high nutrient use efficiency) and gradually decreases to zero at the economically optimal nutrient rate. The net return per unit cost of nutrient is expected to be greater with low nutrient levels compared to higher nutrient levels. Thus, for a smallholder farmer, instead of applying fertilizer at EOR to less land, it would be more profitable to apply nutrients to more land at less than the EOR (Kaizzi *et al*., 2013).

2. 14 Fertilizer Optimization Tool

The Excel Fertilizer Optimization Tool (FOT) was first developed by Jansen *et al* (2013). It has been adapted to 67 country-AEZs of Africa including the six savanna AEZs of Nigeria. The FOTs are public resources that can be accessed by individuals at https://agronomy.unl.edu/OFRA. Educational institutions are encouraged to access the tool for use in their curriculum. The FOTs are Excel Solver© (Frontline Systems, Inc.) tools (Figure 2.2).

To use the FOT, the Solver add-in of Excel needs to be engaged and macros need to be enabled; see the 'Help and Instructions' worksheet of the Excel FOT. More detailed instructions are in Extension Materials and the FOT Manual, also available at https://agronomy.unl.edu/OFRA. When Solver is enabled, it is indicated in the upper right of the Quick Access Toolbar under the Data tab.

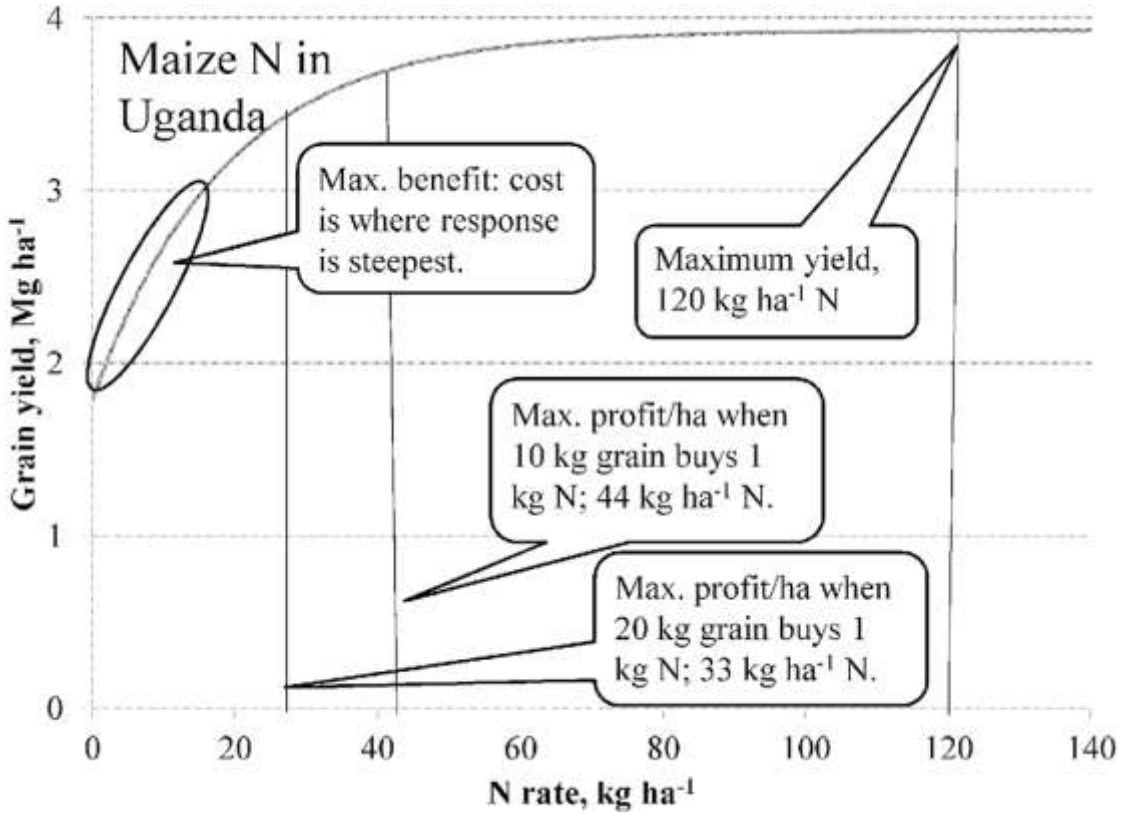


Figure 2.1. Maize response to nitrogen fertilization in Uganda (Adapted from Jansen *et al.*, 2013)

The FOT is used to optimize investment in fertilizer use for the crops that the farmer chooses to cultivate in that season. It accounts for agronomic efficiency and economic returns from money invested in fertilizer use. The tool provides recommendations based on fertilizer cost, crop grown and resource level of the farmer, as well as the expected values of the various crops to be produced. It provides the best crop-nutrient-rate combinations to maximize returns on fertilizer investment for that farmer's situation.

The FOT has information input and output sections. The input section is a panel to enter: 1) area (ha) to be cultivated and expected value of each crop at harvest, 2) cost of buying and applying 50 kg bags of available fertilizers and 3) amount of money available for the farmer to invest in fertilizer use (Figure 2.2). When steps 1, 2 and 3 are completed, the user clicks on the 'Optimize' 4) button to run the optimization calculations.

The output panel (Figure 2.2) provides results of the optimization calculations. It displays: 5) recommended fertilizer rates for each selected crop, 6) expected average yield increases and net returns per hectare resulting from fertilizer use for each crop and 7) expected total net return on fertilizer investment.

2.15 Fertilizer Calibration Tool

Once the optimal fertilizer rates are known, the farmer needs to know how to apply the fertilizer at the right rate. Therefore, the Nigerian OFRA project developed a calibration tool to guide application for the correct rates (Figure 2.3). The calibration tool is a reminder that optimization of fertilizer use does not include haphazard application. The Excel calibration tool offers options of measuring units of different volumes that are common in Nigerian rural communities. The type of fertilizer needs to be selected as fertilizers differ in specific gravity. Method of application and plant spacing information is provided. Depending on the amount and type of fertilizer that will be applied, the tool provides the application solution. The Nigeria calibration tool used FARO water bottle

caps (FARO-9ml), Gino tomato cans (GINO-70ml), and Peak Milk tins (PEAK-180ml). These measuring units were selected because of their availability in rural communities. The calibration units were designed to provide the farmer with visually estimates of fertiliser to be applied for a broadcast area, meters of band, or number of plant stands. After the farmer has 'calibrated' her eye and feel for the rate, the farmer proceeds with the actual fertiliser application free hand.

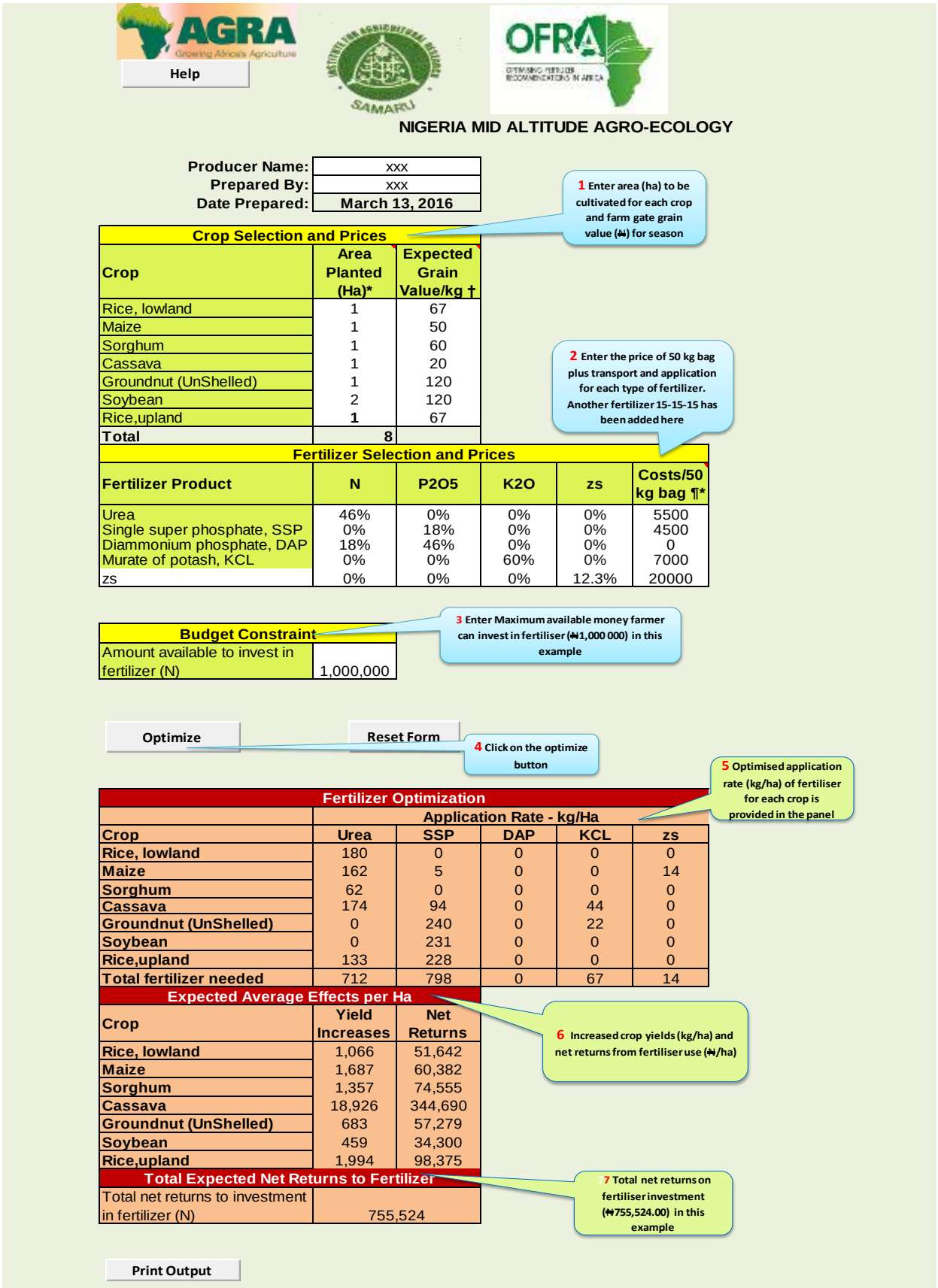


Figure 2.2. Excel Fertilizer Optimization Tool developed by Tarfa *et al*. (2017)

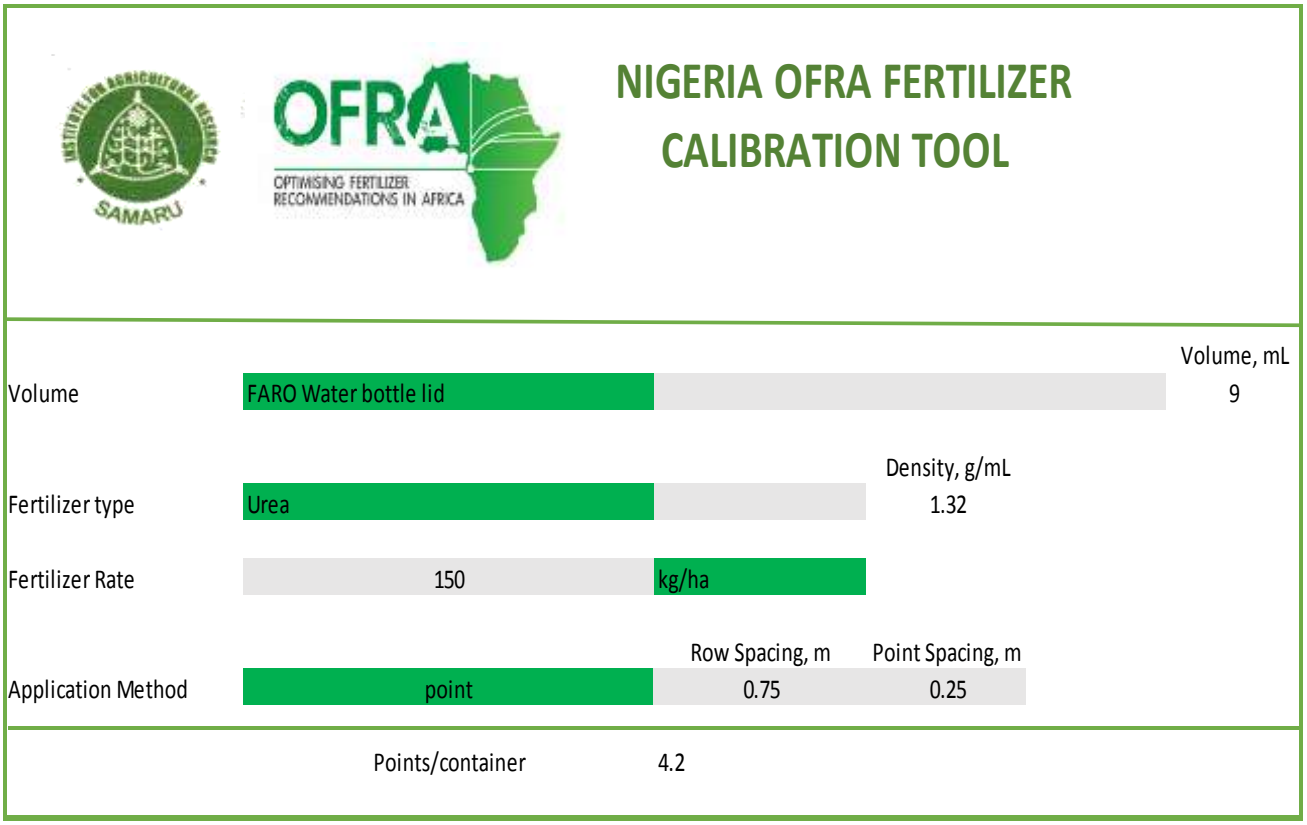


Figure 2.3. Excel Fertilizer Calibration Tool developed by Tarfa *et al*. (2017)

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Experimental Sites

An On-station trial was conducted during the rainy season of 2015 at Institute for Agricultural Research farm, Samaru, Zaria (Kaduna state) located between latitude 11°11'N and longitude 7°38'E at an altitude of 686 m above sea level (Fig 3.1). On-farm trials were also established at Unguwar Chida, Tsafe Local Government (Zamfara State) located on latitude 11°50'N and longitude 7°51'E at an altitude of 612 m above sea level and at Zarewa, Rogo Local Government (Kano State) located on latitude 11°24'N and longitude 7°49'E at an altitude of 689 m above sea level (Figure 3.1). The annual rainfall at the three locations was around 1011±161 mm received mainly between May and September, with peak rainfall in August. Average annual minimum and maximum temperatures are 20.32°C and 33.38°C respectively (Oluwasemire and Alabi, 2004).

3.2 Treatments and Experimental Design

The experiment was set up in a randomized incomplete block design with sorghum SAMSORG 42 as the test crop in both trials (on-station and on-farm). For the on-station the field was laid out in 3 replicates consisting of 25 plots for each replicate. Each plot had a dimension of 4.5m x 6m. There was a 0.75 m alley between plots and 1m alleys between replicates. For the On-farm trials, each of the fifteen farmers' field was consider as a replicate. Detailed of the experimental layout is presented in Figure 3.2

The fertilizer nutrient rates evaluated were 30, 60, 90, and 120 kg N/ha; 7.5, 15 and 22.5 kg P/ha, and 10, 20 and 30 kg K/ha. A diagnostic treatment was added to determine the combine effect of other nutrients when N, P and K are applied (60N-15P-20K-15S-2.5Zn-10Mg-0.5B). The incomplete factorial arrangement limited the number of

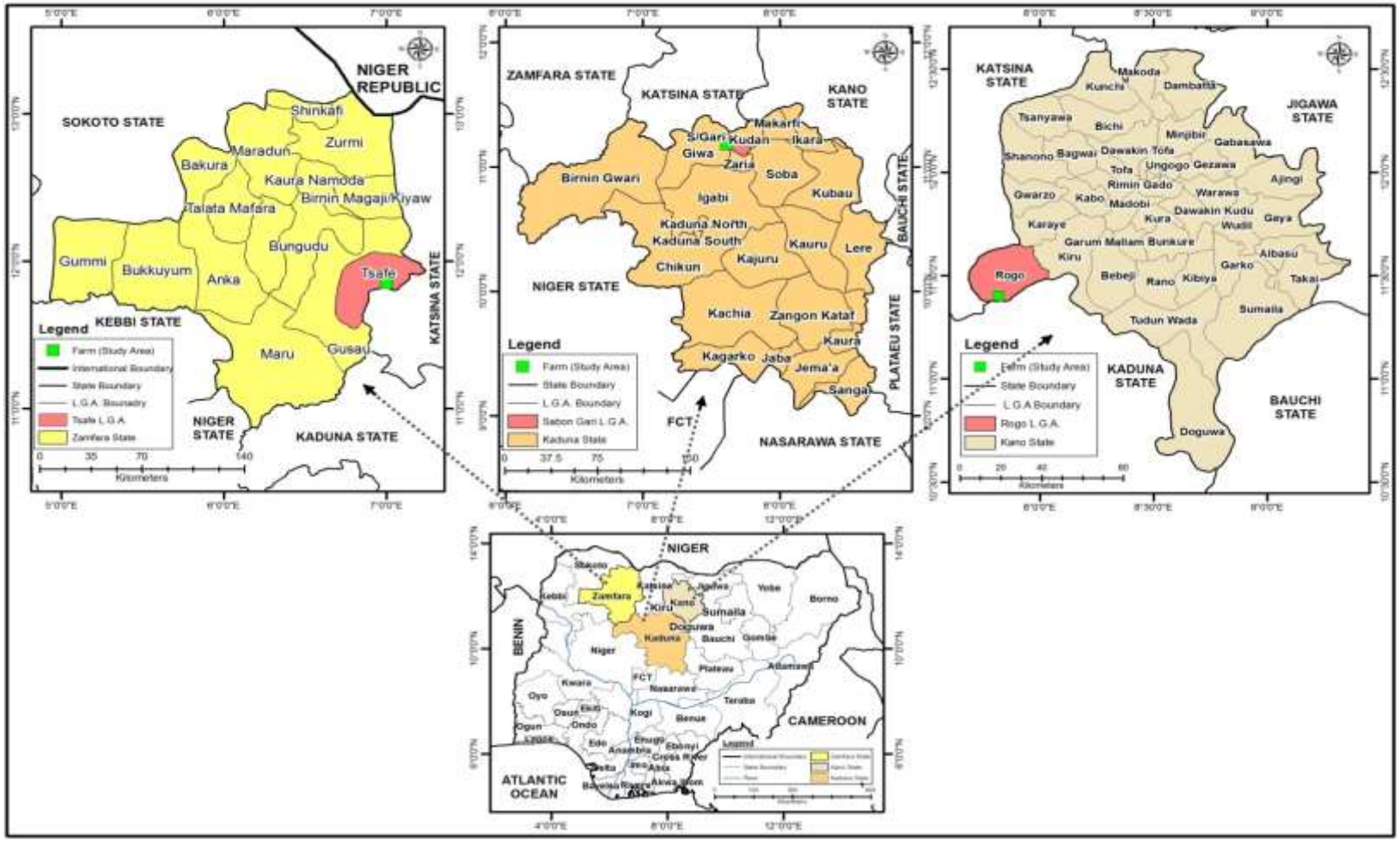


Figure 3.1: Map of Kaduna, Kano and Zamfara States showing Study Area (Villages).

treatments according to the Liebig's law of minimum; hence we expect N to be the most limiting nutrient followed by P while K was expected to be the least limiting. The treatments with associated nutrient combinations are shown in Table 3.1.

