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Modelling maize (*Zea mays* L.) productivity and impact of climate change on yield and nutrient utilization in sub-humid Ghana

ABSTRACT

Increased pressure on land use and decreased fallow periods have led to a decline in soil productivity in the sub-humid region of Ghana, where low-input subsistence farming system is predominant. The soils are generally poor and require mineral fertilizer to increase crop productivity. The high cost of mineral fertilizers makes it almost impossible for the farmers to purchase these. Low nitrogen use efficiency translates into low output. Climate change and variability is another challenge which poses a serious threat to food production in sub-Saharan Africa. The projected changes in spatio-temporal patterns of rainfall and temperature will likely affect water and nutrient availability and utilization, crop growth, and yield formation.

Experimental data from maize (*Zea mays* L.) grown under various nitrogen (N) and phosphorus (P) regimes in the 2008 major and minor seasons at two sites in Ejura, Ghana, were used to parameterize and evaluate the cropping systems model Agricultural Production Systems sIMulator (APSIM). The simulated effects of climate change on maize in Ejura, known to be one of the high food producing areas in the country, were assessed. Farmers' perception and adaptation to climate change were also assessed. Daily climatic data for the period 2030-2050 under the scenarios A1B and B1 were obtained from the regional mesoscale model MM5. Both scenarios show an increase in mean temperature of 1.6 and 1.3°C, respectively, compared to the 1980-2000 period. Precipitation is projected to decrease by about 20 and 21 % by 2050 in the A1B and B1 scenarios, respectively. Analyses (ANOVA) show a significant effect of N and P on grain yield, total biomass, total N uptake and apparent N recovery. Model evaluation reveals that APSIM was able to quantify the response of maize to soil moisture, N and P, and hence simulated maize grain yields with a coefficient of efficiency (R^2) of 0.90 and 0.88 for the studied maize cultivars Obatanpa and Dorke, respectively. Assessment of climate change impacts on maize grain yield suggests a likely shift in the onset of the rainy season with sowing dates occurring in about 70 % of the years in the 2nd week of May compared to the 3rd week of March in observed historical weather data (1980-2000). This 6-week delay resulted in an average yield reduction of 55 and 34 % for Obatanpa and 59 and 37 % for Dorke cultivars during the major season under A1B and B1 scenarios, respectively. There was a significant increase in yield variability for the 21-year continuous maize simulation period. Potential adaptation measures include early planting, introduction of cowpea and/ or fallow and supplementary irrigation.

Analysis of the farmers' perception and adaptation to climate change shows that they are well aware of climate change, as more than 80 % of the farmers interviewed perceived an increasing temperature and a decreasing precipitation trend. However, only about 44 % of the farmers have adjusted their farming practices to account for the impacts of increasing temperature and 40 % have made adjustments to counteract the decreasing precipitation trend. The determinants of adaptation strategies suggest that land tenure, soil fertility, and access to extension services and credit are the most significant factors affecting the adaptation capacity of farmers. Government policies should therefore ensure that terms for bank credits are flexible to enhance farmers' access to affordable credits, which will increase their ability and flexibility to change crop and soil management strategies in response to climate change. Furthermore, given the inadequate extension services in the region, improving the knowledge and skills of extension service personnel regarding climate change and adapted management strategies, increasing extension-farmer ratio, and making the extension services more accessible to farmers appear to be the key components of a successful adaptation program.

Modellierung der Maisproduktivität (*Zea mays* L.) und der Auswirkung des Klimawandels auf Erträge und Nährstoffnutzung in der subhumiden Zone Ghanas

KURZFASSUNG

Der zunehmende Druck auf die Landnutzung und die kürzer werdenden Brachephasen haben zu einer abnehmenden Bodenproduktivität in der subhumiden Region in Ghana, in der das low-input Subsistenzlandwirtschaftsystem vorherrscht, geführt. Die Böden sind im Allgemeinen nährstoffarm und mineralische Dünger sind zur Ertragssteigerung notwendig. Die hohen Beschaffungskosten machen es den Bauern jedoch fast unmöglich, sie zu kaufen. Die niedrige Effizienz der Stickstoffanwendungen führt zu niedrigen Erträgen. Klimawandel und -variabilität sind eine weitere Herausforderung, die die Nahrungsmittelproduktion in Subsahara-Afrika stark bedroht. Die vorhergesagten Veränderungen in den räumlichen bzw. zeitlichen Niederschlags- und Temperaturmustern werden voraussichtlich die Verfügbarkeit und Nutzung von Wasser und Nährstoffen, Wachstum der Anbaupflanzen sowie Erträge beeinflussen.

Daten aus Versuchen mit Mais (*Zea mays* L.) unter unterschiedlichen Stickstoff-(N)- bzw. Phosphor-(P)-Regimen in der Haupt- und Nebenanbausaison 2008 auf zwei Versuchsflächen in Ejura, Ghana, wurden eingesetzt, um das Modell für Anbausysteme "Agricultural Production Systems sIMulator" (APSIM) zu parametrisieren und bewerten. Die simulierten Auswirkungen von Klimawandel auf Mais in Ejura, einer der größten Nahrungsmittelanbaugebiete des Landes, wurden bewertet. Die Wahrnehmung und Anpassung der Farmer hinsichtlich des Klimawandels wurden ebenfalls untersucht. Die täglichen Klimadaten für den Zeitraum unter den Szenarien A1B und B1 wurde dem Modell MM5 (mittlerer und regionaler Bereich) entnommen. Beide Szenarien zeigen eine Zunahme der mittleren Temperatur von 1.6 bzw. 1.3°C verglichen mit dem Zeitraum 1980-2000. Eine Abnahme des Niederschlags um ca. 20 bzw. 21 % bis 2050 in den A1B- bzw. B1-Szenarien wird vorhergesagt. Analysen (ANOVA) zeigten eine signifikante Wirkung von N und P auf Körnerertrag, gesamte Biomasse, Gesamt-N-Aufnahme, und apparente N-Ausnutzung. Die Modelevaluation zeigt, dass APSIM in der Lage war, die Reaktion von Mais auf Bodenfeuchtigkeit, N und P zu quantifizieren und simulierte daher Maiskörnerertrag mit einem Effizienzsquotienten (R^2) von 0.90 bzw. 0.88 für die untersuchten Maissorten Obatanpa bzw. Dorke. Die Bewertung der Auswirkung des Klimawandels auf Maiskörnerertrag deutet auf eine mögliche Verschiebung des Beginns der Regenzeit hin , wobei die Aussaattermine bei ca. 70 % der Jahre in der zweiten Maiwoche liegen, im Gegensatz zur dritte Märzwoche bei den historischen Wetterdaten (1980-2000). Diese sechswöchige Verschiebung ergab eine durchschnittliche Ertragsminderung um 55 bzw. 34 % für Obatanpa und 59 bzw. 37 % für Dorke während der Hauptsaison unter den A1B- bzw. B1-Szenarien. Die Ertragsvariabilität war signifikant erhöht während der 21-jährigen Simulationsperiode für den kontinuierlichen Maisanbau. Potentielle Anpassungsmaßnahmen umfassen frühe Aussaat, Einführung der Kuhbohne und/oder Brache sowie zusätzliche Bewässerung.