3.3 Fertilizer sources and management

The N, P and K sources were urea (N), Triple Super Phosphate (TSP) and Muriate of Potash (MOP). The diagnostic nutrients was made up of magnesium chloride, sulphur powder, sodium tetra borax and zinc chloride as sources of magnesium (Mg), sulphur (S), boron (B) and zinc (Zn) respectively.

3.4 Agronomic practices

The following agronomic practices were carried out:

3.4.1 Land preparation: The land was ploughed, harrowed and ridged at 75cm inter row spacing at Samaru, while the land was ploughed and ridged at 75cm inter row spacing at Unguwar Chida and Zarewa.

3.4.2 Planting: This was done on 16th and 17th June 2015, and 5-6 sorghum seeds were planted at inter row spacing of 75 cm and intra row spacing of 40 cm.

3.4.3 Thinning: This was done during the first weeding at two (2) weeks after planting and plants were thinned to two (2) plants per stand.

3.4.4 Weeding: Weeding was done twice using hoe.

3.4.5 Fertilizer application: Phosphorus and K fertilizers were applied as side dressing two (2) weeks after planting, while N fertilizer was applied in split doses at two and six weeks after planting.

Table: 3.1 Treatments and nutrient rates that were used in the study (kg/ha)

	Nutrient Rate kg/ha						
Treatment number	**N**	**P**	**K**	**S**	**Zn**	**Mg**	**B**
1	**0**						
2	**30**						
3	**60**						
4	**90**						
5	**120**						
6	**30**	**15**					
7	**60**	**15**	**10**				
8	**90**	**15**					
9	**60**	**15**					
10	**30**	**22.5**					
11	**30**	**7.5**					
12	**120**	**15**					
13	**90**	**7.5**					
14	**60**	**22.5**					
15	**90**	**22.5**					
16	**90**	**15**	**10**	**5**			
17	**90**	**15**	**20**	**10**			
18	**90**	**15**	**30**	**15**			
19	**90**	**15**	**20**	**15**	**2.5**	**10**	**0.5**
20	**60**	**15**			**0.5**		
21	**60**	**15**			**1**		
22	**60**	**15**			**1.5**		
23	**60**	**7.5**					
24	**120**	**7.5**					
25	**120**	**22.5**					

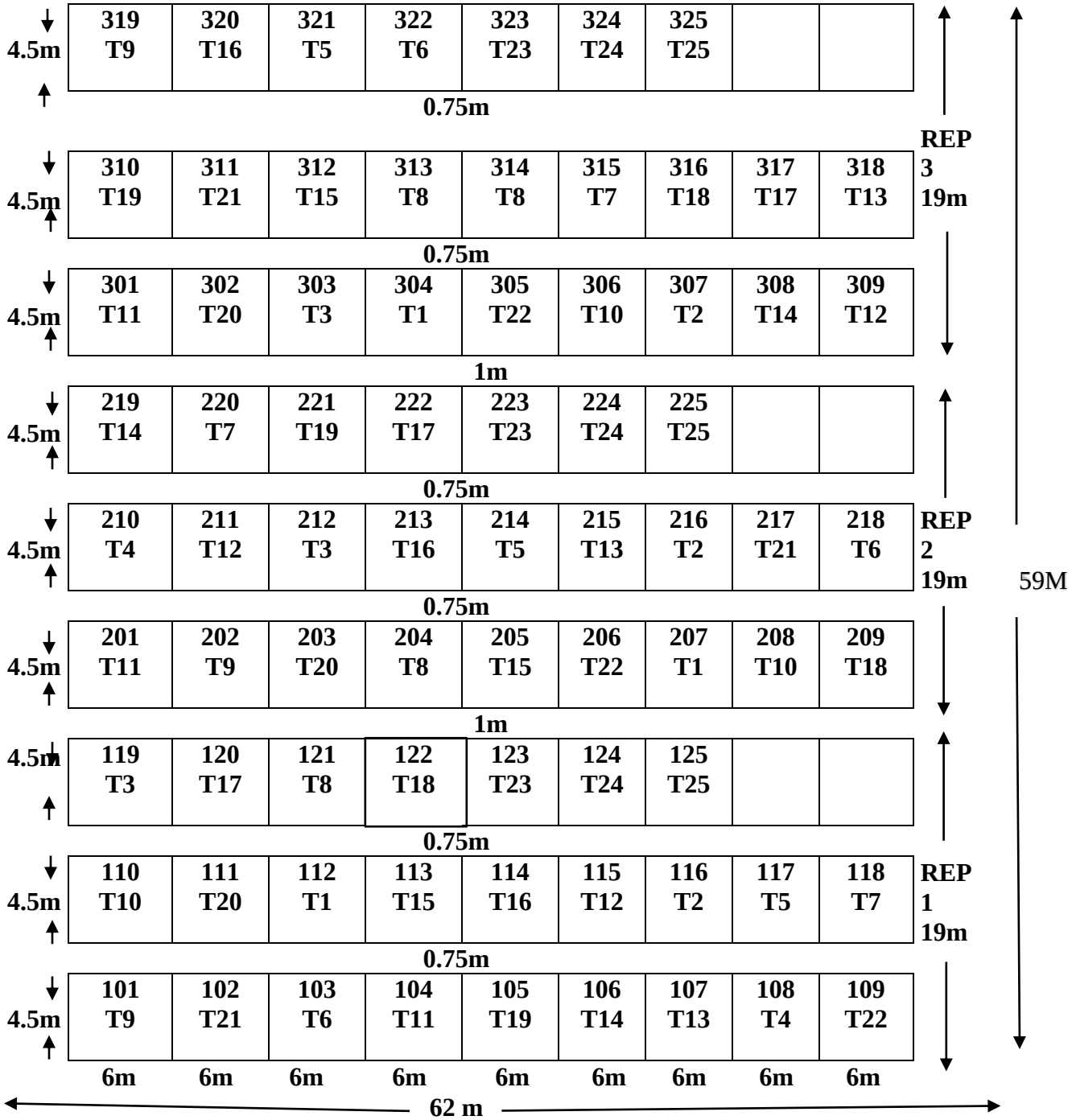


Figure 3.2 Experimental layout of the study

3.5 Laboratory Analysis

3.5.1 Routine soil analysis

Soil preplant samples analysed were made from each of the experimental site sampled at the depth of 0-20 cm. The samples were air-dried, ground and passed through a 0.2-mm mesh sieve. Soil texture (particle-size distribution) was determined using the hydrometer method (Gee and Bauder, 1986). Soil pH, both in water and $CaCl_2$ (1:2.5 soil- water ratio), was determined using glass electrode pH meter. Electrical conductivity (EC) was determined using conductivity meter at 1:5 soil-water ratio and the reading was multiplied by 6.4 to obtain the EC (Landon, 1991). Organic carbon (OC) was determined using the Walkley – Black method and the values were multiplied by 1.73 to get organic matter (Nelson and Sommer, 1982). Total N was determine using the micro Kjeldahl method (Bremner and Mulvaney, 1982). Available P was determined using the Bray-1 method (Olsen and Sommer, 1982). Cation exchange capacity (CEC) was obtained using 1M ammonium acetate (NH_4OAC) saturation method (Page *et al*., 1982). Sodium (Na) and potassium (K) in the extract were determined using the flame photometer, while Ca and Mg were determined on atomic absorption spectrophotometer (AAS). Effective cation exchange capacity was estimated by the summation method of exchangeable acidity and exchangeable bases. The extractable Zn was extracted with 0.1 N HCl and determined in AAS. Extractable Sulphate Sulphur was determined by the procedure of Tabatabai (1974).

3.6 **Data Collection:** The following data was collected at plot level.

- Panicle length (cm): Average length of 5 tagged panicles was measured from the point of initiation to the tip of the panicle and calculated.
- Stover water contents: at harvest, stover sub-sample was weighed, air-dried, oven-dried, reweighed, and water content of oven dried stover was calculated. Air-dried stover water content was determined on a block rather than plot basis.
- Dry stover weight: The stover was dried in an oven to a constant weight and the final dry matter yield was calculated in tons per hectare.

- Grain yield: The panicle head from the net plot was harvested and weighed to determine the moisture content. The harvested panicle was further dried to constant weight. The dried head was threshed and grain yield (kg/ha) computed.

3.7 Statistical and Data Analysis

Analysis of variance (ANOVA) was conducted on all data using SAS (SAS, 2013). Duncan multiple range test (DMRT) was used to separate the means (Gomez and Gomez, 1984). Where replication was considered as random effect; N, P and K were considered fixed effects. Where a significant nutrient rate occured, an asymptotic yield function was determined which is represented as $y = a - bc^n$. Where y = yield in Mg/ha; a = near maximum grain yield; b = yield increase due to nutrient application; c^n determines the shape of the curvilinear response where c was a curvature coefficient and n was the nutrient rate.

The net return above fertilizer cost at different nutrient rates was calculated as follows.

NRF = [P× $(Y_N - Y_O)$]-[C× N] (Wortmann *et al*., 2007).

Where P = Price of grain per kilogram

C = Cost of nutrient per kilogram

N = nutrient application rate (kg/ha)

Y_N = crop yield due to N application (kg/ha)

Y_0 = crop yield with no fertilizer (kg/ha).

Nutrient rate that maximize net return to fertilizer use or the EONR was determined using an asymptotic or quadratic functions for a range of grain price ratios (CPs). Asymptotic or

quadratic equations were developed to relate EONR to CP. The VCR was determined and equations developed to predict the VCR from nutrient rates and CPs. The nutrient rates and CPs were the independent variables. The VCR was calculated as follows.

$$VCR = \frac{[P \times (Y_N - Y_0)]}{C}$$ (Ezui *et al*., 2010)

Where all parameters were as defined above.

Regression analysis that relates components of NUE to the different nitrogen rates was evaluated. The following components of nitrogen use efficiency (NUE) as described by Cassman *et al* (2002) was determined:

1. Harvest index, $HI = \frac{\text{Grain yield}}{\text{Grain and stover yield}}$
2. Agronomy efficiency, $AE = \frac{Y_{+N} - Y_{NO}}{\text{N rate}}$
3. Partial Factor Productivity, $PFP = \frac{Y}{\text{N rate}}$

Where:

N_{RATE} =Amount of Nitrogen fertilizer applied (kg/ha)

Y_{+N} = Crop yield with applied nitrogen fertilizer (kg/ha)

Y_{NO} =Crop yield in control plot with no N (kg/ha)

UN_{+N} = total crop nitrogen uptake in aboveground biomass in a plot that received N (kg)

UN_{NO} = total crop nitrogen uptake in aboveground biomass in a plot that received no fertilizer (kg).The units for all components are expressed in (kg/kg).

Sensitivity analysis was carried out using Excel Fertilizer Optimization Tool (FOT) and optimized fertilizer recommendations for all the sites were developed. The application of the recommended fertilizer dispensed using Calibration tool. The inputs are:

- Area (ha) one hectare land was used and expected grain value of sorghum per kg at harvest was ₦ 60,
- Cost of buying, transporting and applying 50 kg bags of available fertilizers were ₦ 5,500, ₦ 4,500 and ₦7,000 for Urea, SSP and MOP respectively.
- Amount of money available for investment in fertilizer use were ₦ 5,000, ₦ 10,000 and ₦ 20,000 for level 1,2 and 3 financial abilities respectively.

The output panel provided results of the optimization calculations. (Figure 2.2)

- Recommended fertilizer rates for sorghum,
- Expected average yield increases,
- Net returns per hectare resulting from fertilizer use for sorghum and
- Expected total net return on fertilizer investment.

The calibration tool was run and the inputs were:

- Dimension of the container used,
- Volume of cylindrical or rectangular container,
- Type of fertilizer used,
- Number of kg of fertilizer to be applied per hectare and
- Method of application and distance between rows and plants within rows.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Physical and Chemical Properties of the Soils at the Experimental Sites

Results of some of the physical and chemical soil properties of the study areas are presented in Table 4.1. The results showed that the soils were dominated by sand sized particles, and the textural classes were sandy loam at all location. The dominance of sand may be due to the parent materials (granite) from which the soils were developed. Sand particles made of quartz mineral are essential component in granite and is resistant to weathering (FMARD, 2012). This corroboratess the findings of Esu (1999) and that of Odunze *et al*. (2006). These authors reported that sand fractions dominate the surface layer of similar sand loam. The soils had near neutral pH in water ranging from 6.5 to 6.6 while the soil pH in $CaCl_2$ for the three locations were slightly acidic with mean value of 5.7, 5.6, and 5.6 for Samaru, Unguwar Chida and Zarewa respectively. Similar pH values were reported by FMANR (1990) for soils of this region. Similarly, FMARD (2012) reported similar pH values and attributed the moderate acid condition to the silica content of the underlying acid parent materials rendering the soils inherently low in bases hence acidic in nature.

Organic carbon was considered low having a mean value of 0.79 g kg^{-1}, 0.21 g kg^{-1} and 0.58 g kg^{-1} in Samaru, Unguwar Chida and Zarewa respectively (Table 4.1). The low organic carbon content may be attributed to the management practice by smallholder farmers of removing all above the ground biomass at the end of the cropping season. This might be attributed to high rate of chemical and biological actions as well as the abundance of micro organic activity this concurred with the findings of (Ismaila *et al*., 2010).

Table 4.1 Physical and chemical properties of soil at the experimental sites.

Soil properties	Samaru	Unguwar chida	Zarewa
Sand (g kg^{-1})	600	620	680
Silt (g kg^{-1})	300	300	260
Clay (g kg^{-1})	100	80	60
Textual class	Sandy loam	Sandy loam	Sandy loam
pH (H_2O)	6.50	6.60	6.50
p^H ($CaCl_2$)	5.70	5.60	5.60
Organic carbon (g kg^{-1})	0.79	0.21	0.58
Total N (g kg^{-1})	0.28	0.03	0.07
Available P (mg kg-^{1})	8.20	9.00	6.90
Exch. Bases (cmol kg^{-1})			
K^+	0.27	0.85	0.39
Na^+	0.37	0.24	0.30
Ca^{2+}	2.60	2.20	2.70
Mg^{2+}	0.33	0.83	0.06
Exchangeable acidity (cmol kg^{-1})	0.80	0.16	0.13
Effective CEC (cmol kg^{-1})	4.37	4.28	3.58
SO_4^{-2} (mg kg^{-1})	11.29	7.52	10.58
Zn (mg kg^{-1})	5.5	6.5	4.5

ECEC: Effective Exchangeable Cation Capacity

These authors reported low organic matter content and attributed it to be characteristic of most savanna soils. They also linked the result to higher rate of chemical and biological actions as well as the abundance of micro organic activity. The mean total N content of 0.28 g kg^{-1} was recorded in Samaru, while 0.03 g kg^{-1} and 0.07 g kg^{-1} were recorded in Unguwar Chida and Zarewa respectively (Table 4.1). Total N was also low for all sites and may be attributed to low organic matter content of the study areas since the bulk of total N is found in organic form. Low organic matter in most cases connotes low total N for savanna soils. However, considerable amounts of soil available N are released with the onset of rains, yet its uptake by crops is insignificant due to the low N requirements of plants at the early growth stages due to higher N loss through leaching (Kamara *et al*., 2005). The mean available P values are 6.9 g kg^{-1}, 8.2 g kg^{-1} and 9.0 g kg^{-1} in Unguwar Chida, Samaru and Zarewa respectively. Mean available P for the three locations was moderate (8.0 mg kg^{-1}) (Table 4.1) and higher than 7.0 mg kg^{-1} reported by Abdu *et al*. (2007) in similar savanna soils. This may be due to low clay and organic matter content of the soils. Phosphorus is usually associated with finer fraction of the soil and organic matters also contribute significantly to the total P. The mean value for the exchangeable bases were 2.2 cmol kg^{-1} for Ca^{2+}, 0.83 cmol kg^{-1} for Mg^{2+}, 0.24 cmol kg^{-1} for Na^{+} and 0.85 cmol kg^{-1} for K^{+} in Unguwar Chida while in Zarewa the mean values were 2.70 cmol kg^{-1} for Ca^{2+}, 0.06 cmol kg^{-1} for Mg^{2+}, 0.30 cmol kg^{-1} for Na^{+} and a mean of 0.39 cmol kg^{-1} for K^{+}. In Samaru, the mean values were 2.6 cmols kg^{-1} for Ca^{2+}, 0.33 cmols kg^{-1} for Mg^{2+}, 0.37 cmols kg^{-1} for Na^{+} and 0.27 cmols kg^{-1} for K^{+} (Table 4.1). The exchangeable acidity was less than 1 and this implies that there is no exchangeable acidity problem in the soils. This is similar to the findings of (Odunze, 1997). Effective cation exchange capacity

(ECEC) of 4.37, 4.28 and 3.54 cmols kg^{-1} were all low in the soil indicating the capacity of the soils to retain nutrients (Odunze *et al*., 2006). The SO_4^{2-} values are 11.29, 7.52 and 10.58 mg kg^{-1} was moderately high which may be lost in the soil through leaching; plant uptake and a larger proportion of it may be unavailable to plant (Brady and Weil, 2002). Available Zn was considered moderately low and ranged from 1.0-9.5 mg kg^{-1} and could be due to parent materials which the soils were derived from (Abdu *et al*., 2007).

4.2.0 Effect of Inorganic Fertilizer Sources and Rates on Yield Parameters at Harvest

4.2.1 Panicle weight

Table 4.2 presents the effect of inorganic fertilizer sources and rates on yield parameters of sorghum at harvest. At Samaru, the treatments 120N and 22.5P kg ha^{-1} gave the heaviest panicle weight of 4.67 kg only when compared with applied 90N kg ha-^{1} and 90N, 15P, 20K, 15S, 2.5Zn, 10Mg and 0.5B kg ha-^{1} that was statistically similar with other treatments except treatments 90N kg ha-^{1} which gave the lowest panicle weight of 2.83 kg. At Unguwar Chida treatments 90N, 15P, 30K and 15S kg ha^{-1} had mean value of 5.67 kg and while 90N, 15P, 20K, 15S, 2.5Zn, 10Mg and 0.5B kg ha^{-1} had a mean value of 5.61 kg. These rates gave the heaviest panicle weight at harvest. It was however statistically the same ($p<0.05$) with other treatments except 30N and 15P kg ha^{-1} ,that had 4.13 kg mean value, 60N kg ha^{-1},that had mean value of 4.30 kg, 30N kg ha^{-1} with mean value of 4.30 kg and 0-0-0 with mean value of 3.95 kg. At Zarewa the 120N and 22.5P kg ha^{-1} treatment had mean value of 3.18 kg that gave the heaviest panicle weight at harvest. It was significantly higher ($p<0.05$) than 120N and 15P kg ha^{-1} that mean value of 2.15 kg, 90-7.5 kg ha^{-1} that had mean value of 2.04 kg, 90-0-0 kg ha^{-1} that had mean value of 2.20 kg and the control treatment with mean value of 1.96 kg which had lowest panicle weights.

Table.4.2. Effect of nutrients application rates on panicle weight at harvest in Samaru, Unguwar Chida and Zarewa.

Nutrient rates (NPK)	Samaru	Unguwar Cheda	Zarewa
0N-0P-0K	3.63^{abc}	3.95^{c}	1.96^{d}
30N-0P-0K	3.43^{abc}	4.30^{bc}	2.36^{a-d}
60N-0P-0K	3.37^{abc}	4.30^{bc}	2.50^{a-d}
90N-0P-0K	2.83^{c}	4.69^{abc}	2.48^{a-d}
120N-0P-0K	4.20^{abc}	4.87^{abc}	2.20^{bcd}
30N-7.5P-0K	3.83^{abc}	4.51^{abc}	2.93^{abc}
60N-7.5P-0K	3.30^{abc}	4.69^{abc}	2.94^{abc}
90N-7.5P-0K	3.67^{abc}	4.95^{abc}	2.04^{cd}
120N-7.5P-0K	4.17^{abc}	5.13^{abc}	2.26^{a-d}
30N-15P-0K	3.60^{abc}	4.13^{c}	2.86^{a-d}
60N-15P-0K	3.77^{abc}	4.81^{abc}	2.55^{a-d}
90N-15P-0K	3.57^{abc}	4.57^{abc}	2.89^{a-d}
120N-15P-0K	4.00^{abc}	5.57^{ab}	2.15^{bcd}
30N-22.5P-0K	3.83^{abc}	4.51^{abc}	2.61^{a-d}
60N-22.5P-0K	3.57^{abc}	4.81^{abc}	2.94^{abc}
90N-22.5P-0K	3.63^{abc}	5.06^{abc}	2.83^{a-d}
120N-22.5P-0K	4.67^{a}	5.42^{ab}	3.18^{a}
60N-15P-10K	3.83^{abc}	4.95^{abc}	2.35^{a-d}
90N-15P-10K-5S	4.00^{abc}	4.40^{abc}	2.30^{a-d}
90N-15P-20K-10S	4.32^{ab}	5.06^{abc}	2.61^{a-d}
90N-15P-30K-15S	4.16^{abc}	5.67^{a}	2.81^{a-d}
60N-15P-0K-0.5Zn	3.73^{abc}	4.8^{abc}	2.48^{a-d}
60N-15P-0K-1Zn	3.73^{abc}	4.91^{abc}	2.65^{a-d}
60N-15P-0K-1.5Zn	4.30^{ab}	4.57^{abc}	2.38^{a-d}
90N-15P-20K-15S-2.5Zn-10Mg-0.5B	3.17^{bc}	5.61a	3.04^{ab}
SEM	$\pm$0.39	$\pm$0.37	$\pm$0.27

Mean followed by the same letter within the column are not significantly different at 5% level of probability.

There were significant differences at ($p<0.05$) due to influence of fertilizer application on the panicle weight at harvest. These differences might be due to adequate supply of nutrients that allowed crop to grow to full maturity. This observation is similar to the report of Zerihun (2016) who observed rapid growth of sorghum with large amount of succulent, green foliage as a result of adequate supply of nitrogen.

4.2.2 Panicle Length

The treatment effects on panicle length at harvest are statistically shown in Table 4.3. At Samaru, the treatments 90N and 22.5P kg ha^{-1}, 30N and 7.5P kg ha^{-1}, and 60N, 15P and 1.5Zn kg ha^{-1} ha^{-1} gave the longest panicle of 36.0cm, 36.0cm and 35.6cm which were statistically the same with other treatments except with applied 60N kg ha^{-1} which has the shortest panicle of 31.33 cm. Similarly, at Unguwar Chida the treatment 90N,15P,20K,15S,2.5Zn, 10Mg and 0.5B kg ha^{-1} gave the longest panicle of 35.71 cm which was statistically the same with other treatments, but significantly different from the control 0-0-0 which had a length of 31.4 cm. At Zarewa treatment 120N and 15P kg ha^{-1} had the longest panicle length of 34.00cm which was statistically similar with other treatments, except the absolute control treatment which had a length of 30.13 cm. Generally, the length of panicle determines the number of grain per panicle. This observation could be as a result of combine influence of nitrogen and phosphorus fertilizers that enhances better growth and development of the crop. This is in agreement with the report of Sujathamma *et al*. (2015).

Table 4.3. Effect of nutrients application rates on panicle length at harvest in Samaru, Unguwar Chida and Zarewa

Nutrient rates (NPK)	Samaru	Unguwa Chida	Zarewa
0N-0P-0K	32.33^{ab}	31.4^{3b}	30.13^{c}
30N-0P-0K	33.33^{ab}	31.43^{b}	31.86^{abc}
60N-0P-0K	31.33^{b}	32.57^{ab}	32.38^{abc}
90N-0P-0K	34.33^{ab}	33.86^{ab}	33.13^{ab}
120N-0P-0K	33.67^{ab}	32.29^{b}	33.50^{ab}
30N-7.5P-0K	36.00^{a}	31.14^{b}	31.75^{abc}
60N-7.5P-0K	34.33^{ab}	32.29^{b}	32.13^{abc}
90N-7.5P-0K	33.33^{ab}	33.57^{ab}	30.75^{bc}
120N-7.5P-0K	34.67^{ab}	33.57^{ab}	33.13^{ab}
30N-15P-0K	33.00^{ab}	32.57^{ab}	33.63^{ab}
60N-15P-0K	34.33^{ab}	32.00^{b}	31.25^{abc}
90N-15P-0K	34.33^{ab}	32.00^{b}	32.13^{abc}
120N-15P-0K	32.33^{ab}	33.71^{ab}	34.00^{a}
30N-22.5P-0K	34.67^{ab}	31.86^{b}	33.13^{ab}
60N-22.5P-0K	34.67^{ab}	32.14^{b}	32.50^{abc}
90N-22.5P-0K	36.00^{a}	32.14^{b}	33.25^{ab}
120N-22.5P-0K	33.67^{ab}	33.17^{ab}	32.50^{abc}
60N-15P-10K	33.67^{ab}	33.71^{ab}	32.13^{abc}
90N-15P-10K-5S	34.00^{ab}	32.57^{ab}	32.50^{abc}
90N-15P-20K-10S	35.33^{ab}	33.28^{ab}	32.25^{abc}
90N-15P-30K-15S	35.33^{ab}	34.43^{ab}	31.25^{abc}
60N-15P-0K-0.5Zn	34.00^{ab}	31.29^{b}	31.25^{abc}
60N-15P-0K-1Zn	32.00^{ab}	31.86^{b}	32.25^{abc}
60N-15P-0K-1.5Zn	35.67^{a}	33.71^{ab}	33.50^{ab}
90N-15P-20K-15S-2.5Zn-10Mg-0.5B	32.67^{ab}	35.71^{a}	32.25^{abc}
SEM	$\pm$1.16	$\pm$0.95	$\pm$0.86

Mean followed by the same letter within the column are not significantly different at 5% level of probability.

4.2.3 Grain yield

Table 4.4 present the Effects of inorganic fertilizer types and rates on grain yield of sorghum at harvest. The highest grain yield of 2567.3 kg was obtained in treatments 60N,15P and 10K and 60N,15P, and 1.5Zn kg ha^{-1} at Samaru. It was statistically similar ($p<0.05$) with other treatments except with the control, 30N and 15P kg ha^{-1} while lowest grain yield of 1645.4 kg was obtained with the latter. Grain yield significantly ($p< 0.05$) responded to N application across the three sites. Therefore, the longer the length of panicle the more the number of grains and the shorter the length of a panicle the lower the grains per panicle. This indicates that N is limiting nutrient to sorghum production irrespective of the locations. At the same time, maximum grain yield of 2567 kg was obtained at Samaru by applying 60N,15P and 10K kg ha-^{1}. This explained that higher application rates of NPK fertilizer above 60-15-10 depresses sorghum yield. This result is in line with the report of FMARD (2012a) that while satisfying nutrient requirements of sorghum, one must be cautious to avoid over fertilization that generally depresses yield especially tall and long duration cultivars. On the other hand, at application rate of 60N, 15P and 1.5Zn kg ha^{-1} and addition of Zn rate boosted the sorghum yield. This implies that Zn could replace or substitute K for sorghum.Thus, inclusion of Zn in commercial fertilizers is highly desirable for the location.

At Unguwar Chida, treatment 120N and22.5P kg ha^{-1} gave the highest grain yield of 2432.1 kg which was statistically similar with some other treatment but significantly different from the control 0-0-0. At this location, grain yield measured ranged from 1401 kg ha^{-1} when no mineral N fertilizer was applied to 2432 kg ha^{-1} at the application rate of 120N and 22.5P kg ha^{-1}. The low yield in the control indicates that it is a normal practice

of smallholder farmers who are generally reluctant to apply inorganic fertilizer to sorghum crops. Moreover, the application of 120N and 22.5P kg ha^{-1} gave a maximum yield of 2432.1 kg. Thist may be due to increasing availability of soil nutrients with increased N and P fertilizer rates and positive effect of N and P elements on the production of grain sorghum as reported by Abou-Amer and Kewan (2014). At Zarewa, the treatment 30N and15P kg ha^{-1} gave the highest grain yield of 2181.6 kg which was statistically similar with other treatments but significantly different from the absolute control that had the yield of 843.7 kg. At Zarewa significant ($p<0.05$) grain yield increase was obtained with application of 30N and15P kg ha^{-1} over the control. The application of this small quantity of fertilizer depicts the normal practice by smallholder farmers. This proved the more balanced and efficient use of the fertilizer rates as reported by Abbas *et al*. (2015) that inorganic fertilizer that is very costly be used judiciously. It is evident that there was variation in response between Samaru, Unguwar Chida and Zarewa. These findings support the idea that it is important to consider the variability between soil fertility status of individual fields (Vanluawe and Zingore, 2011). The rates mentioned above could be relied upon to give a worthwhile return in sorghum production. It would seldom result in the optimum yield and hence, in optimum fertilizer use efficiency.

Table.4.4. Effect of nutrients application rates on grain yield at harvest in Samaru, Unguwar Chida and Zarewa

Nutrient rates (NPK)	Samaru	Unguwar Chida	Zarewa
0N-0P-0K	1538.6^{bc}	1400.5^{f}	843.7^{e}
30N-0P-0K	1763.1^{abc}	1535.7^{ef}	1651.1^{a-d}
60N-0P-0K	1886.7^{abc}	1849.4^{b-f}	1502.9^{bcd}
90N-0P-0K	1981.3^{abc}	1945.9^{a-e}	1891.6^{abc}
120N-0P-0K	2032.2^{abc}	2066.1^{a-e}	1867.7^{abc}
30N-7.5P-0K	2523.0^{ab}	1613.2^{def}	1535.8^{bcd}
60N-7.5P-0K	1981.3^{abc}	1824.0^{b-f}	1743.1^{a-d}
90N-7.5P-0K	2146.5^{abc}	2060.2^{a-e}	1295.0^{de}
120N-7.5P-0K	2456.6^{ab}	2192.3^{abc}	1549.0^{bcd}
30N-15P-0K	1645.4^{c}	1686.8^{c-f}	2181.6^{a}
60N-15P-0K	2348.6^{abc}	1959.7^{a-e}	1535.8^{bcd}
90N-15P-0K	2008.1^{abc}	1886.9^{b-f}	1726.2^{a-d}
120N-15P-0K	2384.6^{abc}	2099.7^{a-d}	1651.1^{a-d}
30N-22.5P-0K	2373.5^{abc}	1771.8^{b-f}	1874.6^{abc}
60N-22.5P-0K	2151.1^{abc}	1924.5^{a-e}	1902.6^{abc}
90N-22.5P-0K	2051.4^{abc}	2225.9^{ab}	1295.0^{de}
120N-22.5P-0K	2296.0^{abc}	2432.1^{a}	1950.0^{abc}
60N-15P-10K	2567.3^{a}	1968.8^{a-e}	1743.1^{a-d}
90N-15P-10K-5S	2259.1^{abc}	1652.4^{def}	1919.9^{abc}
90N-15P-20K-10S	2150.2^{abc}	2131.3^{a-d}	1488.1^{cd}
90N-15P-30K-15S	2382.9^{abc}	2013.9^{a-e}	2059.4^{ab}
60N-15P-0K-0.5Zn	2159.4^{abc}	1973.1^{a-e}	1519.2^{bcd}
60N-15P-0K-1Zn	2073.6^{abc}	1987.8^{a-e}	1515.1^{bcd}
60N-15P-0K-1.5Zn	2541.5^{a}	1911.4^{a-e}	1923.4^{abc}
90N-15P-20K-15S-2.5Zn-10Mg-0.5B	1990.5^{abc}	2297.4^{ab}	2059.4^{ab}
SEM	±225.9	±153.7	±163.5

Mean followed by the same letter within the column are not significantly different at 5% level of probability.

4.2.4 Stover yield

The Effects of inorganic fertilizer sources and rates on stover yield of sorghum at harvest is shown in Table 4.5. The stover yields at Samaru were statistically similar ($p<0.05$) among treatments. At Unguwar Chida treatment 90N and 22.5P kg ha^{-1} gave the highest stover yield of 7329.8 kg.which was statistically similarbto all other treatments except with the control, 30N kg ha^{-1} and 60N kg ha-^{1}. At Zarewa treatment 90N, 15P, 10K and 5B kg ha^{-1} had the highest stover yield of 3178.5 kg which was statistically similar with other treatments but different from treatment 120N and 15P kg ha^{-1}, 90N and 7.5P kg ha^{-1} which gave the lowest stover yield of 2145.8, and 2148 kg respectively.The difference obtained in stover yield could be due to increased N and P uptake by the crop. These improvements with increasing fertilizer levels were similar to the report by Buah and Mwinkaara (2009) and Sujathamma *et al*. (2015) who reported positive effect of N accumulation on grain and yield attributes of sweet sorghum. Increased grain yield due to N application could be ascribed to increased stover production, improved harvest index and increased seed set with N fertilization. This implies that stover yield could be used for economic purposes.