Die Analyse der Wahrnehmung und Anpassung der Farmer an den Klimawandel zeigen, dass sie sich des Klimawandels sehr bewusst sind, da mehr als 80 % der befragten Farmer steigende Temperaturen und abnehmenden Niederschlag bemerkt hatten. Jedoch haben nur ungefähr 44 % der Farmer ihre Anbaumethoden den steigenden Temperaturen entsprechend angepasst und 40 % treten dem abnehmenden Niederschlag mit entsprechenden Maßnahmen entgegen. Die Bestimmungsfaktoren der Anpassungsstrategien deuten darauf hin, dass Landbesitzverhältnisse, Bodenfruchtbarkeit sowie Zugang zu landwirtschaftlichen

Beratungsdiensten und Krediten die Anpassungskapazität der Farmer am signifikantesten beeinflussen. Staatliche Politik sollte daher sicherstellen, dass Kreditbedingungen flexibel sind damit es für die Farmer leichter ist, bezahlbare Kredite aufzunehmen. Dadurch wären sie flexibler und könnten leichter Anbau- und Bodenbewirtschaftungsstrategien den Auswirkungen des Klimawandels anpassen. Vorausgesetzt, dass ausreichende landwirtschaftliche Beratungsdienste in der Region vorhanden sind, scheinen außerdem Verbesserungen der Kenntnisse dieser Mitarbeiter hinsichtlich Klimawandel und angepasster Managementstrategien, ein besseres Mitarbeiter-Farmer-Verhältnis sowie ein erleichterter Zugang der Farmer zu diesen Leistungen die wichtigsten Elemente eines erfolgreichen Anpassungsprogramm zu sein.

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LIST OF ABREVIATIONS

ANOVA	Analysis of variance
ANR	Apparent nitrogen recovery
APSIM	Agricultural Production Systems sIMulator
BD	Bulk density
C	Carbon
Ca	Calcium
CERES	Crop Environment Resource Synthesis
CIMMYT	International Maize and Wheat Improvement Center
cm	Centimeters
C:N	Carbon nitrogen ratio
CRI	Crop Research Institute
CRU	Climate Research Unit
DAAD	German Academic Exchange Services
DAS	Days after sowing
DM	Dry matter
DSSAT	Decision support system for agro-technological transfer
DUL	Field capacity
E1	Modified coefficiency
ECEC	Effective cation exchange capacity
ECHAM4	European Center/Hamburg Model
ET	Evapotranspiration
Expt.	Experiment
FAO	Food and Agriculture Organization
Finert	Proportion of soil carbon assumed not to decompose
GDD	Growing degree days
ha	Hectare
IFPRI	International Food Policy Report Institute
IITA	International Institute of Tropical Agriculture
K	Potassium
kg	Kilogram
KNUST	Kwame Nkrumah University of Science and Technology
LAI	Leaf area index
LL15	Permanent wilting point
m	Meter
m.a.s.l	Meters above sea level
MdUAPE	Median unbiased absolute percentage error
mg	Milligram
mm	Millimeter
MM5	Mesoscale model
MOFA	Ministry of Food and Agriculture
MZs	Management zones
N	Nitrogen
NS	Not significant
P	Phosphorus
R^2	Coefficient of determination

RCBD	Randomized complete block design
RMSE	Root mean square error
SAT	Volumetric water content at saturation
SOC	Soil organic carbon
SoilN	Soil nitrogen module
soilP	Soil phosphorous module
soilWAT	Soil water module
SSA	Sub-Sahara Africa
Tt	Thermal time
ZEF	Center for Development Research

1 INTRODUCTION

Cereal production is a major component of small-scale farming in West Africa. Among cereals, maize is one of the most important crops, as it forms the major staple food for most communities and contributes about 20% of calories to the diet (Braimoh and Vlek, 2006). However, average maize yields per unit of land have fallen over the years partly due to loss in soil fertility as a result of unsustainable farming activities, especially in the wetter areas where the yield potential is higher (Sanchez, 2002) and partly due to low external inputs (Fosu et al., 2004).

An important practice that restores some level of fertility is long fallows. This practice is no longer common due to increasing pressure on land (Gilbert *et al.,* 1993; Wopereis et al., 2006). For instance, Wopereis et al. (2006) observed a drastic decline in maize yield from 3 to 0.7 t ha^{-1} for a low input system in Benin, where fallow periods have reduced from 6 to 2 years. The increasing pressure on land necessitates continuous cropping, which has resulted in soil nutrient deficiencies particularly for the major soil nutrients; nitrogen (N) and phosphorus (P) (Bationo et al., 2003). Lal (2007) reported depletion of soil N, P and K at a rate of 20 – 40 kg ha^{-1} yr^{-1} since the 1950s in Ghana. Sustainable use of land under intensive cultivation requires that nutrients lost by plant uptake be consistently replenished through fertilization.

Fertilizer use in Africa, however, is by far the lowest of any developing region for various reasons including non-availability and high cost (Fosu et al., 2004). Farmers apply about 9 kg/ha fertilizer in Africa compared to 86 kg/ha in Latin America, 104 kg/ha in southern Asia, and 142 kg/ha in Southeast Asia (Kelly, 2006).

In the sub-humid region or forest-savanna transition zone of Ghana, maize is one of the most frequently cultivated crops with the region producing about 50 % of the total maize production in the country (MOFA, 2003; Gerken et al., 2001). In Ghana, smallholder farming characterized by low inputs forms the greater part of crop production (FAO, 2007).

Most soils in Ghana are both N and P deficient. While N is the most limiting nutrient, Delve et al. (2009) has shown that deficiency of soil P reduces the efficiency of N use by crops. Phosphorus is mainly lost from the soil through crop harvest and only little is left in residue for recycling (Vlek et al., 1997). To solve this problem, the use of

mineral fertilizer needs to be encouraged to improve soil fertility and hence productivity. Whereas mineral fertilizer application is important, it is also necessary to increase N use efficiency to make the use of mineral fertilizer cost effective and attractive to smallholder farmers. Farmers are sometimes reluctant to apply N fertilizer due to the low use efficiency, which translates into low output. Whitbread et al. (2004) reported a significant increase in maize yield and N use efficiency between 17 and 33 kg grain/kg in the sub-humid region of Zimbabwe when P was applied compared to treatments without P application. A significant increase in grain yield was reported by Kinyangi et al. (2004) when 50 kg P ha^{-1} and 60 kg N ha^{-1} were applied to maize compared to 60 kg N ha^{-1} without P in a field experiment conducted in sub-humid Kenya. It has been shown that low soil-available P content in sub-humid soils limits crop growth due to low P content of underlying parent rock, and moderate to high P sorption capacity of the soils. With the country's growing population, the demand for maize, which is one of the three most important crops, will increase. However, the increase in production will have to come from an increase in productivity rather than expansion of arable land.