Table 4.5. Effect of nutrients application rates on stover yield at harvest in Samaru, Unguwar Chida and Zarewa

Nutrient rates (NPK)	Samaru	Unguwar Chida	Zarewa
0N-0P-0K	5555	5532.6^{bc}	2217.2^{ab}
30N-0P-0K	5278	4968.1^{c}	2470.2^{ab}
60N-0P-0K	4841	5635.2^{bc}	2758.9^{ab}
90N-0P-0K	4603	5625.7^{bc}	2812.4^{ab}
120N-0N-0K	4722	5707.4^{abc}	2145.8^{b}
30N-7.5P-0K	6905	6061.1^{abc}	2755.9^{ab}
60N-7.5P-0K	6667	7108.7^{abc}	2907.7^{ab}
90N-7.5P-0K	5714	6299.2^{abc}	2148.8^{b}
120N-7.5P-0K	5714	7010.0^{abc}	2452.3^{abc}
30N-15P-0K	5913	6020.3^{abc}	2755.9^{ab}
60N-15P-0K	6309	6754.6^{abc}	2627.9^{ab}
90N-15P-0K	5555	6180.1^{abc}	3178.5^{a}
120N-15P-0K	6190	6955.6^{abc}	2586.3^{ab}
30N-22.5P-0K	6309	6700.5^{abc}	3107.1^{a}
60N-22.5P-0K	5833	6758.6^{abc}	2842.2^{ab}
90N-22.5P-0K	5238	7329.8^{a}	2708.3^{ab}
120N-22.5P-0K	6071	6496.5^{abc}	3020.8^{a}
60N-15P-10K	5476	6734.5^{abc}	2261.9^{ab}
90N-15P-10K-5S	6071	6115.5^{abc}	2705.3^{ab}
90N-15P-20K-10S	6785	5986.3^{abc}	2633.9^{ab}
90N-15P-30K-15S	5674	7142.7^{ab}	2529.7^{ab}
60N-15P-0K-0.5Zn	6627	6758.4^{abc}	2958.3^{ab}
60N-15P-0K-1Zn	5714	6649.5^{abc}	2633.9^{ab}
60N-15P-0K-1.5Zn	5436	7091.7^{ab}	2568.4^{ab}
90N-15P-20K-15S-2.5Zn-10Mg-0.5B	4873	6836.6^{abc}	2589.2^{ab}
SEM	±303.6	±370.97	±276.8

Mean followed by the same letter within the column are not significantly different at 5% level of probability.

4.2.5 Harvest Index

The effect of inorganic fertilizer types and rates on yield parameters at harvest was presented in (Table 4.6). At Samaru the treatment 120-0-0 kg ha^{-1} gave the highest mean harvest index of 0.042. The value was statistically similar ($p<0.05$) with other treatments, except treatment 30N and 15P kg ha^{-1} with mean harvest index of 0.023. Similarly, at Unguwar Cheda the treatment 90N, 15P, 20K and 10S kg ha^{-1} gave the highest mean harvest index of 0.022, while in Zarewa the treatment that gave the highest harvest index was 60N,15P and 10K kg ha^{-1} ha^{-1} with value of 0.074. Harvest index is the ratio of grain yield to the biomass yield. Among the different fertilizer rates studied there was significant ($p<0.05$) variation in harvest index range from 0.23 to 0.42 at Samaru, 0.22 to 0.29 at Unguwar Chida and 0.37 to 0.74 at Zarewa. The variation found for the harvest index could be largely explained by differences in assimilation during grain filling and remobilation of pre-anthesis assimilates. Similar variation has been reported by Sujathamma *et al*. (2015).

Table. 4.6. Effect of nutrients application rates on harvest index at Samaru, Unguwar Chida and Zarewa.

Nutrient rates (NPK)	Samaru	Unguwar Chida	Zarewa
0N-0P-0K	0.29^{abc}	0.22^{b}	0.37^{f}
30N-0P-0K	0.35^{abc}	0.22^{b}	0.66^{a-d}
60N-0P-0K	0.32^{abc}	0.27^{ab}	0.54^{b-e}
90N-0P-0K	0.38^{ab}	0.29^{ab}	0.56^{b-e}
120N-0P-0K	0.42^{a}	0.29^{ab}	0.70^{ab}
30N-7.5P-0K	0.31^{abc}	0.22^{b}	0.56^{b-e}
60N-7.5P-0K	0.38^{ab}	0.28^{ab}	0.49^{def}
90N-7.5P-0K	0.30^{ab}	0.28^{ab}	0.48^{ef}
120N-7.5P-0K	0.38^{ab}	0.26^{ab}	0.52^{c-f}
30N-15P-0K	0.23^{c}	0.24^{ab}	0.69^{ab}
60N-15P-0K	0.31^{abc}	0.25^{ab}	0.54^{b-e}
90N-15P-0K	0.32^{abc}	0.26^{ab}	0.56^{b-e}
120N-15P-0K	0.34^{abc}	0.26^{ab}	0.66^{a-d}
30N-22.5P-0K	0.31^{abc}	0.23^{ab}	0.54^{b-e}
60N-22.5P-0K	0.27^{abc}	0.23^{ab}	0.74^{a}
90N-22.5P-0K	0.33^{abc}	0.25^{ab}	0.57^{b-e}
120N-22.5P-0K	0.33^{abc}	0.29^{ab}	0.56^{b-f}
60N-15P-10K	0.39^{ab}	0.24^{ab}	0.49^{def}
90N-15P-10K-5S	0.32^{abc}	0.23^{ab}	0.51^{c-f}
90N-15P-20K-10S	0.26^{bc}	0.30^{a}	0.51^{c-f}
90N-15P-30K-15S	0.35^{abc}	0.23^{ab}	0.67^{abc}
60N-15P-0K-0.5Z	0.28^{abc}	0.24^{ab}	0.54^{b-e}
60N-15P-0K-1Z	0.32^{abc}	0.25^{ab}	0.49^{c-f}
60N-15P-0K-1.5Z	0.38^{ab}	0.23^{ab}	0.61^{a-e}
90N-15P-20K-15S-2.5Zn-10Mg-0.5B	0.36^{abc}	0.28^{ab}	0.67^{abc}
SEM	$\pm$0.04	$\pm$0.02	$\pm$0.05

Mean followed by the same letter within the column are not significantly different at 5% level of probability.

4.3 Yield Response to Nitrogen, Phosphorus, Potassium and some Micronutrients

From the regression analysis which gave quadratic function, optimum N rate was attained for all the locations as presented in Figure 4.1. At Samaru, the optimum was attained at 127.1 kg N ha^{-1} which gave the optimum yield of 3.5 tons ha^{-1}. However, at Unguwar Chida N rate was 208.1 kg N ha^{-1} and gave the optimum yield of 2.2 tons ha^{-1}. While at Zarewa N rate was 102.7 kg N ha^{-1} and gave the optimum yield of 1.8 tons ha^{-1}. The responses of sorghum to N at different rates of fertilizer was positive and this implies that N has positive effect on grain yield across the three sites. (Ismaila *et al*., 2010) described N to be the most important limiting element in sorghum production.

Figure 4.2. Shows the results of P response curve by sorghum in Samaru, Unguwar Chida and Zarewa. At Samaru, the optimum P rate was attained at 14.7 kg ha^{-1} which gave the optimum yield of 2.3 tons ha^{-1}. However, at Unguwar Chida P rate was 19.1 kg ha^{-1} and gave the optimum yield of 2.0 tons ha^{-1}. While at Zarewa P rate was 17.2 kg ha^{-1} and gave the optimum yield of 1.8 tons ha^{-1}. Among the locations, Samaru response to P application gave the lowest P rate, while Zarewa yield response was the lowest. There was a positive response to P application in all three locations with R^2 of 1, 0.94 and 0.97 for Zarewa, Unguwar Chida and Samaru respectively. The response to P fertilization was also significant and indicated that P was also a limiting nutrient element in all the three sites. This implies that application of Phosphorus fertilizer is important for sorghum growth and root development (Fageria *et al*., 2003).

Figure 4.3 shows K response curve by sorghum at Samaru, Unguwar Chida and Zarewa. At Samaru, the optimum K rate was attained at 24.9 kg ha^{-1} which gave the optimum yield of 2.3 tons ha^{-1}. However, at Unguwar Chida K rate was 27.5 kg ha^{-1} and gave the

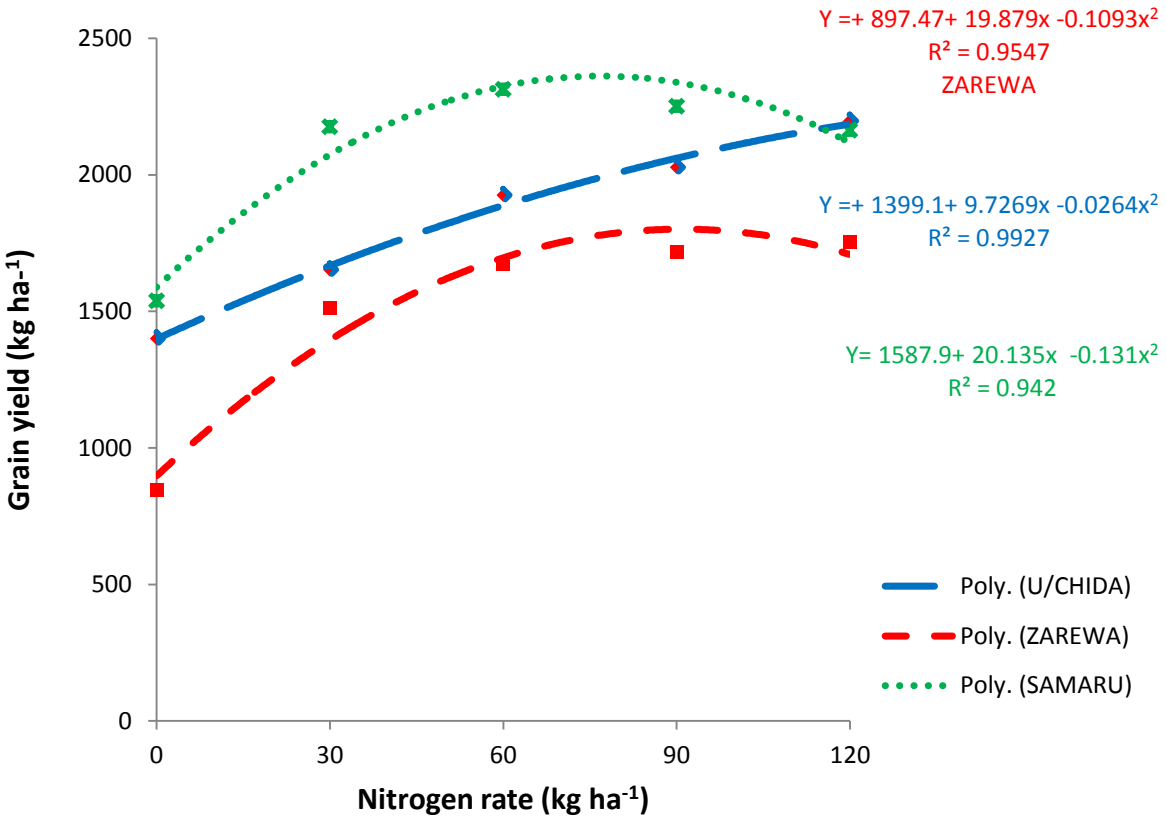


Figure 4.1 Effects of nitrogen application on sorghum grain yield at Samaru, Unguwar Chida and Zarewa.

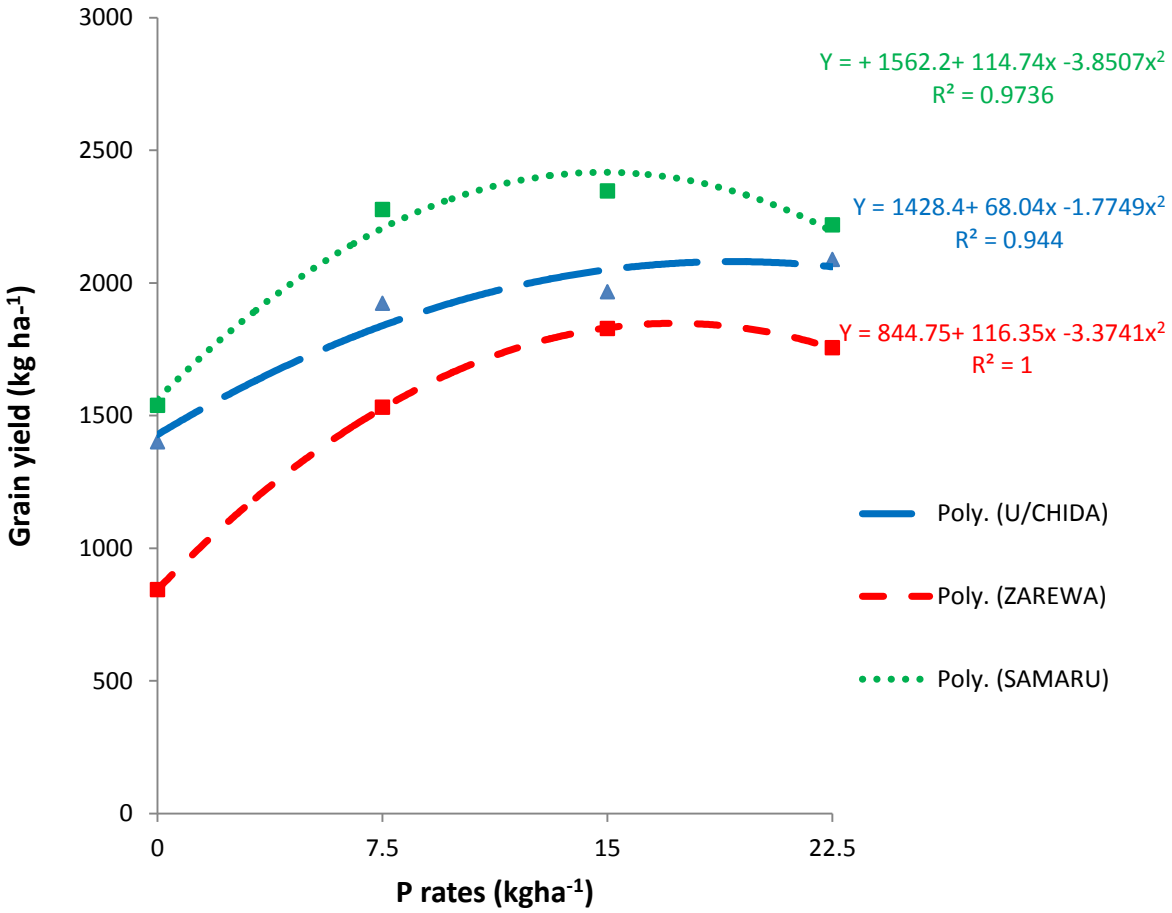


Figure.4.2: Effects of Phosphorus application on grain yield at Samaru, Unguwar Chida and Zarewa.

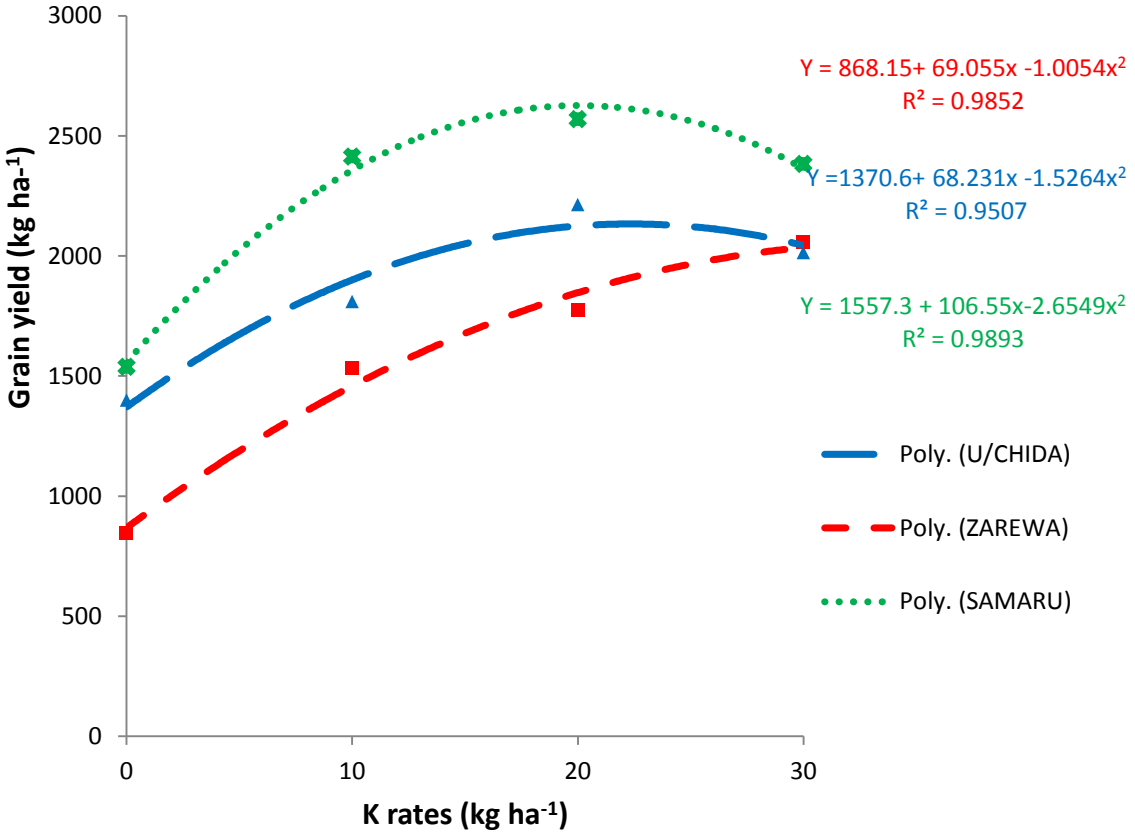


Figure.4.3: Effects of potassium application on grain yield at Samaru, Unguwar Chida and Zarewa.

optimum yield of 2.0 tons ha^{-1}. While at Zarewa K rate was 27.7 kg ha^{-1} and gave the optimum yield of 1.9 tons ha^{-1}. Samaru, Unguwar Chida and Zarewa responded positively to K application with the R^2 value of 0.84, 0.90 and 0.65 respectively. However, the sorghum response to K fertilization at different rates reveals that there was a response to K application but when N and P are present. The balance nutrients did not boost grain yield due to the low buffering capacity of potassium in the soil therefore causing yield depression (FMARD, 2012a).

The results of N and P applications on sorghum grain yield 30 kg N ha^{-1} with P rates at Samaru, Unguwar Chida and Zarewa are shown in Figure 4.4. At Samaru, the optimum P rate was attained at 38.62 kg ha^{-1} which gave the optimum yield of 2.2 tons ha^{-1}. However, at Unguwar Chida P rate was 25.2 kg ha^{-1} and gave the optimum yield of 1.7 tons ha^{-1}. While at Zarewa P rate was 16.8 kg ha^{-1} and gave the optimum yield of 2.0 tons ha^{-1}. The two locations responded positively to application of 30 kg/ha N rate with P rates with R^2 between 0.99 to 0.96. The response at Samaru was found to be linear with R^2 of 0.09. The effect of 30 kg ha^{-1} N rate with phosphorus rates was significant at Samaru and is marked by the linear increase in P rates. This might be related to loss by erosion across the gradient as reported by (Fageria *et al*., 2003). There was a significant effect of P rates at Uguwar Chida and Zarewa on sorghum yield which was marked by a response curve to P rates and was noted in increased straw yield and grain as also observed by Oseni (2009) in northern Guinea savanna soils of Nigeria.

The result of the response curve of 60 kg N ha^{-1} with P rates at the three locations are presented in Figure 4.5. At Samaru, the optimum was attained at 16.7 kg ha^{-1} which gave the optimum yield of 2.2 tons ha^{-1}. However, at Unguwar Chida N rate was 16.8 kg ha^{-1}

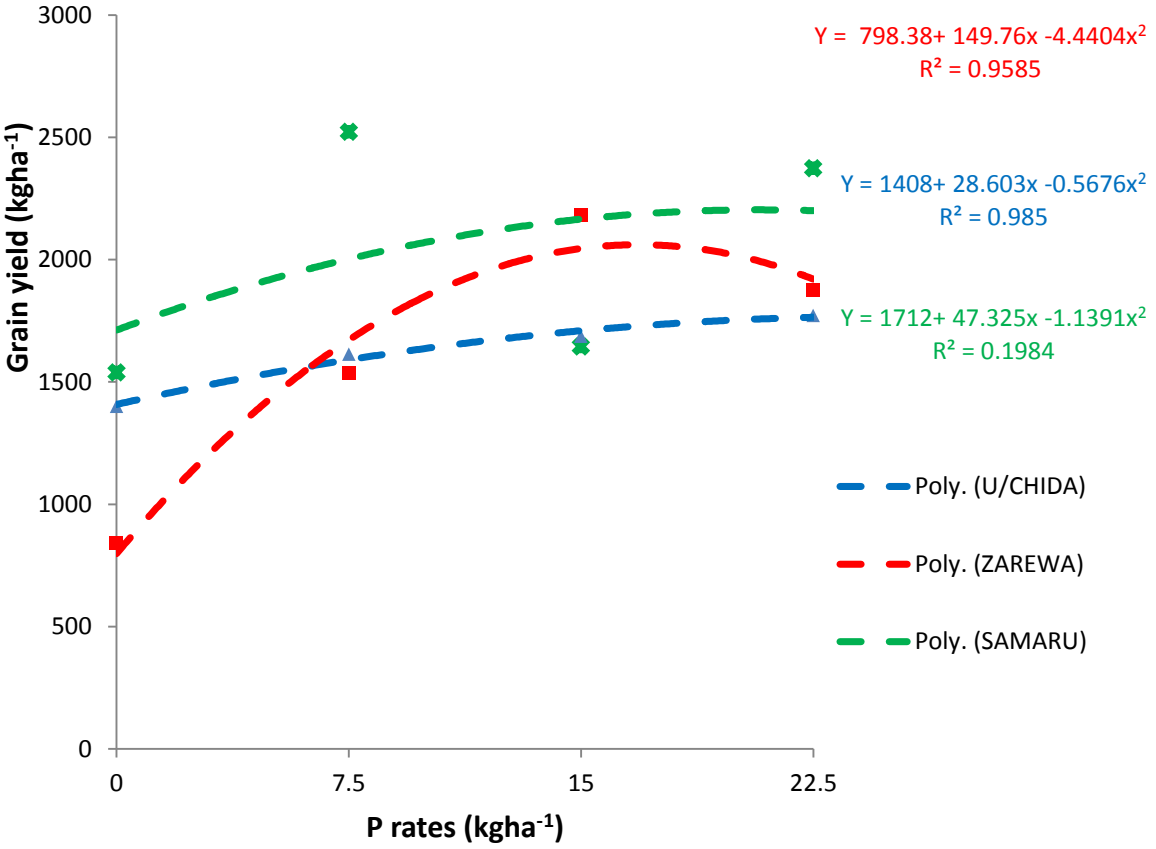


Figure.4.4: Effects of 30 kg N rate with phosphorus application on grain yield at Samaru, Unguwar Chida and Zarewa.

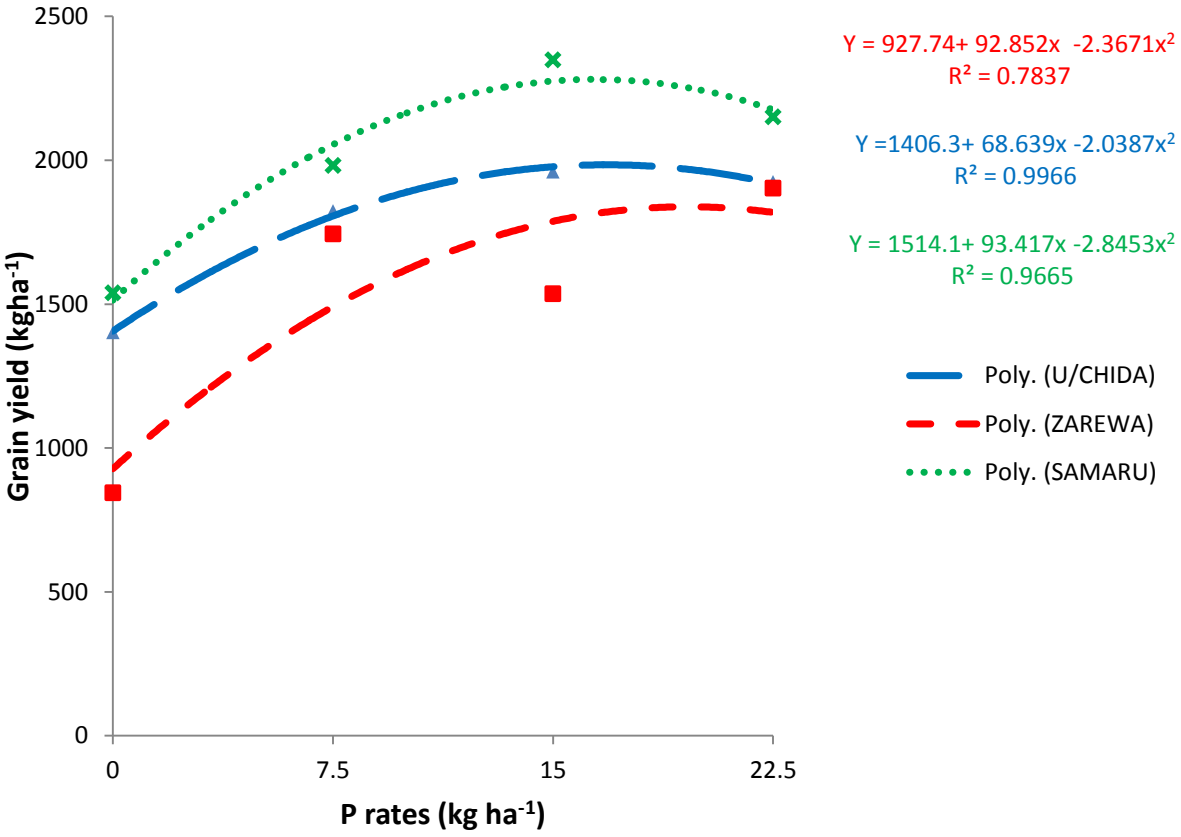


Figure.4.5: Effect of 60 kg N rate with P application on grain yield at Samaru, Unguwar Chida and Zarewa.

and gave the optimum yield of 1.9 tons ha^{-1}. While at Zarewa N rate was 19.6 kg ha^{-1} and gave the optimum yield of 1.8 tons ha^{-1}. The effect P application rates in the presence of N increased sorghum grain and straw yields with response of N and P rates. Roy and Khandarkar (2010) reported that lack of P is as important as lack of N in limiting plant performance. Phosphorus application contributes to the grain seed quality and biomass quantity of sorghum.

Figure 4.6 shows results of sorghum grain yield under 90 kg ha^{-1} N rate and P rates at Samaru, Unguwar Chida and Zarewa. At Samaru, the optimum P rate was attained at 14.5 kg ha^{-1} which gave the optimum yield of 2.1 tons ha^{-1}. However, at Unguwar Chida P rate was 22.0 kg ha^{-1} and gave the optimum yield of 2.1 tons ha^{-1}. While at Zarewa P rate was 14.2 kg ha^{-1} and gave the optimum yield of 1.6 tons ha^{-1}. The three locations responded positively to the rate of 90 kg N ha^{-1} together with the mentioned P application rates with R^2 value of between 0.91 to 0.71. There was a good response to higher dose of N rate with P application rates because of the low inherent nutrient supply of the soils. This may be due to increasing availability of soil nutrients with the increased in N and P fertilizer rate and positive effect of N and P elements on sorghum yield (Abou-Amer and Kewan 2014).

Response curve with the application of 120 kg ha^{-1} N rate with application of P rates at Samaru, Unguwar Chida and Zarewa are shown in Figure 4.7. At Samaru, the optimum P rate was attained at 14.2 kg P ha^{-1} which gave the optimum yield of 2.5 tons ha^{-1}. However, at Unguwar Chida P rate was 21.0 kg P ha^{-1} and gave the optimum yield of 2.3 tons ha^{-1}. While at Zarewa P rate was 23.8 kg P ha^{-1} and gave the optimum yield of 1.9 tons ha^{-1}. This can be attributed to the sufficiency of supplied N and P nutrients for the plant up take.

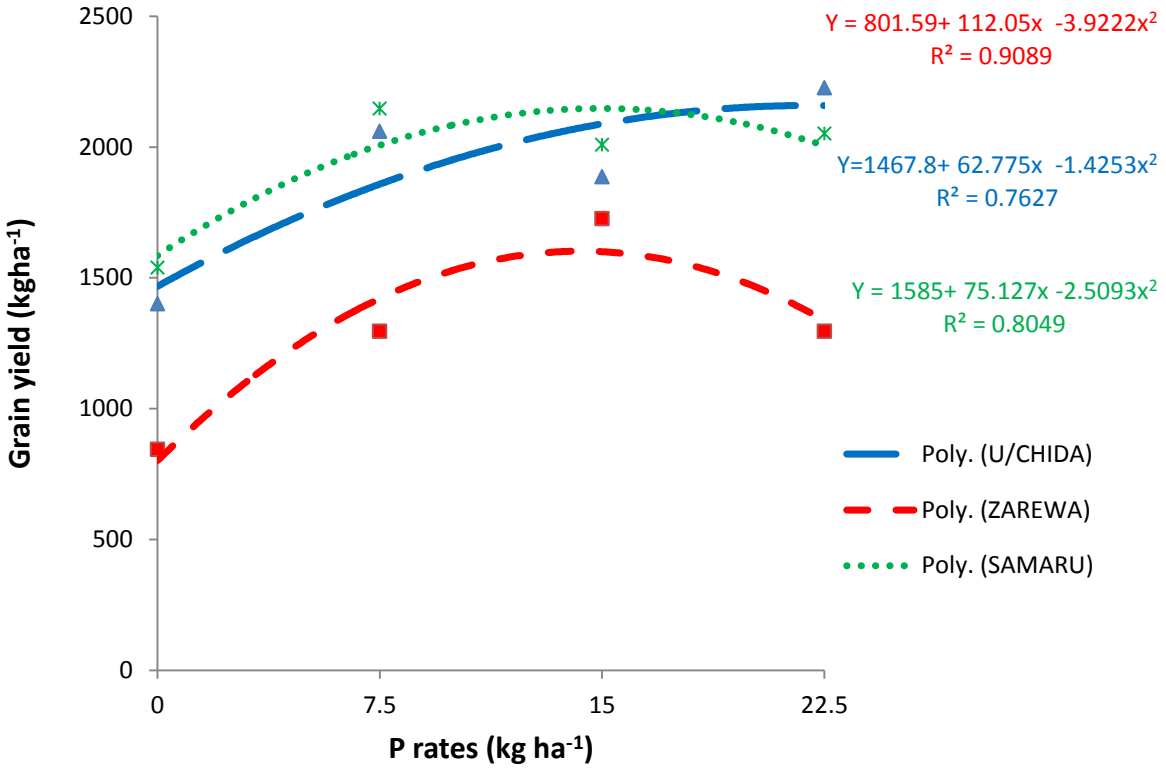


Figure. 4.6: Effect of 90 kg N rate with P application on grain yield at Samaru, Unguwar Cheda and Zarewa.

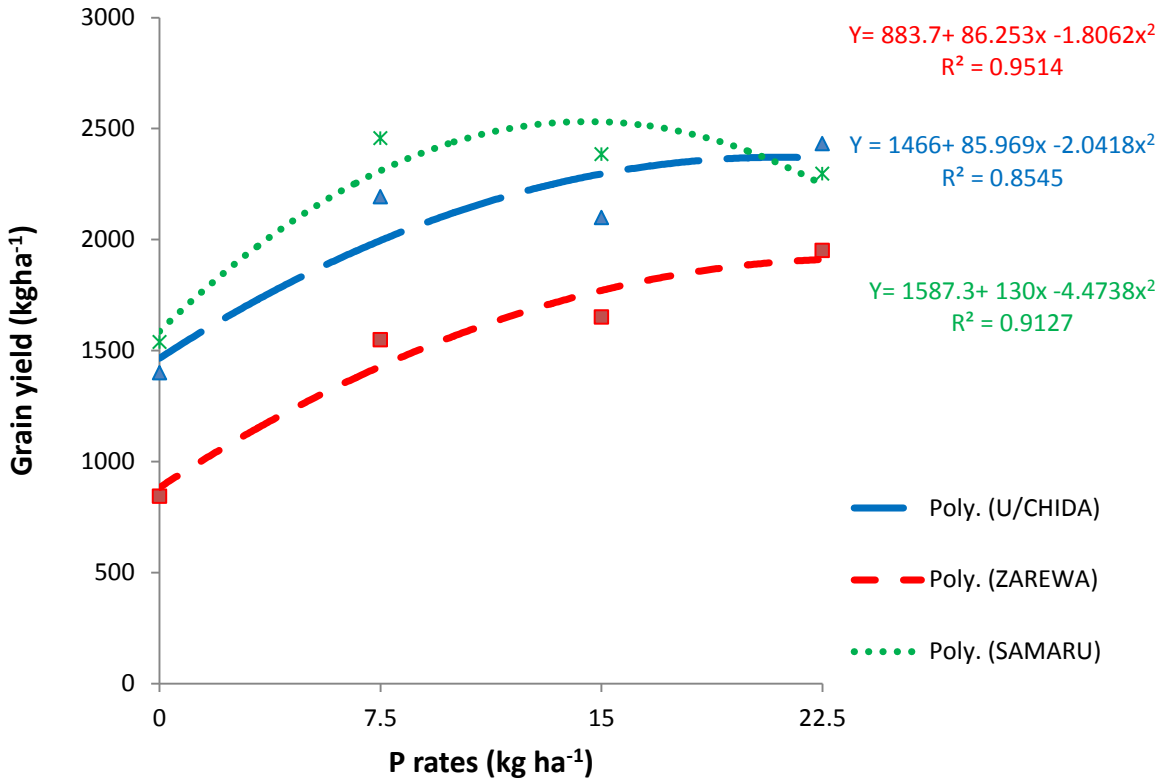


Figure.4.7: Effect of 120 kg N rate with P application on grain yield at Samaru, Unguwar Cheda and Zarewa.

This is similar to the findings of Akdeniz *et al*. (2006) who reported higher grain yield with increased rates of N and P in sweet sorghum.

Figure 4.8 shows response curve of sorghum to combined application of NPK with sulphur at Samaru, Unguwar Chida and Zarewa. At Samaru, the optimum S rate was attained at 13.8 kg ha^{-1} which gave the optimum yield of 2.3 tons ha^{-1}. However, at Unguwar Chida S rate was 13.7 kg ha^{-1} and gave the optimum yield of 2.0 tons ha^{-1}. While at Zarewa S rate was 13.8 kg ha^{-1} and gave the optimum yield of 2.7 tons ha^{-1}. The three locations responded positively to sulphur application with R^2 ranging from 0.90 to 0.65. The effect of S rate with NPK gave a positive response which translated into higher sorghum yield. This result corroborated Wortmann *et al.* (2013) who stated that sandy soils that are low in organic matter might need adequate supply of sulphur for optimum grain sorghum production.