As farmers battle with low soil fertility, climate change presents an additional burden, which for them translates into production risks associated with crop yields, due to the probability of extreme events, the uncertainty of the timing of field operations, and of investments in new technologies. The concern for the present and future climate aberrations, weather trends and their implications for agriculture continue to stimulate researchers as well as public and policy-level interests regarding the analysis of climate change in relation to agricultural productivity (IPCC 2007; Cooper et al., 2006). Reported projections indicate that with the trend in climate change and variability, the impacts on people's livelihoods will be greatest in Africa, where many poor smallholders largely or totally rely on rain-fed agriculture and have few alternatives (IPCC, 2001; Boko et al., 2007), due to high levels of poverty, low levels of human and physical capital, and poor infrastructure (IFPRI, 2009).

In the semi-arid regions of Africa, it is evident that in systems reliant on rainfall as a sole source of moisture for crop production, seasonal rainfall variability inevitably leads to highly variable production levels and risks. This phenomena is gradually shifting to the sub-humid regions, where increasing variability in seasonal

rainfall totals and distribution is occurring (Cooper et al., 2006). While seasonal rainfall totals and their season-to-season variability are themselves important, the nature of the within-season variability can also have a major effect on crop production.

Ghana's agriculture in all regions depends heavily on rainfall, and the year-to-year and within-season variability in rainfall is a significant constraint to the sustainability of rainfed farming systems. These systems already have problem of low soil fertility resulting in low crop yields posing challenges for development such as insufficient domestic production, national food insecurity and poverty thus raising many questions. What will be the impacts of climate change on maize production at local and regional levels? How will these impacts add to the development challenges?

The use of models to predict crop production over long periods under climate change has matured over the years. These models are able to capture the interactive soil-climate effect on crop yields in different cropping systems. The Agricultural Production Systems sIMulator (APSIM) has been proven to be a useful tool to investigate the potential impacts of climate change on crop productivity (Keating et al., 2003; Wu et al., 2006; Wang et al., 2009). With the use of crop simulation models to simulate crop yields, faster results and greater understanding can be obtained more quickly hence reducing the risk of total crop loss or drastically low yields which are results of low N use efficiency and the impact of climate change.

This study sought to first assess the extent to which a P-responsive maize-model can capture the variable response to N fertilizer observed under smallholder farming conditions for two maize cultivars and subsequently assessed the potential impact of climate change on yields in the sub-humid region of Ghana using the Agricultural Production Systems sIMulator (APSIM) model.

1.1 Objectives

The overall objective of the research was to quantify yield responses of maize to N and P inorganic fertilizer and the potential impact of climate change on crop yield using a modeling approach.

To achieve this, the following specific objectives were followed to:

1. determine the effect of cultivars, N and P rates on growth, development and yield of maize.
2. parameterize and evaluate the capability of the APSIM-Maize model to simulate growth, development and yield of maize cultivars at different locations.
3. evaluate the application of the APSIM-Maize model to assess the impact of climate change and variability on maize production in sub-humid Ghana.
4. explore management practices to reduce the impact of climate change on regional maize production potentials.
5. assess farmers' perception and adaptation to climate change in the Sekyedumase district of the Ashanti region.

1.1.1 Hypotheses

1. Nitrogen, P and cultivar have an influence on growth, development and yield of maize which can be modeled using APSIM.
2. The expected future increase in mean temperature and decrease in rainfall will decrease grain yield.
3. Access to extension services and credit/loan will increase likelihood of farmers perceiving climate change and adapting to climate change.

1.2 Outline of thesis

The thesis is structure into six main chapters. The first of the six chapters of thesis gives an introduction and define the context of which the study was done. It also outlines the objectives that guided the study. Chapter 2 presents a review of relevant literature. Chapter 3 provides a description of the study area and the materials and methods used in the study. Chapter 4 presents results of the study. Chapter 5 discusses of the results. Chapter 6 gives a summary of the major conclusion (findings) of the study and related policy implication and recommendation for further study.

2 LITERATURE REVIEW

2.1 Soil phosphorus and its dynamics

Phosphorus is an important mineral nutrient for plants growth and other processes in plants. However, this element is frequently limited in most Africa soils. Soil P is very reactive and undergoes many transformations. The dynamics of soil P are characterized by interactions between physico-chemical (sorption and desorption) and biological (immobilization and mineralization) processes (Seeling and Zasoski, 1993; Tang et al., 2007). The rate and direction of these reactions are influenced by chemical conditions, physical properties, added extraneous materials, micro-biological components as well as by the agricultural crops adopted (Blake et al., 2000; Krishna, 2002 and Bunemann et al., 2004).

Soil P undergoes biological (Hedley et al., 1982) and pedological (Smeck, 1985) transformations, which are short- and long-term transformations, respectively. The main source of P in most rock or parent material is Apatite (Ca-P) of which the proportion in the underlying parent material of a soil influences the status of soil P.

In the West African savannah soils, which have undergone progressive weathering, bases such as calcium (Ca) silicate and carbonates are leached out of the reach of crops and plants, resulting in the release of P into solution. Some of this P is taken up by plants and other organisms, while the remaining form complexes with oxides of iron (Fe) and aluminium (Al), which serve as a sink to P. Hence, the more weathered a soil is, the lower is its Ca concentration, and the more complex Fe and Al oxides are formed with P, which is occluded with time (Tiessen et al., 1984).

Biological transformation of P is governed by the bio-cycling of organic matter. During the process of transformation and losses of bases, carbonates and silicates, some of the P released into solution is taken up by soil biomass and plants (Kpongor, 2007).

In addition, the release of organic exudates by soil microbes and plant roots or added organic material may affect sorption P and the exchangeability of added P by competing for the sites P sorption (Nziguheba et al., 1998; Nziguheba et al., 2000). Labile P is the result of adsorption of soluble P on surfaces of secondary minerals forming part of the pool. The reverse can occur with P desorbed into solution or

transformed into forms that are more stable thermodynamically and are not easily available to plants (Gijsman et al., 1996). In the sub-humid regions of Ghana, the soils are low in available soil P.

Three main factors influence the availability of soil P. These are (i) the quantity factor, which is the amount of P ions potentially released into the soil solution from the solid phase during the growth period of the plant, (ii) the intensity factor, which describes the activity of P ions ($H_2PO_4^-$, HPO_4^{2-}) in solution, and (iii) the buffer capacity, which is the ability of the soil to keep the intensity factor at equilibrium (Kpongor, 2007). The routine analysis of P availability in soil, however, describes only the quantity factor (Sinja et al., 2001).

2.2 Factors influencing the distribution of phosphorus

In tropical soils, the main determinants of the amount and distribution of soil P are the parent material (Smeck et al., 1985), position in the landscape (Abekoe and Tiessen, 1998), extent of weathering (Gijsman *et al.,* 1996) and the land use type (Sinja et al., 2001; Hedley et al., 1982). These factors result in a high variability of total P concentration in tropical soils. In Brazil, Caiado, (2005) reported total P values ranging from 7 to 272 mg kg^{-1} whiles Nwoke et al. (2004) reported values ranging from 90 to 198 mg kg-^{1} in top soils of West Africa.

2.3 Factors affecting maize growth, development and yield

A number of factors are known to affect maize growth, development and yield. These can be classified under two broad categories, namely crop genetic factors and environmental factors.

2.3.1 Genetic factors

The rate of development and yield potential of crops such as maize is determined by the genetic makeup of the crop. The increase in grain yield of maize observed over the years is a result of improved cultivars, open pollinated as well as hybrids. Other characteristics such as quality, disease resistance, and drought resistance are determined by the genetic makeup of the crop.