The result of response of sorghum grain yield to Zn application is presented in Figure 4.9. At Samaru, the optimum Zn rate was attained at 4.1 kg ha^{-1} which gave the optimum yield of 3.5 tons ha^{-1}. However, at Unguwar Chida Zn rate was 0.9 kg ha^{-1} and gave the optimum yield of 2.0 tons ha^{-1}. While at Zarewa Zn rate was 1.9 kg ha^{-1} and gave the optimum yield of 1.9 tons ha^{-1}. The three locations responded positively to Zn fertilization with R^2 ranging from 0.95 to 0.83. Furthermore, the effect of Zn application with N and P fertilzation indicates that Zn plays essential metabolic roles in the plant (Alekhina and Kharitonashvill, 2005). However, Mohan *et al*. (2015) reported a synergistic effect of N, P and Zn in plant nutrition.

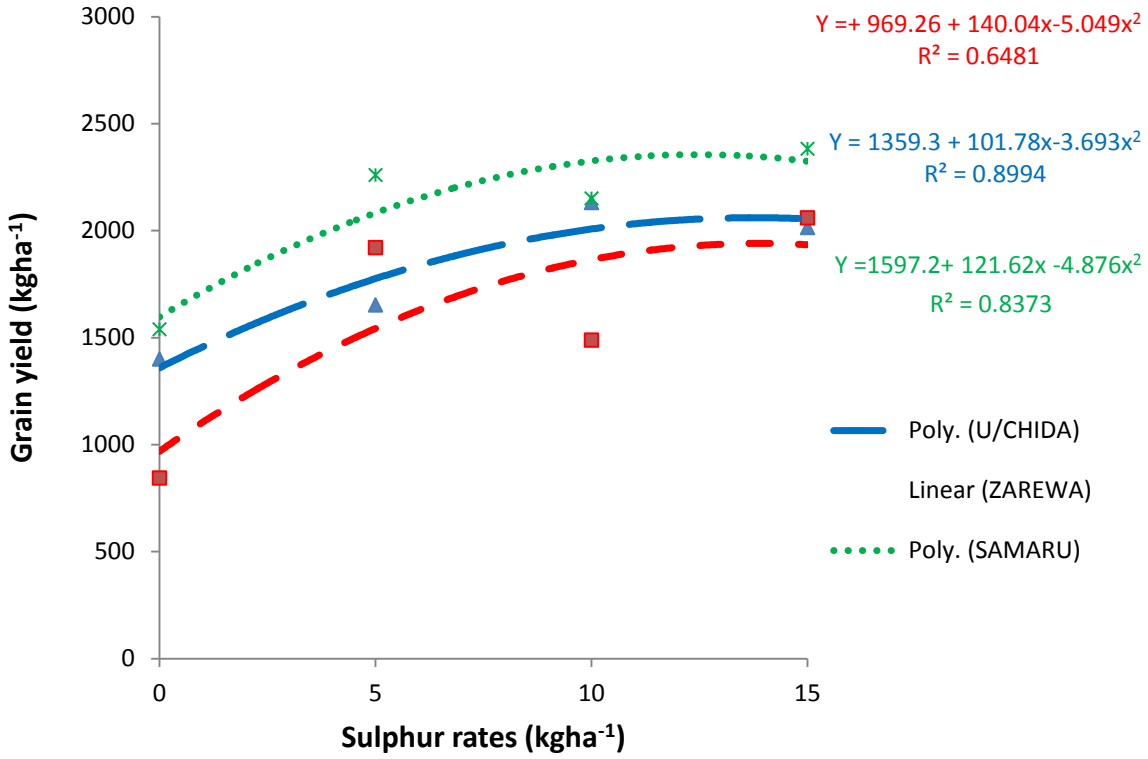


Figure.4.8: Effect of S rate with NPK application on grain yield at Samaru, Unguwar Chida and Zarewa.

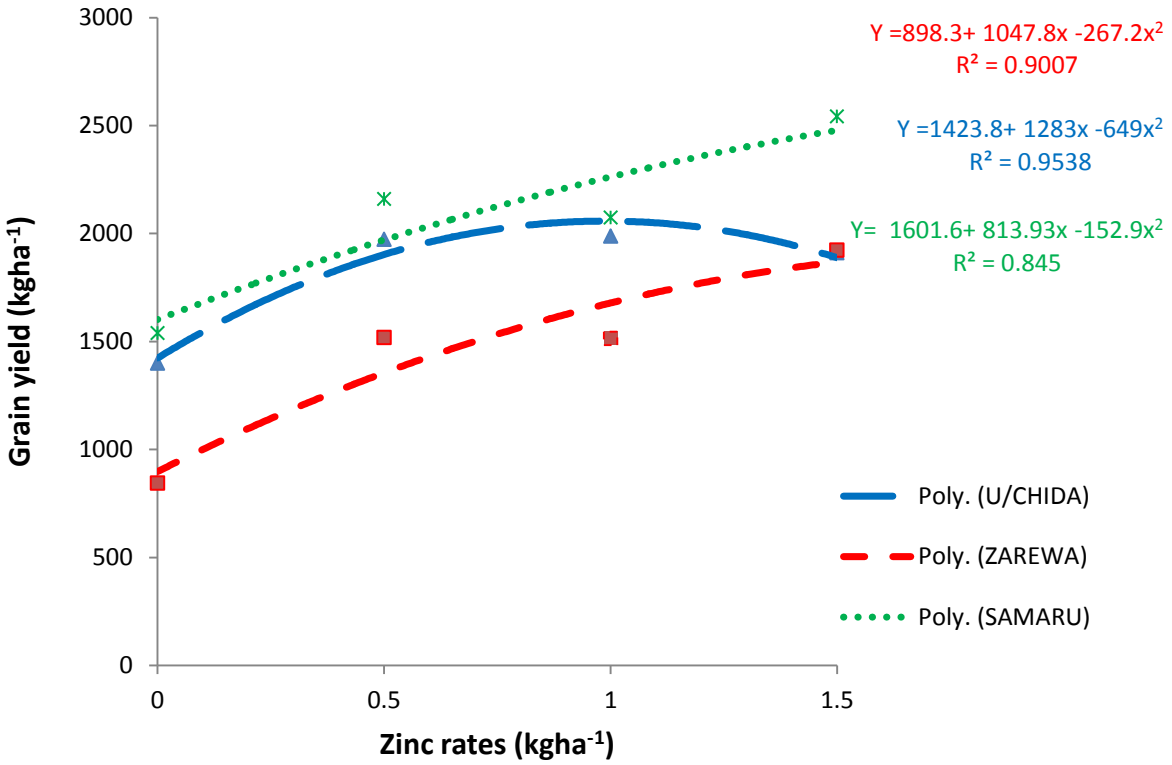


Figure.4.9: Effects of N and P with Zn application on grain yield at Samaru, Unguwar Chida and Zarewa.

4.4 Economically Optimal Nutrients Rates

4.4.1 Economical Optimal Nitrogen Rate

The economic optimal rate for nitrogen application is described by the following equations:

$$\text{Yield} = 1.825 - 0.96\ (0.96^{N}) \quad (1)$$

$$\text{Yield} = 2.17 - 1.29\ (0.96^{N}) \quad (2)$$

$$\text{Yield} = 2.120 - 0.58\ (0.98^{N}) \quad (3)$$

The coefficient $(a\text{-}bc^{N})$ in equations 1, 2 and 3 above and as presented in Table 4.7 revealed that (a) is the yield at maximum, (b) is the increase in yield due to nitrogen application, and (c^{N}) determined the shape of the quadratic response, where c is a curvature coefficient and N is the nutrient rate. Table 4.7 showed the result of the economic optimal nitrogen rate (EONR) across different CPs at Zarewa onfarm, the grain values were ₦75, ₦65, ₦55, ₦45 and ₦35 per Kg and (Figure 4.10) the cost of 1 kg of urea nitrogen were ₦239 and the EONR were 45 kg ha^{-1}, 41 kg ha^{-1}, 37 kg ha^{-1}, 32 kg ha^{-1} and 26 kg ha^{-1} respectively. Similarly, at Unguwar Cheda nitrogen application was profitable at all CPs and EONR ranged from 34 to 49 N kg ha^{-1} and represented in Figure 4.11.

The economic optimal nitrogen rate (EONR) across different grain price ratio (CP) at Samaru ranged from 40 to 2 kg N ha^{-1} and represented in Figure 4.12.

Table 4.7. Asymptotic response coefficients (Yield= a-bc^{nutrient}) for sorghum yield to applied N and economic optimal rates (EONR) at different fertilizer use cost to sorghum grain price rations (CP), in Unguwar Chida, Zarewa and Samaru.

	Coefficients			EONR at different CPs.				
	---------- Mg ha-^{1}----------			---------- ₦ kg-^{1}----------				
Location	a	b	c	2	3	4	5	6
Unguwar Cheda	2.170	1.290	0.960	52	49	45	40	34
Zarewa	1.825	0.960	0.960	45	41	37	32	26
Samaru	2.120	0.580	0.980	40	33	25	15	2

Y = a - bc^n. Where y = yield in Mg/ha; a = near maximum grain yield; b = yield increase due to nutrient application; c^n determines the shape of the curvilinear response where c was a curvature coefficient and n was the nutrient rate. CPs = Grain price ratio relative to fertilizer cost.

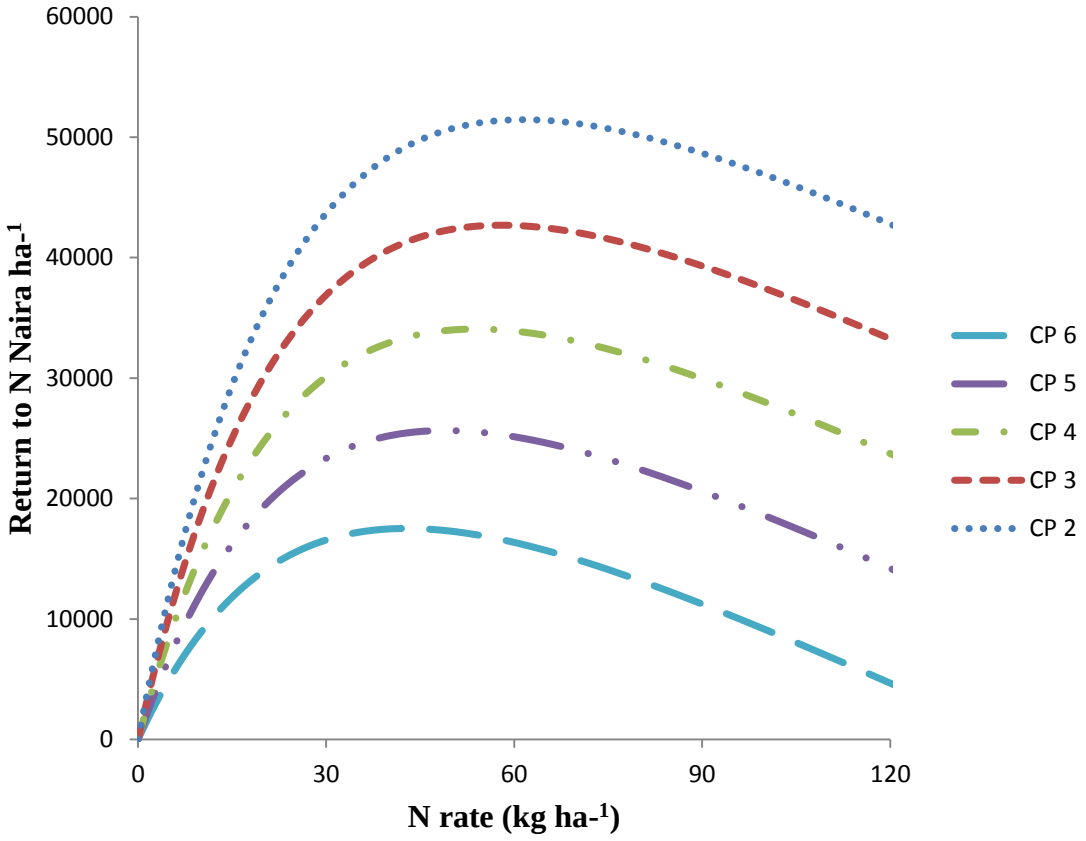


Figure 4.10. Economically optimal N rates for sorghum production in Zarewa for five ratios of fertilizer use to farm gate grain price (CP).

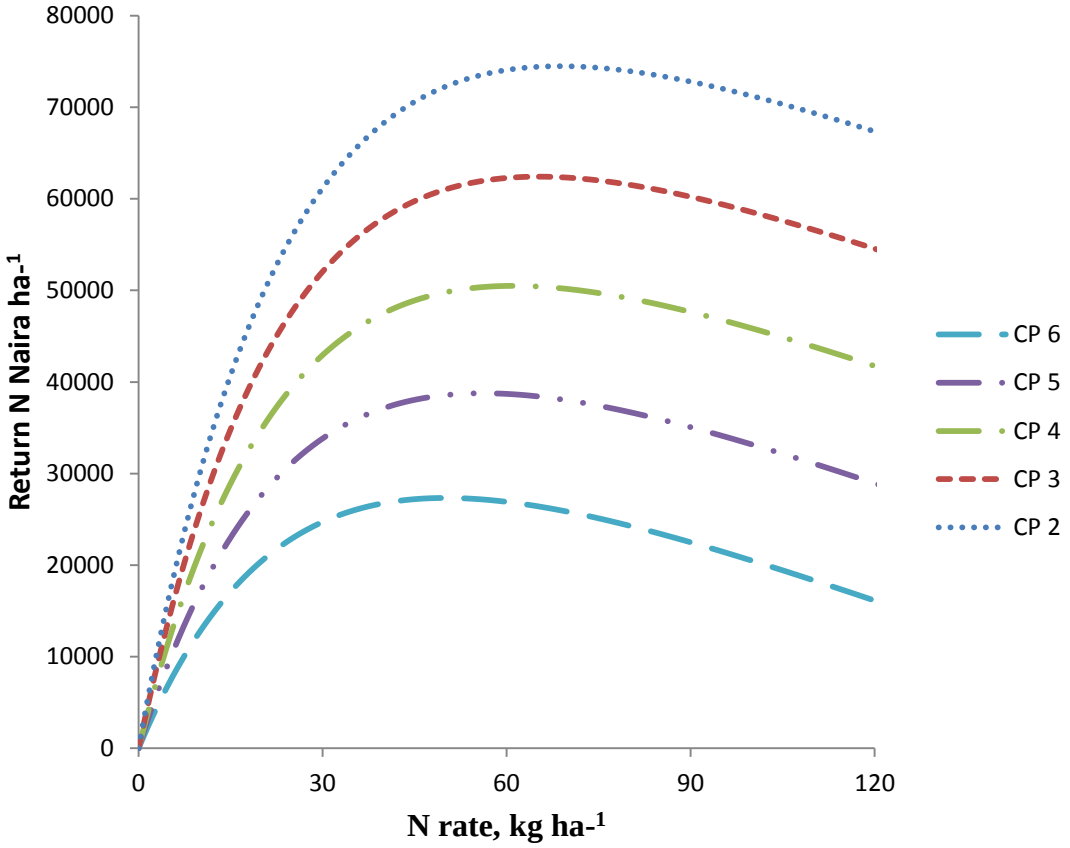


Figure 4.11. Economically optimal N rates for sorghum production in Samaru for five ratios of fertilizer use to farm gate grain price (CP).

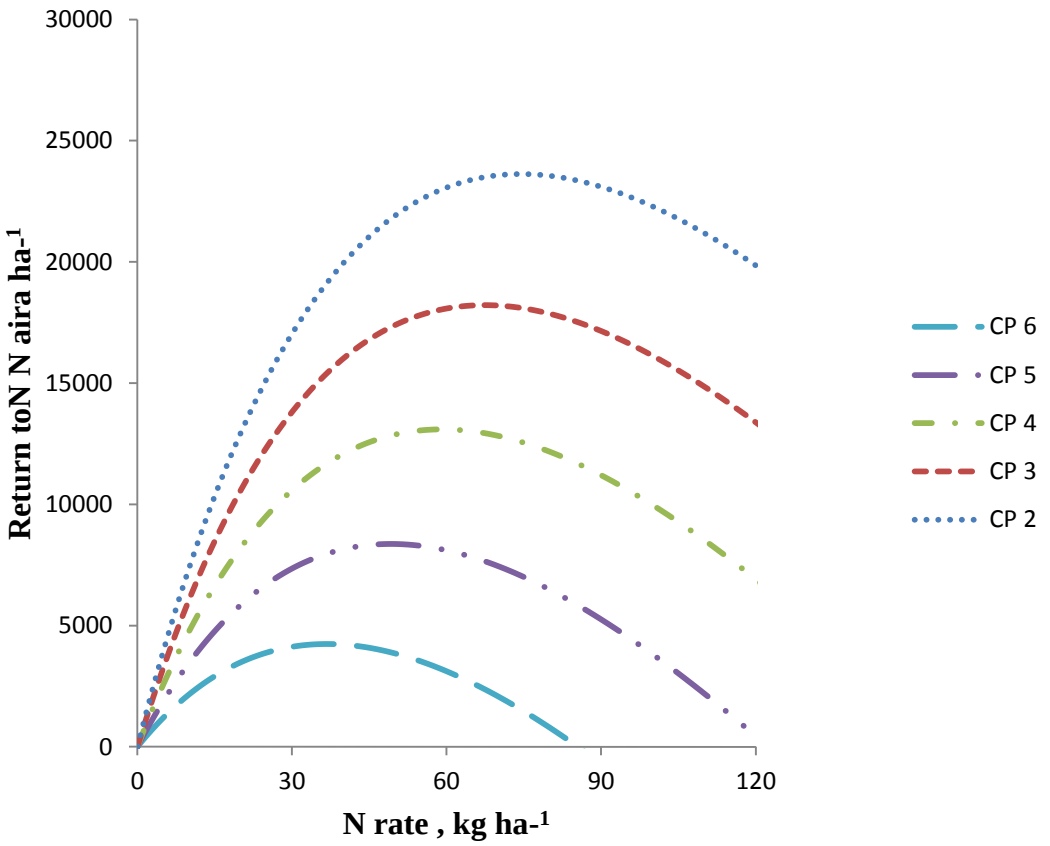


Figure 4 .12. Economically optimal N rates for sorghum production in Unguwar Chida for five ratios of fertilizer use to farm gate grain price (CP).