Effect of cultivar

The type of cultivar affects the yield component of maize. In a study carried out by Costa et al. (2002) to evaluate the effect of N rates on maize genotypes, it was observed that genotype 3905 consistently yielded best (12.4 and 10.3 t ha^{-1} in 1997 and 1998, respectively), while the NLRS hybrid performed worst; however, the genotypic grain yield ranking varied between sites. Overall, the yields of cultivar LRS exceeded its conventional counterpart (P3979) by 12 % at one site and by 26 % at another. Similarly, Kogbe and Adediran (2003) conducted an experiment to test the effect of five N rates (0, 50, 100, 150 and 200 kg N ha^{-1}) on three hybrids (8516-12, 8321-18 and 8329-15) and two open-pollinated maize varieties (TZSR-Y and TZSR-W) in Nigeria. They reported that hybrid maize produced higher yields with high N-use efficiency compared to the open-pollinated varieties. They concluded that hybrid 8516-12 had a higher N use efficiency than the other varieties, and all hybrids responded up to 150 and 200 kg N ha^{-1}.

In a similar study, D'Andrea et al. (2006) conducted experiments in Argentina to analyze the response of morpho-physiological traits to different N rates of 12 maize inbred lines from different origins (USA and Argentina) and breeding eras (from 1952 onward). Traits considered included canopy structure, light interception, shoot biomass production, yield components and grain yield. Significant differences in these parameters among the genotypes were reported.

2.3.2 Environmental factors

A number of environmental factors affect growth and development of maize. The most important ones are temperature, moisture availability, solar radiation, soil structure, soil reaction, biotic factors and supply of nutrients.

Temperature directly affects photosynthesis, respiration and transpiration (loss of water, absorption of water and nutrients). The rate of these processes increases with an increase in temperature and is different for different crops. The temperature of the soil affects the rate of uptake of water and nutrients from the soil.

Water is essential for all plant growth and development and is an integral part of living systems. Crop growth is limited by water stress. Oldeman and Suardi (1977) stated that maize crops need an average monthly precipitation of 100 to 140 mm. They

basically take 3-3.5 months for optimum growth and will need an average of 300-500 mm of precipitation during this period.

Light is an important environmental factor that affects crop growth and development. It is necessary for photosynthesis and is also a factor of changes in day length needed (photoperiod-sensitive plants) for physiological processes such as growth and which takes place only when a certain number of daylight is assured (Kyei-Baffour 2006). http://www.wmo.int/pages/prog/wcp/agm/gamp/documents/chap13C-draft.pdf.

2.4 Modeling crop growth and development

A model is a set of mathematical equations describing a bio-physical system (in this case soil–plant–atmosphere). Crop models predict the response of crops to weather, soil, and management by simulating the growth and development of plant organs such as leaves, roots, stems and grains. Thus, a crop growth simulation model not only predicts the final state of total biomass or harvestable yield, but also contains quantitative information about major processes involved in the growth and development of a plant. Changes in climatic conditions influence soil moisture availability, nutrients and water uptake by plant root. The phenology of the crop is also affected and, depending on the growth stage of a plant, unfavorable climatic conditions can result in large losses in crop yield or total crop failure.

In recent years, crop growth models have become state-of the art research tools and are an important component of agriculture-related decision-support systems (Jame and Cutforth, 1996; Stephens and Middleton, 2002). These models serve as a research tool for evaluating optimum management of cultural practices, fertilizer use, and water use. Modeling crop yield response to management options and prevailing environmental conditions can be done through empirical and process-based (simulation) models, and each approach has its merits and limitations (Park et al., 2005).

2.4.1 Empirical approach

Empirical models, also called descriptive or regression models, are direct descriptions of observational data (e.g., response of maize yield to different rates of fertilizer) and driving variables. Statistical analyses such as correlation or regression analysis are used to derive patterns of response of crop yield without explaining the crop growth and

yield processes. These models are relatively simple to build, and their ability to predict depends on the range and quality of the empirical data sets. The ecological processes that define crop yield dynamics are often not well explained by pure empirical functions (Kpongor, 2007). These models are widely used in optimizing agricultural inputs with the aim of maximizing crop input use efficiency (Belanger et al., 2000; Zhang and Evans, 2003). Unlike process-based models, the yield predicted by these models does not go beyond the range of the data set.

2.4.2 Crop simulation models

The process-based modeling approaches use the knowledge or understanding of the crop yield formatting process through mathematical relations that are based on plant physiology, agro-climatic and plant-soil-atmosphere interactions (physiological and biochemical processes) Kpongor, (2007). These models arise primarily from the understanding of processes rather than from statistical relationships (Willmott, 1996). They can be used to quantify potential yield gaps between prevailing management options and potential yields of different crops. They provide a means of quantifying possible dynamics in crop yield responses over a given time within a given location. On the contrary, agronomic research usually focuses on results that are site and season specific. Thus, the in-depth framework for explaining the processes under-lying yield formation is inadequate, and their outputs provide insufficient knowledge of crop responses to prevailing environmental conditions and management options. Models provide a means of evaluating possible causes for changes in yield over time within a given location (Keating and McCown, 2001). In addition, they serve as a research tool to evaluate optimum management of cultural practices, fertilizer use water use and also evaluate impact of climate change on agricultural production, economies of climate change impact, etc.

Predictive models of crop growth and yield are required in carrying out analysis of yield formation beyond agronomic research. Process models are capable of simulating both temporal and spatial dynamics of crop yields since they explicitly consider plant physiology, agro-climatic conditions, and biochemical processes. Consequently, the ability to include temporal changes of crop yields and extrapolation potentials are much higher than in the case of empirical models (Jame and Cutforth,

1996). The processes of crop growth, grain yield and the temporal changes in grain is as a result of farmers' management practices which form the basis of this study; hence the process-based approach is preferred to the empirical approach.

Gungula et al. (2003) tested the phenology module of the CERES-Maize model version 3.5 under varying N rates in the southern Guinea Savanna of Nigeria. Data on seven late-maturing cultivars of maize (*Zea mays* L.) grown under four levels of N (0, 30, 60, 90, and 120 kg N ha^{-1}) for two seasons were used for the modeling. There was a linear relationship between N rates and days to silking and maturity with R^2 values of 0.70 for most of the cultivars. There was a good prediction of days to silking at high N rates (90 and 120 kg N ha^{-1}), with most prediction errors of < 2 days. Similarly, days to maturity were closely predicted by the model at high N rates with errors of < 2-day for most predictions. Greater deviations were however observed at low N rates. The authors stated that the CERES-Maize model can be reliably used for predicting maize phenology only under non-limiting N conditions. Thus, there is the need to incorporate an N stress factor into the model for more accurate phenology predictions in low-N tropical soils.

Kpongor (2007) evaluated the application of the APSIM-Sorghum model version 4.0 to predict grain and biomass yield response of sorghum to inorganic N and P fertilizer in a semi-arid region of Ghana under two management systems. The model performed well in predicting grain and biomass yield with an average R^2 of 0.81 and 0.86, respectively.

Delve et al. (2009) simulated P responses in annual crops on contrasting soil types using the APSIM-model for maize and beans in Kenya. The goodness fit (R^2) between simulated and observed grain yield of maize was 0.81 and 0.74, whereas for biomass, this was 0.88 on Oxisol and 0.83 on an Andisol. An average R^2 of 0.79 and 0.69 was reported for grain and biomass of beans. The authors concluded that the model performed creditably in predicting the growth of maize and bean crops for the different P sources (fertilizer or chicken manure) and treatments (rates and frequency of application).

Chen et al. (2010) used a model to analyze the response of crop productivity to irrigation in the North China Plain, where excessive use of water for irrigation has caused a rapid decline in the groundwater table. Using data from three sites (Luancheng,

Yucheng and Fengqiu), they parameterized and evaluated the APSIM-Wheat model. The results showed that the model was able to simulate growth and yield of wheat and maize in a double cropping system. Root mean squared error (RMSE) of yield and biomass simulations was 0.83 and 1.40 t ha^{-1} for wheat, and 1.07 and 1.70 t ha^{-1} for maize, respectively. Soil water and evapotranspiration (ET) were also reasonably predicted. The simulated rainfed yields ranged from 0 to 6.1 t ha^{-1} for wheat and for maize 0 to 9.7 t ha^{-1} in a double cropping system. It was reported that for each 60 mm additional irrigation water, crop yield increased by 1.2 t ha^{-1}; to achieve a yield potential of 7.1 t ha^{-1} of wheat and 8.3 t ha^{-1} of maize, 540 mm irrigation water would be required. The authors concluded that the model predicted grain yield, soil water and ET quite well.

Similarly, Miao et al. (2006) evaluated the potential of a crop growth model to simulate maize yield at various N levels in different management zones (MZs) and to estimate optimal N rates based on long-term weather conditions. Data on maize yield from three years experiments were used to parameterize a modified version of the CERES-Maize (Version 3.5) model for a commercial field divided into four MZs in eastern Illinois (USA). The model performance was evaluated in simulating grain yield for two hybrids (33G26 and 33J24) at five N levels (0, 112, 168, 224, 336 kg N ha^{-1}) in two independent years. The model explained 93 % of yield variability and performed well at non-zero N rates, with errors <10 %. Model-estimated economically optimum N rate (EONR) varied from 70 to 250 kg ha^{-1}. Economic analyses based on these models showed the benefits of tailoring N fertilizer use on the basis of year, hybrid, and MZ.

Bert et al. (2007) evaluated the sensitivity of CERES-Maize yield predictions to uncertainty in a set of soil-related parameters and solar radiation in the Argentine Pampas. A 31-year climatic data were used to simulate Maize yields. Under the scenarios evaluated, the model results showed higher sensitivity to changes in radiation (normalized sensitivity was -0.69 and 0.45 for rainfed and irrigated conditions, respectively) compared to the soil variables (normalized sensitivity ranged from 0.20 to 0.28). The CERES-Maize model was found to have similar sensitivity for the different soil inputs. In addition, some of the variables evaluated (soil curve number, soil water content at sowing and radiation under rainfed conditions) showed an important non-linear response.

Similarly, Soler et al. (2007) evaluated the Cropping System Model (CSM)-CERES-Maize for its capability to simulate growth, development, and grain yield for four different maturity maize hybrids grown off-season in a subtropical region of Brazil under rainfed and irrigated conditions. The evaluation showed that the model was able to accurately simulate phenology and grain yield for the four hybrids. Total biomass and LAI were also well simulated by the model.

2.5 Impact of climate variability on crop production

The high spatial and temporal variability of rainfall, reflected by dry spells and recurrent droughts and floods, may be considered the most important factor affecting agricultural productivity in SSA (Laux et al., 2010). The within- and between-season variability is often given as the reason for crop failure and food shortages (Usman et al., 2005; Sultan et al., 2005; Mishra et al., 2008). The availability of plant water strongly depends on the onset, cessation, and length of the rainy season.

The onset of the raining season directly affects farming management practices, especially planting, which, in turn, significantly affects crop yield and the probability of agricultural droughts (Kumar, 1998). For sowing, it is important to know whether the rains are continuous and sufficient to ensure enough soil moisture during planting, and whether this level will be maintained or even increased during the growing period in order to avoid total crop failure (Walter, 1967). There is, however, no consensus in the literature about how much rain and over which periods define the onset of the rainy season for climate variability impact studies. The definition of Stern et al. (1981) cited in Laux et al., (2010) is probably the most widely rainfall-based definition used to estimate the local onset of rainy season. The approach states that the wet season starts when for the first time after March 1st, 25 mm of rain falls within two consecutive days and no dry period of 10 or more days occurs in the following 30 days. This criterion, however, depends on local weather conditions, soil types, the evaporative demands of crops, and cropping practices (Laux et al., 2010). This definition was extended by Laux et al. (2008) to regional usability in a case study for the Volta Basin in (West Africa) using a fuzzy logic approach.

2.6 Impact of climate change on crop production

Climate change is real, and the question is how to reduce its impact. Climate change as projected by climate models for the twenty-first century has the potential to significantly alter the conditions for crop production, with important implications for world food security (Rosenzweig and Hillel, 1998). Although there are differences among regions, the majority of the regions will face increased temperatures, particularly minimum temperatures, changes in precipitation and higher concentrations of carbon dioxide (CO_2) in the atmosphere (Meza et al., 2008).

Climate change has an impact on different growth and development processes. For example, an increase in CO_2 will simulate photosynthesis rates and sometimes result in higher yields (Kimball, 1983). Changes in temperature and precipitation may also affect crop photosynthesis, and plant development rates, as well as water and nutrient budgets in the field (Long, 1991).

One of the most important processes that will be affected by climate change is Photosynthesis. Like many other C4 plants, maize can fix carbon in the mesophyll cells, separating RuBisCO from the atmosphere (Meza et al., 2008). The direct effects of CO_2 enrichment on plants is that an increase in CO_2 concentrations increases the rate of photosynthesis and water-use efficiency (WUE; the efficiency with which plants use water to produce a unit of biomass or yield). As CO_2 concentration increases, the transpiration intensity of plants reduces by partially closing the stomata, which leads to improved WUE and thereby lowers the probability of the occurrence of water-stress. These physiological responses are known as the CO_2-fertilisation effect or the direct effect of increased CO_2. Experiments conducted in a controlled environments indicated that crop growth would increase by about 11-14 % for C4 plants (e.g., maize) at doubled CO_2 (Kimball, 1983). If water is a limiting factor, the yields may increase much more than under non-limiting conditions due to the additional effect of improved WUE. Lin et al. (2005), based on a simulation using Hadley model (PRECIS), reported an increase in maize yield of 9.6% in China when CO_2 was increased from 440 to 559 ppm under rainfed conditions but a decrease of 0.6% under irrigation. A report by the IPCC Second Assessment (IPCC, 1996) indicated that the effect of a doubling in CO_2 concentrations (from the present) will increase biomass varying from a 10 % increase to almost a 300 % increase; the increase in WUE may also go up to 50 % or more. Thus,

the effect of decreasing precipitation is likely to be offset by the beneficial effects of increased concentrations of CO_2. However, the effect of CO_2 on crops in Africa, where nutrients often are a limiting factor and leaf temperatures are high, remains highly uncertain (Watson et al., 1998).