4.4.2 Economically Optimal Phosphorus Rate

The economical optimal rate for P application is described by the following equations:

$$\text{Yield} = 1.827\text{-}0.424(0919^{N}) \quad (4)$$

$$\text{Yield} = 1.820\text{-}0.90(0.839^{N}) \quad (5)$$

$$\text{Yield} = 2.282\text{-}0543(0.517^{N}) \quad (6)$$

The coefficient ($a\text{-}bc^{N}$) in equations 4, 5, and 6 above and presented in Table 4. 8 revealed that (a) was the yield at plateau, (b) was the increase in yield due to phosphorus application, and (c^{N}) determined the shape of quadratic response, where c was a curvature coefficient and N was the nutrient rate. The economic optimal phosphorus rate (EOPR) for different CPs. The CPs increases from 2, 3, 4, 5 and 6. The economic optimal phosphorus rate and grain value decreases and the maximum net return to investment increases (Table 4.8). At Zarewa onfarm trial, the grain values were ₦65, ₦55, ₦45, ₦35 and ₦25 (Figure 4.14) the cost of 1 kg of P_2O_5 was ₦195 and the EOPR were 21, 19, 17, 14 and 10 P kg ha^{-1} respectively. Similarly, at Unguwar Chida phosporus application was profitable at all CPs where the CPs increase from 2 to 6, while the grain value decreased from ₦65 to ₦25 and the EOPR ranged from 20 to 14 kg ha^{-1} and presented in Figure 4.13.

The economic optimal phosphorus rate (EOPR) across different grain price ratio (CP) at Samaru ranged from 7 to 5 kg ha^{-1} and presented in Figure 4.15.

The CP affects the EONR and EOPR. At Unguwar cheda, the economic optimal N rates decreased from 52 to 34 kg N ha^{-1}, while at Zarewa the EONR ranged from 45 to 26 kg N ha^{-1}. Similarly at Samaru the EONR ranged from 40 to 2 kg N ha-^{1} as the cost of fertilizer relative to grain price (CP) increased from 2 to 6. The cost of fertilizer in West Africa sub

region and Nigeria in particular ranged from 2 to 6 times greater than in Europe (Sanchez, 2002). Financially constraint farmers with inadequate access to fund to apply fertilizer at Economic optimal rate (EOR) to sorghum need to consider the VCR above 2 for different rates and nutrients. Application at less than EONR or EOPR to more land will then give higher returns compared with applying at the EOR to less land (Kaizzi *et al*., 2012a). This suggests that farmers should decide which nutrients combination to apply to sorghum that give them maximum net return to investment. The productivity of sorghum in northern Guinea savanna is highly favourable and grain prices can fluctuate within and across years. This is in agreement with Kaizzi *et al*. (2012b) that reported rainfed maize production in Uganda to be highly variable with grain prices fluctuating across seasons. After harvest, the price of sorghum grain is relatively low to meet the immediate smallholder farmer's needs. They therefore, tend to sell much of their surplus immediately due to lack of storage infrastructure. The profitability is poor and the net return to investment might not be achieved but when stored and allowed to stay for 2 or 3 months when price is higher, the profitability is considerably increased (Kaizzi *et al*., 2012b).

Table 4.8. Asymptotic response coefficients (Yield= a-bc^{nutrient}) for sorghum yield to applied P and economic optimal rates (EOPR) at different fertilizer use cost to sorghum grain price ratios (CP), in Unguwar Chida, Zarewa and Samaru.

	Coefficients			EOPR at different CPs.				
	---------- Mg ha-^{1}----------			---------- ₦ kg-^{1}----------				
Location	a	b	c	2	3	4	5	6
Unguwar Cheda	1.827	0.424	0.919	21	19	17	14	10
Zarewa	1.823	0.903	0.838	20	18	17	16	14
Samaru	2.282	0.543	0.517	7	6	6	6	5

Y = a - bc^n. Where y = yield in Mg/ha; a = near maximum grain yield; b = yield increase due to nutrient application; c^n determines the shape of the curvilinear response where c was a curvature coefficient and n was the nutrient rate. CPs = Grain price ratio relative to fertilizer cost.

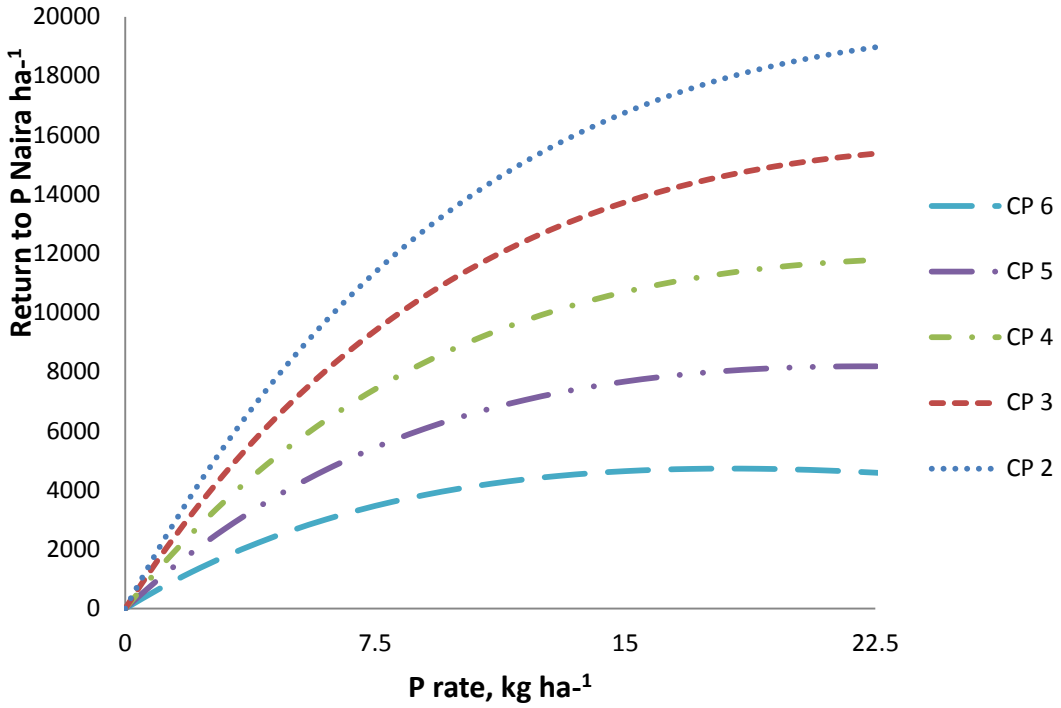


Figure 4.13. Economically optimal P rates for sorghum production in Unguwar Chida for five ratios of fertilizer use to farm gate grain price (CP).

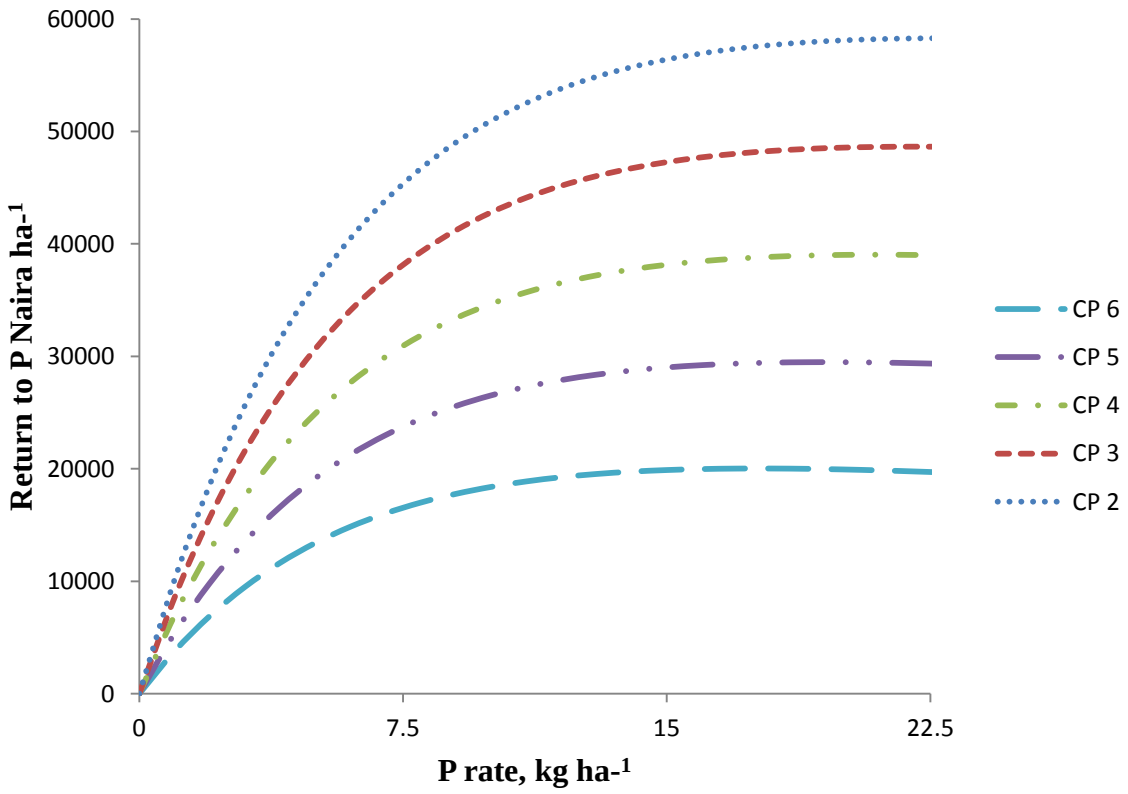


Figure 4.14. Economically optimal P rates for sorghum production in Zarewa for five ratios of fertilizer use to farm gate grain price (CP).

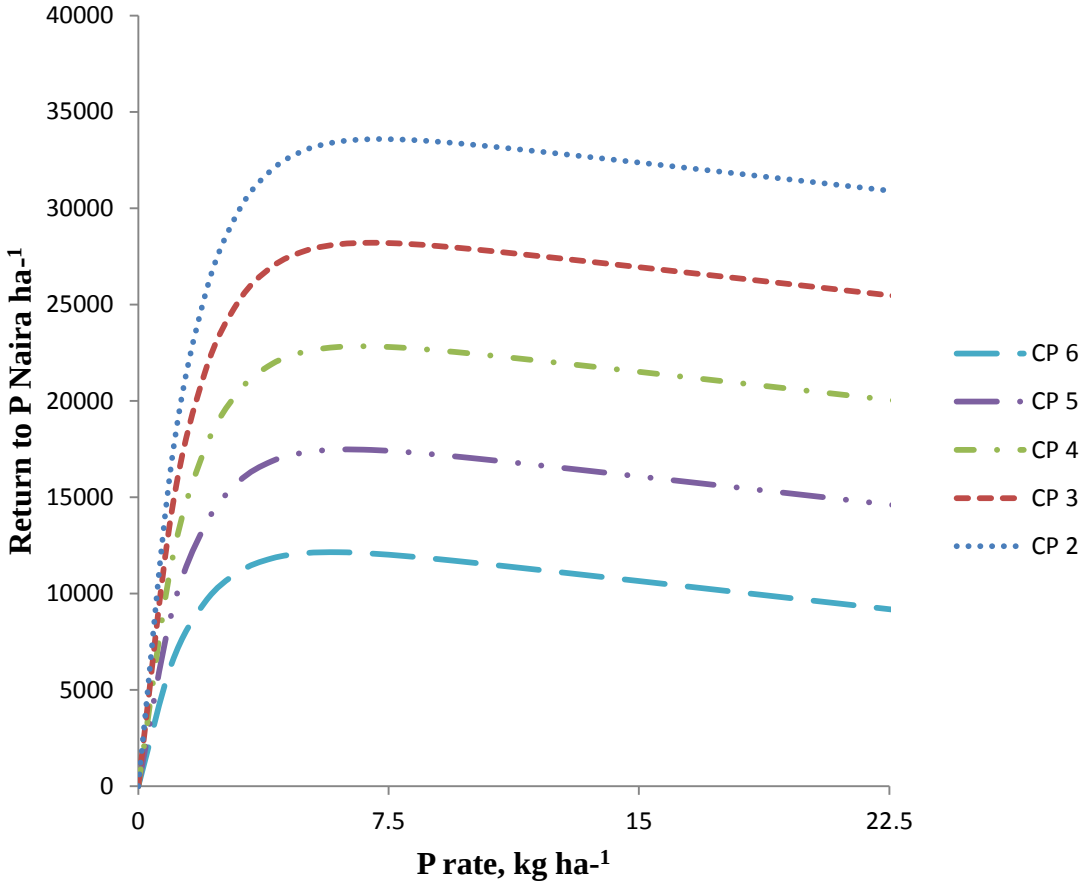


Figure 4.15. Economically optimal P rates for sorghum production in Samaru for five ratios of fertilizer use to farm gate grain price (CP).

4.5 Profitability of Fertilizer Use

The profitability of inorganic fertilizer use on grain sorghum nutrient application was evaluated using value cost ratio (VCR). The results are shown in Table 4.10. Value cost ratio represents the ratio of revenue from grain to the total cost of fertilizer applied. Value cost ratio ranged from 1.74 to 17.59, while the averaged mean VCR was 5.21 at Samaru. The highest 17.59 VCR was recorded with application of 30-7.5-0 NPK kg ha^{-1} and the lowest 1.74 was recorded with application of 30-15-0 NPK kg ha^{-1}. Similarly, VCR at Unguwar Chida ranged from 0.41 to 5.59 with an averaged mean VCR of 5.60. The highest 5.59 VCR was with application of 30-22.5-0 NPK kg ha^{-1} and the lowest 0.41 was with application of 90-7.5-0 NPK kg ha^{-1} application.

At Zarewa the VCR ranged from 0.28 to 21.88 with mean of 7.54. The highest 21.88 VCR was with application of 30-15-0 NPK kg ha^{-1} and the lowest 0.28 was with application of 90-7.5-0 NPK kg ha^{-1}.

The value cost ratio was better when inorganic N and P were applied at lower rates than at higher application rates. The reason is attributed to better agronomic efficiency of nitrogen and maximum grain yield from supplied nutrient at low rates. The result of this study, showed that the use of N rate alone is profitable but is more profitable when N and P were applied together. To justify investment, resource poor farmers need to consider VCR > 2 that is profitable using the appropriate nutrient combinations (Yanggen *et al.*, 1998). Markets do not function efficiently in the absence of infrastructure. The most important infrastructure for output markets includes roads for transportation, storage facilities to stock grain until prices are higher, and various communication facilities to transmit information concerning market conditions (Morris *et al.,* 2007).

Table 4.9. Effect of inorganic fertilizer on profitability of fertilizer use in sorghum production

Nutrient rates (NPK)	Samaru	Unguwar Chida	Zarewa
0N-0P-0K			
30N-0P-0K	4.42	2.66	15.91
60N-0P-0K	3.42	4.42	6.49
90N-0P-0K	2.90	3.58	6.88
120N-0P-0K	2.42	3.27	5.04
30N-7.5P-0K	17.59	3.80	12.37
60N-7.5P-0K	4.14	3.96	8.43
90N-7.5P-0K	3.85	0.41	0.28
120N-7.5P-0K	4.40	3.80	3.38
30N-15P-0K	1.74	4.68	21.88
60N-15P-0K	7.23	4.99	6.18
90N-15P-0K	2.88	2.98	5.42
120N-15P-0K	3.95	3.27	3.78
30N-22.5P-0K	12.58	5.59	15.54
60N-22.5P-0K	5.22	4.47	9.09
90N-22.5P-0K	3.05	4.91	2.69
120N-22.5P-0K	3.46	4.71	5.06
60N-15P-10K	8.38	4.63	7.33
90N-15P-10K-5S	4.15	1.45	8.77
90N-15P-20K-10S	3.31	3.96	3.50
90N-15P-30K-15S	4.32	3.14	6.23
60N-15P-0K-0.5Zn	5.54	5.11	6.04
60N-15P-0K-1Zn	4.78	5.24	6.00
60N-15P-0K-1.5Zn	8.96	4.61	9.65
90N-15P-20K-15S-2.5Zn-10Mg-0.5B	2.42	3.27	5.04
Mean	5.21	5.60	7.54

4.6 Nitrogen Use Efficiency

4.6.1 Agronomic Efficiency of Nitrogen

Agronomic efficiency of N (AEN) for the three locations is described by the following equations:

$$\text{Zarewa AEN} = 8.78+87.5\ (0.955^{N}) \quad (7)$$

$$\text{Unguwar Cheda AEN} = 2.46+11.46\ (0.992^{N}) \quad (8)$$

$$\text{Samaru AEN} = 2.19+23.5\ (0.964^{N}) \quad (9)$$

Agronomic efficiency of nitrogen across the locations was maximum with 30 kg N ha^{-1} and decreased with every increase in N rate. Among the locations Zarewa exhibited maximum agronomic efficiency of (31.10 kg ha^{-1}) followed by Unguwar Chida with (11.50 kg ha^{-1}) and then Samaru with (10.00 kg ha^{-1}) at application rate of 30 kg N ha^{-1}. Agronomic efficiency of nitrogen is lower with increasing N rates although no significant differences were observed between 30 and 120 kg N ha^{-1} (Yusuf *et al.*, 2009). This implies that plants are unable to absorb N when applied in excess quantities, which might be attributed to saturation of absorption mechanism. Under this condition, nitrogen may be loss through ammonia gas, leaching or de-nitrification (Shamme *et al.*, 2016). This report is similar to the findings of Yusuf *et al.* (2009). Who reported the nitrogen losses from the system due to inappropriate time of fertilizer application with the period of high crop demand without deficiency. Agronomic efficiency therefore, can improve sorghum yield at a particular rate of fertilizer nutrients at the right time, place, amount, source, and planting density so that there are enough plants to ensure maximum nutrient uptake and response and in several split applications in order to reduce the amount of fertilizer nutrients lost due to leaching

(Fairhurts, 2012). Much of the applied N at the EONR was therefore used by the crop to produce grain.