The increase in temperature due to climate change has both positive and negative impacts on crop production. For example, in the middle and higher latitudes, global warming will extend the length of the potential growing season, allowing earlier planting of crops in the spring, earlier maturation and harvesting, and the possibility of completing two or more cropping cycles during the same season (Rosenzweig et al., 2004). Crop-producing areas may expand poleward in countries such as Canada and Russia, although yields in higher latitudes will likely be lower due to the less fertile soils there. In warmer, lower latitude regions, increased temperatures may increase the rate at which plants release CO_2 in the process of respiration, resulting in less than optimal conditions for net growth. High temperature reduces yield by accelerating physiological development (hastening maturation), not allowing the crop to progress slowly through the season so as to maximize time for the capture of resources and for assimilate partitioning to reproductive structures (Boote and Sinclair, 2006). Therefore, under warming conditions, yields are expected to decrease.

Crop simulation models indicate that by 2050 in Sub-Saharan Africa, average rice, wheat, and maize yields will decline by up to 15, 22, and 10 %, respectively, as a result of climate change (IFPRI, 2009).

In Argentina, Travasso et al. (2009) observed a reduction in the growing season of maize crops by 27 days and consequently reduction in yields when crop yield was simulated using version 3 of Hadley Center coupled model (HadCM3) climatic projections for 2080 under A2 scenario.

Under non-limiting water supply and considering CO_2 effects, maize grain yields could decrease with temperature increases < 1°C (Magrin and Travasso, 2002). In contrast, Easterling and Apps (2005) analyzed maize response to temperature increases in temperate zones, using the results of 30 crop-modeling studies. The authors concluded that this crop slightly benefited from a warming of up to 2°C. Although C4 plants like maize have a higher temperature optimum than C3 plants, photosynthesis is usually inhibited when leaf temperatures exceed about 38°C (Crafts-Brandner and

Salvucci, 2002). Furthermore, global warming will not necessarily favor C4 over C3 plants, because the timing of warming could be more critical than the warming itself (Sage and Kubien, 2003). Thus, the timing of temperature increase is very important for the growth and development of the crop. Short episodes of high temperature at critical stages of crop development can impact yield independently of any substantial changes in mean temperature (Wheeler et al., 2000). This has been confirmed by field studies, for example, Ramadoss et al. (2004) reported that in Australia, extreme air temperatures (>38°C) can lead to lower maize grain yields, grain numbers and harvest index if they coincide with the flowering stage. When temperatures exceed the optimum for biological processes, crops often respond negatively with a steep drop in net growth and yield.

2.6.1 Impact of climate change on maize production and adaptation measures

Maize has been one of the primary crops for which climate change impact assessments have been carried out. The responses of this crop under climate change conditions are acceleration of the rate of development, reduction of grain unit weight and reduction of grain number (Parry, 1990).

A study by Alexandrov and Hoogenboom (2000) in Bulgaria investigating impact of climate change on maize showed that maize yields could be reduced by between 5% and 10%. The authors deduced that this is the result of a reduction of the growing period. Cuculeanu et al. (1999) in Romania reported similar values, where maize showed yield reductions of 10%. Travasso et al. (2009) reported a reduction in maize grain yield in Argentina of 9 and 6% under SRES A2 and B2 respectively, without consideration of CO_2 elevation. Consideration of elevated CO_2 concentration in the model simulation increased maize yield by 19 and 11% for A2 and B2, respectively.

Tao et al. (2006) studied climate change impact on phonological and yield trends of field crops (rice, wheat, maize) in China where significant warming trends were observed at most of the regions studied. They observed that the changes in temperature had changed crop phenology and affected crop yields during the past two decades. The observed climate change patterns, as well as their impacts on crop phenology and yields were spatially diverse across China. The study recommended the need for further research on the combined impacts of CO_2 concentration and

temperature on physiological processes and mechanisms governing crop growth and production.

With the use of projections for 2005, Jones and Thornton (2003) studied the performance of maize in several locations of Latin America. They came to the conclusion that maize yield is expected to reduce by 10% for the region, with higher impacts on dry lowland tropical areas. Similarly, Madiyazhagan et al. (2004) carried out a study on the effects of water and high-temperature stress on maize production in Australia. They observed that high temperature (> 38º C) with water stress occurring at the same time decreased kernel set in dryland environments.

In the Pampas region in Argentina, Magrin et al. (1997) simulated maize growth under both current and 2055 climate conditions. Even with consideration of the CO_2 effect, there was still a 16% yield reduction. The results also show that crop duration was reduced by 10 days with a 10% reduction in unit grain weight.

Meza et al. (2008) reported that with climate change, the high yielding maize variety DK 647 in Chile showed a reduction between 15 and 28%. They attributed the reduction in yield to the shortening of the growth period of maize of as much as 40 and 28 days for the A1F1 and B2B scenarios, respectively. Early sowing and the reduction of fertilizer use was recommended as an adaptation measure under the B2B scenario, as lower yields no longer justify intensive use of resources.

The A1F1 scenario describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies but intensive reliance on fossil source of energy while the B2B describes a world in which the emphasis is on local solutions to economic, social, and environmental sustainability (IPCC, 2000).

Similar trends were observed under irrigation agriculture in the Mediterranean climate, where Guereña et al. (2001) reported a reduction in biomass accumulation of maize and yield reductions of 16% in Spain. Reductions in seasonal evapotranspiration and irrigation needs in the order of 30 and 40 mm respectively, were also reported. In Italy, where maize is grown under irrigated conditions Tubiello et al. (2000) reported that warmer temperatures accelerated plant phenology and reduced dry-matter accumulation, which translated into a 20% yield reduction. They also found that the

maize growing cycle was shortened by 16 days and actual evapotranspiration was reduced by 70 mm.

Makadho (1996), using Global Circulation Models (GCMs) and the CERES-Maize model to assess the potential effects of climate change on maize in Zimbabwe, reported that maize productivity in Zimbabwe will decrease in the range of 11 to 17% under irrigated conditions in some regions of agricultural production. The reductions in maize yields were primarily attributed to the increased temperature, which shortened the crop growth period, particularly the grain-filling period.

Bancy (2000) reported an increase in maize yield in Kenya in regions with altitudes between 1150 and 1580 m.a.s.l. by 2030 using CCCM and GFDL models. This increase depended on the planting date of the crop. He explained that in order to counter the adverse effects of climate change in maize production, it might be necessary to use early-maturing cultivars and practice early planting.

2.7 Implication of increased temperatures on soil fertility

Increases in air temperatures will be felt in the soil, where warmer conditions are likely to speed the rate of natural decomposition of organic matter and increase the rates of other soil processes that affect fertility (Rosenzweig and Hillal, 1995). Additional application of fertilizer especially in Africa may be needed to counteract these processes and to take advantage of the potential for enhanced crop growth that can result from increased atmospheric CO_2. The continual cycling of plant nutrients (C, N, P, K, and S) in the soil-plant-atmosphere system is also likely to accelerate in warmer conditions, thus enhancing CO_2 and N_2O greenhouse gas emissions (Rosenzweig and Hillal, 1995).