4.6.2 Partial Factor Productivity

The partial factor productivity (PFP) for the three locations is described by the following equations:

$$\text{Zarewa PFP} = 21.62+1118\ (0.898^{N}) \quad (10)$$

$$\text{Unguwar Chida PFP} = 15.41+102.77\ (0.971^{N}) \quad (11)$$

$$\text{Samaru PFP} = 14.89+148.61\ (0.967^{N}) \quad (12)$$

Table 4.11 shows the results of partial factor productivity (PFP) for all location studied as affected by N rates on grain yield of sorghum. Partial Factor Productivity declined substancially with every increase in the rate of N applied from 30 kg ha^{-1} to 120 kg ha^{-1}. Samaru revealed maximum PFP of (69.25 kg ha^{-1}) followed by Zarewa with (66.22 kg ha^{-1}) and Unguwar Chida with (58.25 kg ha^{-1}). Furthermore, partial factor productivity decreased as linear function of N rate. No corresponding increase across the location with the use of 90 or 120 kg N ha^{-1}. The effect of N rate on PFP for the various locations are represented by equations 10, 11 and 12. Partial factor productivity also decline with incremental N rates across the sites. This is in line with the findings of Kaizzi *et al*. (2012b) who reported increase in stover and grain yield with increased N fertilization.

4.6.3 Harvest Index

Harvest index is the ratio of harvested grain to total shoot dry matter, and this can be used as measure of reproductive efficiency.

Zarewa HI = 0.41950-1235 (0.290^{N}) 13

Unguwar Chida HI= 0.3589+0.1529 (0.996^{N}) 14

Samaru HI=0.201+0.057 (1.0069^{N}) 15

The effect of N rate on sorghum harvest index (HI) is presented in Table 4.10. Harvest index at Unguwar Chida were not significantly different with the N rates and it ranged from 0.211 to 0.260 kg ha-^{1} with the economic optimum nitrogen rate (EONR) of 0.211 kg ha-^{1}. Similarly, harvest index at Zarewa were not significantly different ($p<0.05$) and ranged from 0.296 to 0.461 kg ha-^{1} with EONR of 0.420 kg ha-^{1}. However, Samaru harvest index ranged from 0.253 to 0.333 kg ha-^{1} with EONR value 0.271 kg ha^{-1} and it was not significantly different between 30 and 120 kg N ha^{-1}. The effects of N rate on HI at the various locations are represented by the following equations 13, 14 and 15. The relationship between sorghum yields and total crop nitrogen uptake in above ground biomass is firmly conserved in attaining higher yield with greater total crop nitrogen uptake in above ground biomass (Cassman *et al*., 2002). In comparing the NUE components of sorghum in all locations under similar conditions, HI are moderate while AE and PFP were lower. Nitrogen in soil with no supply of N is vulnerable to loss through leaching and denitrification. Harvest Index was markedly increased with N application due to larger proportion that increased grain yield compared to stover yield (Kaizzi *et al*., 2012).

Table 4.10. Mean effect of N rate on components of nitrogen use efficiency across all sites

Locations	N Rate effect					P>*F*	EONR†
	0 kg ha^{-1}	30 kg ha^{-1}	60 kg ha^{-1}	90 kg ha^{-1}	120 kg ha^{-1}		
				Agronomic efficiency			
U/Cheda	0.211	11.50	9.45	8.15	6.80	NS	11.50
Zarewa	0.296	31.10	14.08	11.20	8.97	NS	31.10
Samaru	0.253	10.00	5.40	1.90	3.20	NS	10.08
				Partial factor productivity			
U/Cheda		58.25	33.10	23.11	18.36	**	57.91
Zarewa		66.22	23.20	24.38	19.14	**	65.95
Samaru		69.25	35.10	21.60	17.90	**	61.19
				Harvest index			
U/Cheda	0.211	0.211	0.243	0.260	0.259	NS	0.211
Zarewa	0.296	0.436	0.380	0.401	0.461	NS	0.420
Samaru	0.253	0.297	0.277	0.310	0.333	NS	0.271

NS, no significant effect at p≤ 0.05. ** significant effect at p≤0.001. † economically optimum N rate

4.7 Optimized Fertilizer Recommendation for Three Levels of Financial Capability of Smallholder Farmers in the study areas

Results of the optimization illustrated that the net return on investment on fertilizers increased as the percentage of the full budget (₦20,000.00) increased and net returns per hectare also increased (Table 4.11). Farmers that are financially constrained and can only afford 25% (₦5,000.00) of the assumed budget of (₦20,000.00) to procure fertilizers. Application of N rate of 37, 19 and 31 kg ha^{-1} to grain sorghum along with P at 10, 32 and 17 kg ha^{-1} are hence recommended. The expected increase in yield are 1,137 kg ha^{-1}, 1,218 kg ha^{-1} and 1,228 kg ha^{-1} which gave net return to fertilizer use of ₦63,241, ₦ 68,091 and ₦ 68,655 per hectare at Unguwar Chida, Zarewa and Samaru respectively.

Application rates increased with doubling of the budget by 50% (₦10,000.00) of the assumed ₦20,000.00 budget. The optimized recommended N rates increased to 78, 51, and 72 kg ha^{-1} compared to the ₦5,000.00 financial budget. The optimized N recommendation rate with the ₦10,000.00 budget increased by 52.56, 62.75, and 56.94% over the ₦5,000 budget. The optimized P rate also increased to 16, 49 and 23 kg ha^{-1} applied compared to the ₦5,000.00 budget. These increases were 37.5, 34.69 and 25.81%. The expected yield increased were 1,786 kg ha^{-1}, 1,649 kg ha^{-1} and 1,544 kg ha^{-1} and net return to fertilizer use was ₦97,176, ₦88,920 and ₦82,645 per hectare at Unguwar Chida, Zarewa and Samaru respectively. The net return by increasing the budget from ₦5,000.00 to ₦10,000.00 were 34.92, 23.42%, and 16.93% at Unguwar Chida, Zarewa and Samaru respectively.

Finally, with an allocation of the entire budget (₦20,000.00) per hectare for fertilizer procurement as the optimized recommended N rates increased to 129, 114 and 112 kg ha^{-1} compared to the ₦10,000.00 budget. The optimized recommendation N rate with the

₦20,000.00 budget increased by 39.53% in Unguwar Chida, 55.26% at Zarewa and 35.71% at Samaru over the ₦10,000.00 budget. The optimized recommended P rates were 64,83 and 29 kg ha^{-1}. With ₦20, 000.00 budget the increase in N recommendation were 75,40.96 and 20.69% over ₦10,000.00. The expected yield increase were 2227 kg ha^{-1}, 2017 kg ha^{-1} and 1709 kg ha^{-1} and the net return to fertilizer use were ₦113,620, ₦101,024 and ₦86,534 at Unguwar Chida, Zarewa and Samaru respectively. The percentage net return decreased by 14.47%, 11.98% and 4.49% per hectare. The tool did not recommend expenditure on procurement of K fertilizers.

Sensitivity analysis of the optimised fertilizer recommendation for the three sites showed that N and P were increased at all sites for the ₦5000 - ₦20,000.00 budget investment in fertilizer. The higher return obtained at the lowest investment on fertilizer showed that lower rates of fertilizer application provided maximum profit than when higher rates were used. This suggests that the farmer is operating within the steep slope of yield response to fertilizer rate. The relatively smaller increase in net return obtained when the full budget of ₦20,000.00 was invested support that the farmers were operating on the rate of diminishing return or at the curvature of the response curve.

Generally, net return from investment on fertilizer was higher (₦97,176) with 34.92% increase in yield at Unguwar Chida and lower (₦82,645) with 16.93% increase in yield per hectare at Samaru. This also suggests that it is profitable to operate within the steep slope of the response curve to fertilizer investment compared to 14.47% and 4.49% at Unguwar Chida and Samaru net return from fertilizer investment. The tool did not recommend expenditure on procurement of K fertilizers.

Table 4.11 Optimized fertilizer recommendation for Sorghum at Unguwar Chida, Zarewa and Samaru

LOCATION	**N Kgha^{-1}**	**P kgha^{-1}**	**K kgha^{-1}**	**Sorghum grain cost ₦ kg^{-1}**	**Net return ₦ ha^{-1}**	**Yield increase kg ha^{-1}**
Level 1 (5000)						
Unguwar Cheda	37	10	0	60	63, 241	1,137
Zarewa	19	32	0	60	68,091	1,218
Samaru	31	17	0	60	68,655	1,228
Level 2 (10,000)						
Unguwar Cheda	78	16	0	60	97,176	1,786
Zarewa	51	49	0	60	88,920	1,649
Samaru	72	23	0	60	82, 645	1,544
Level 3 (20,000)						
Unguwar Cheda	129	64	0	60	113,620	2,227
Zarewa	114	83	0	60	101,024	2,017
Samaru	112	29	0	60	86,534	1,709

In this evaluation, the land area planted for sorghum was one hectare. The Sorghum grain prices is ₦60 kg^{-1}, The expected fertilizer nutrient costs were Urea ₦5,500, SSP ₦4,500 and MOP ₦7,000 respectively.

CHAPTER FIVE

5.0 SUMMARY

The emphasis of the study was to provide recommendations for optimizing yield and profit from fertilizer use for financially constrained and smallholder sorghum farmers in the northern Guinea savanna zone of Nigeria. The effect of N, P and K on grain yield response and nitrogen use efficiency of sorghum were also evaluated. The study also determined the economically optimal nutrient rate for N and P, and value to cost ratio at different grain prices to fertilizer cost. The experiment was arranged in a RCBD replicated three, seven and eight times at Samaru (on-station), Unguwar Chida (on-farm) and at Zarewa (on-farm) respectively. Inorganic fertilizer sources used were urea, triple superphosphate, muriate of potash and diagnostic nutrients were made up of magnesium chloride, sulphur powder, sodium tetra borax and zinc chloride as sources of magnesium (Mg), sulphur (S), boron (B) and zinc (Zn). Urea was applied in two split doses; two weeks after planting and at 6 weeks after planting. Triple superphosphate, muriate of potash and diagnostic nutrients were applied at 2 weeks after planting. Soil samples were taken before fertilizer application and were subjected to routine physical and chemical analyses.

Sorghum stover and yield and yield components were sampled at harvest, weighed per plot and extrapolated per hectares bases. Agronomic efficiency, partial factor productivity and harvest index were computed using appropriate formulas. The economically optimal nutrient rate for nitrogen and phosphorus were determined using fertilizer optimization tool (FOT). The value cost ratio was calculated using the appropriate formula.

5.1 Conclusion

- The treatment containing 60 kg N ha^{-1}, 15 kg P ha^{-1}, and 10 kg K ha^{-1} gave the highest grain yield of 2567.3 kg at Samaru, the treatment containing 120 kg N ha^{-1}, 22.5 kg P $ha^{-1}$and 0 kg K ha^{-1} had the highest grain yield of 2432.1 kg at Unguwar Chida, while the treatment containing 30 kg N ha^{-1}, 15 kg P ha^{-1} and 0 kg K ha^{-1} gave the highest grain yield of 2181.6 kg at Zarewa.
- The N fertilizer response coefficient (*abc*) for the three locations were 2.170, 1.290 and 0.96 at Unguwar Chida, 1.825, 0.960 and 0.96 at Zarewa and 2.120, 0.580 and 0.98 at Samaru.
- The P fertilizer response coefficient (*abc)* are 1.827, 0.424 and 0.919 at Unguwar Cheda, 1.823, 0.903 and 0.838 at Zarewa, and 2.282 0.543 and 0.517 at Samaru.
- The economically optimal nitrogen rates (EONR) were 52 to 34 kg N ha^{-1} at Unguwar Cheda, 45 to 26 kg N ha^{-1} at Zarewa and 40 to 2 kg N ha^{-1} at Samaru with fertilizer cost relative to grain price ratios (CPs) of 2, 3, 4, 5 and 6 respectively. Mean economically optimal phosphorus rate (EOPR) were 21 19, 17, 14 and 10 kg P ha^{-1} at Unguwar Chida, 20,18, 17, 16 and 14 kg P ha^{-1} for Zarewa and 7, 6, 6, 6 and 5 kg P ha^{-1} in Samaru.
- Harvest index was not linear with increase in N fertilizer rate and both agronomic use efficiency and partial factor productivity decreased with increasing nitrogen rates across the locations.
- Agronomic efficiency of fertilizer N at the EONR was high (30 kg N ha^{-1}), therefore reducing the N losses. The sole application of inorganic N fertilizer resulted in improved AE of N and sorghum grain yield.

- The economic analysis shows that the VCR can be high with the current fertilizer N prices but much less so for fertilizer P.

5.2 Recommendations

- The fertilizer response coefficient (*abc)* should be used to calibrate the FOT for the locations and used to derive site specific fertilizer recommendation for the sites.
- The optimized fertilizer recommendation for the sites studied should be (78 kg N and 16 kg P ha^{-1}) at Unguwar Chida, (51 kg N and 49 kg P ha^{-1}) at Zarewa, and (72 kg N and 23 kg P ha^{-1}) at Samaru, should be deployed to farmers in the locations and promoted.
- Further research should be carried out to validate the findings of this work and the need to also introduce combine effect of organic with the inorganic fertilizers to determine their responses and predict their economically optimal nutrient rate (EOR).
- Favourable policies that will make availability of single sources of fertilizer nutrients available in Nigeria and reduced cost of transportation should be implemented to relief smallholder farmer from procurement of expensive inorganic fertilizer and over reliance on blends.

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APPENDIX

Paper Fertilizer Optimization Tool

Paper Fertilizer Optimization Tool for Unguwar Chida

Level 1 Assumption of Financial Ability (5,000.00): Recommendation for Sorghum (Urea and SSP)

Mix 37 kg Urea with 10 kg SSP and point apply using FARO water bottle lid for 8 plants at three weeks after planting.

Level 2 Assumption Financial Ability (10,000.00): **Recommendation for Sorghum (Urea and SSP)**

Mix 78 kg Urea with 16 kg SSP and point apply using Faro water bottle lid for 6 plants at three weeks after planting.

Level 3 Assumption Financial Ability (20,000.00): Recommendation for Sorghum (Urea and SSP)

Broadcast 64 kg SSP using Gino can for 8 meters long, 3m widths at land preparation and point apply 65 kg Urea using Faro water bottle lid for 2 plants at three weeks after planting. Point apply 65 kg Urea using Faro water bottle lid for 6 plants at six weeks after planting.

4.8.2 Paper Fertilizer Optimization Tool for Zarewa

Level 1 Assumption Financial Ability (5,000) Recommendation for Sorghum (Urea and SSP)

Mix 19 kg Urea with 32 kg SSP and point apply using FARO water bottle lid for 7 plants at three weeks after planting.

Level 2 Assumption of Financial Ability (10,000) Recommendation for Sorghum (Urea and SSP)

Mix 51 kg Urea with 49 kg SSP and point apply using FARO water bottle lid for 4 plants at three weeks after planting.

Level 3 Assumption of Financial Ability (20,000) Recommendation for Sorghum (Urea and SSP)

Broadcast 83 kg SSP using 1 GINO can for 6.2 meters, 3m width at land preparation and point apply 57 kg Urea using FARO water bottle lid for 6 plants at two weeks after planting and point apply 57 kg Urea using faro water bottle lid for 6 plants at eight weeks after planting.

Paper Fertilizer Optimization Tool- Samaru.

Level 1 Assumption for Financial Ability (5,000) Recommendation for Sorghum (Urea and SSP)

Mix 31 kg urea with 17 kg SSP and point apply using FARO water bottle lid for 8 plants at three weeks after planting.

Level 2 Assumption for Assumption for Financial Ability (10,000) Recommendation for Sorghum (Urea and SSP)

Mix 72 kg urea with 23 kg SSP and point apply using FARO water bottle lid for 7 plants at three weeks after planting.

Level 3 Financial Ability (20,000) Recommendation for Sorghum (Urea and SSP)

Broadcast 29 kg SSP using GINO can broadcast at 13.4 meters long, 4 widths at land preparation and point apply 56 kg Urea using FARO water bottle lid for 7 plants at three weeks after planting and point apply 56 kg Urea using FARO water bottle lid for 7 plants at eight weeks after planting.

The paper FOT across the study area can be a paper based version used to advice farmers on the field who do not have access to computer in order to have accurate fertilizer application. The use of FARO water bottle lid at point application and GINO can for broadcasting are advisable to farmers to adopt in order to achieve their target yield and return to investment.