2.8 Vulnerability, adaptation, and adaptive capacity

Vulnerability to climate change is how susceptibility people are to harmful stresses and their ability to respond or adapt to these stresses (Adger, 2006; USAID, 2007; Adger et al., 2007). In most climate change and adaptation literature, vulnerability and adaptive capacity is seen as key concepts for understanding how people in developing countries cope with and adapt to climate change and variability (Adger 2006; Challinor et al 2007; Mimura et al., 2007). Both terms are very important for studying human-environment interactions (Reenberg et al., 2008). In defining vulnerability there is a

need to put it into context and must be linked to specific harmful stress and the exposure to the impacts of these hazards (Brooks et al., 2005). Luers (2005) suggested that vulnerability assessments should focus on the susceptibility of specific variables (such as income, food supply) that characterize the welfare of people with respect to a specific damage (such as drought and famine or hunger).

Adaptation, on the other hand, comprises the actions taken to reduce vulnerability or enhance resilience or to coping capacity to deal with actual or expected climate change (Adger et al., 2007; USAID 2007). The relationship between vulnerability, adaptive capacity, and adaptation are seen to be circular rather than linear. The adaptive capacity of people is defined as their ability to control the variables that determine vulnerability (Luers, 2005; Smit and Wandel, 2006). Mertz at al. (2009) reported that people turned to respond to stress by allocating resources differently such as abandoning/changing farming areas. They however stated that, adapting to stress might in itself bring about vulnerability. For example, for a farmer to adapt to drought he might take up a credit to purchase drought-resistant crop cultivars. When there is a complete crop failure the people will not only suffer from hunger but also have debts they are unable to repay. Kelly and Adger (2000) stated that the true vulnerability of people can only be assessed after adaptation has taken place, as the solution of one problem may create another problem. Barnett and Mahul (2007) therefore stated that credit schemes and new crop varieties, for example, need to be accompanied by weather insurance, as indicated in results from some developing countries.

3 MATERIALS AND METHODS

3.1 Study area

The study site was in Ejura in the Sekyedumase district of the Ashanti Region of Ghana. Ejura is situated on the southern fringes of the Volta Basin in a slightly hilly terrain (150 – 250 m.a.s.l.). It lies in the transitional zone from the moist forest in the south to the Guinea savanna zone in the north of Ghana. The region is bounded by latitude 7°22'N and longitude1°21'W. It had a population of 29,478 as of the year 2000, which is projected to increase to 34,612 by the year 2009 (Ghana Statistical Services, 2002).

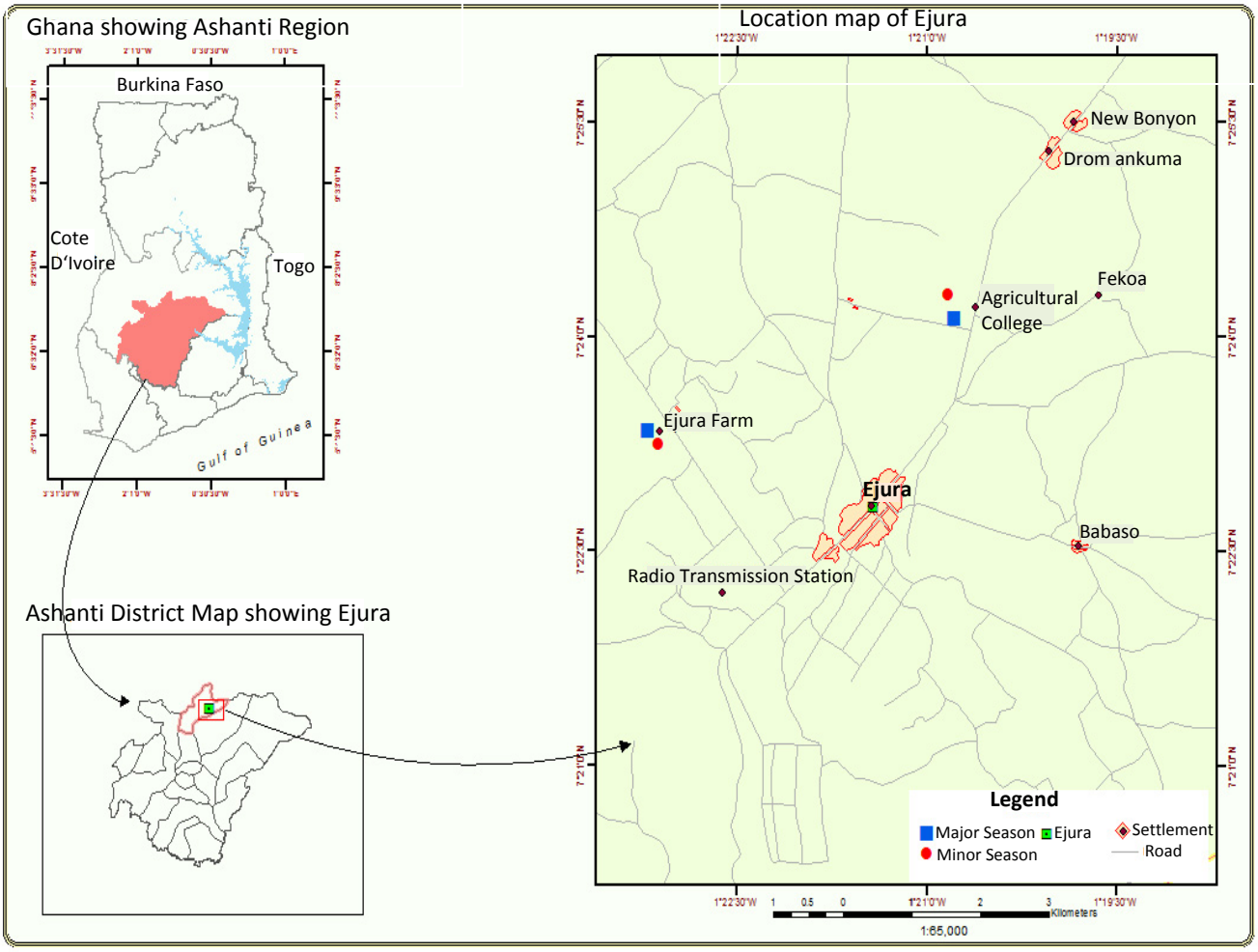


Figure 3.1: Map showing the study area and experimental sites

3.1.1 Climate

The transitional zone of Ghana between the Guinea savanna ecological zone to the north is characterized by monomodal rainfall, and the forest ecological zone to the south by bimodal rainfall.

Mean annual rainfall is about 1400 mm. Rainfall follows a pseudo bi-modal pattern, meaning that in August there is a slight decrease in rainfall (marking the end of the major season and the beginning of minor season); the peak of the season is in September and/or October. The wet season lasts for roughly 7 months from April till October; the onset of the season is highly variable. The period from April through October has 80% of the annual precipitation and is defined as the wet season (corresponding to the growing season), and the period from mid-November through March is defined as the dry season in this study. Relative humidity is very high during the rainy season, i.e., 90% at its peak in June and 55 % in February. Solar radiation is very high during the dry season.

In this study historical rainfall data collected in Ejura over a 36-year period from 1972 – 2007 was used. The average rainfall for the period is 1288 mm. Variability in annual rainfall was wide during this period (Figure 3.2). The first bar on the graph shows 1502.1 and the second bar 1095.2 mm, indicating that the annual rainfall in 1972 was 406.9 mm higher than that of 1973. The lowest rainfall was recorded in 1981 and 1983 with total rainfall of 1006.8 and 834 mm, respectively followed by the year 2000 with a total annual rainfall of 1065.7 mm. In 1983, there was a countrywide drought. Generally, there was more rainfall in the major season than minor season.

The major season rainfall was higher and more evenly distributed than the minor season rainfall (Figure 3.3). The major season received a total rainfall of 756.2 mm whereas the minor season received only a total of 511.2 mm rainfall, which reflected in grain yield.

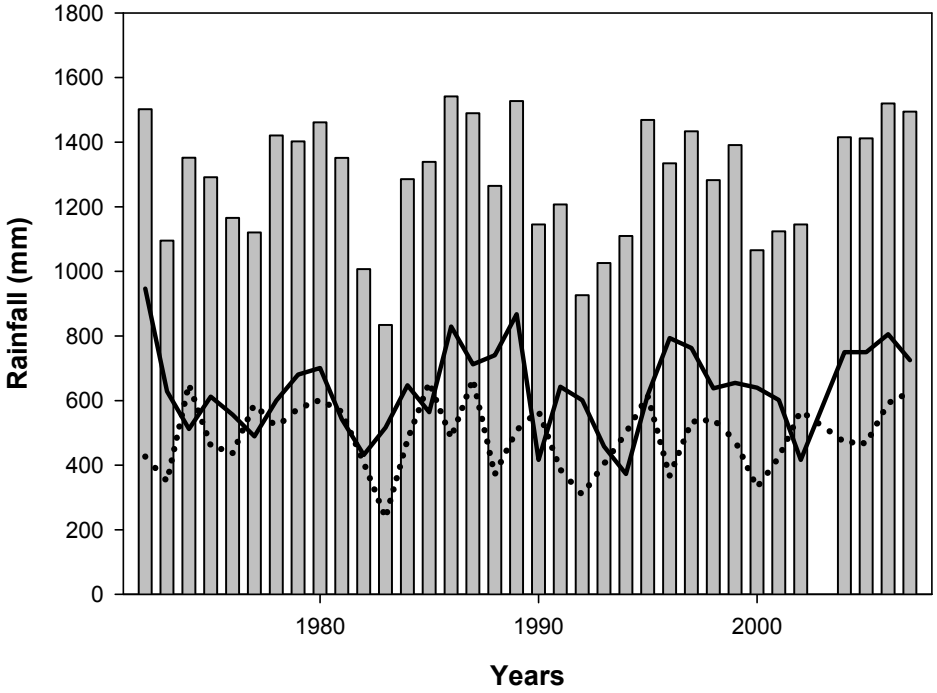


Figure 3.2: Annual (bar), major (continuous line) and minor (dotted line) season rainfall for Ejura from 1972 – 2007 with omission of 2003 (Source of data: Ghana Meteorological Agency, 2007).

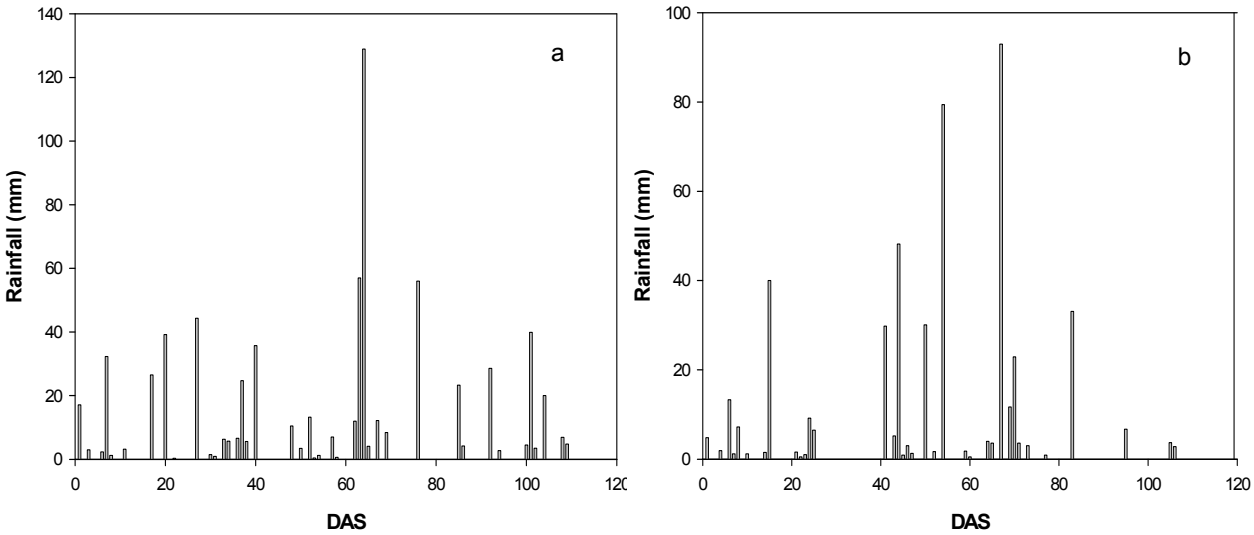


Figure 3.3 (1) Daily rainfall during major (a) and minor (b) season in Ejura, 2008.

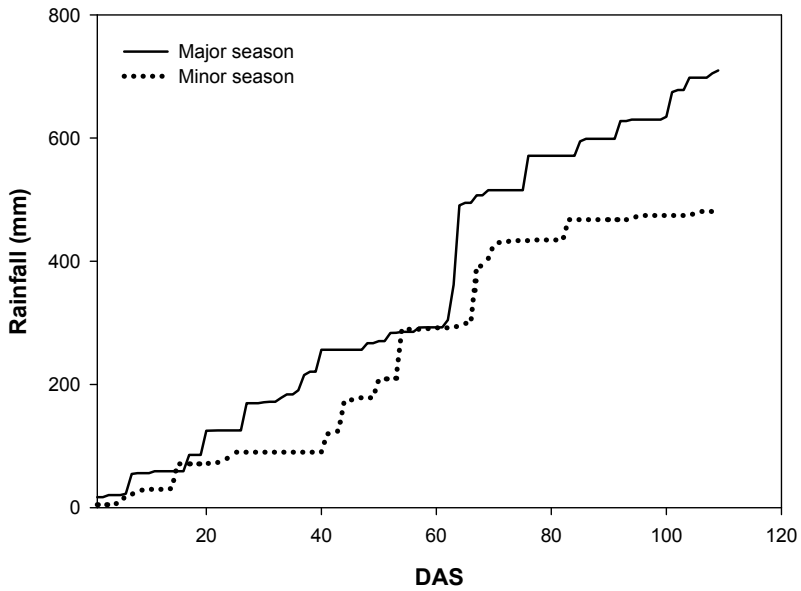


Figure 3.3 (2) Cumulative rainfall during major and minor season in Ejura, Ghana, (2008).

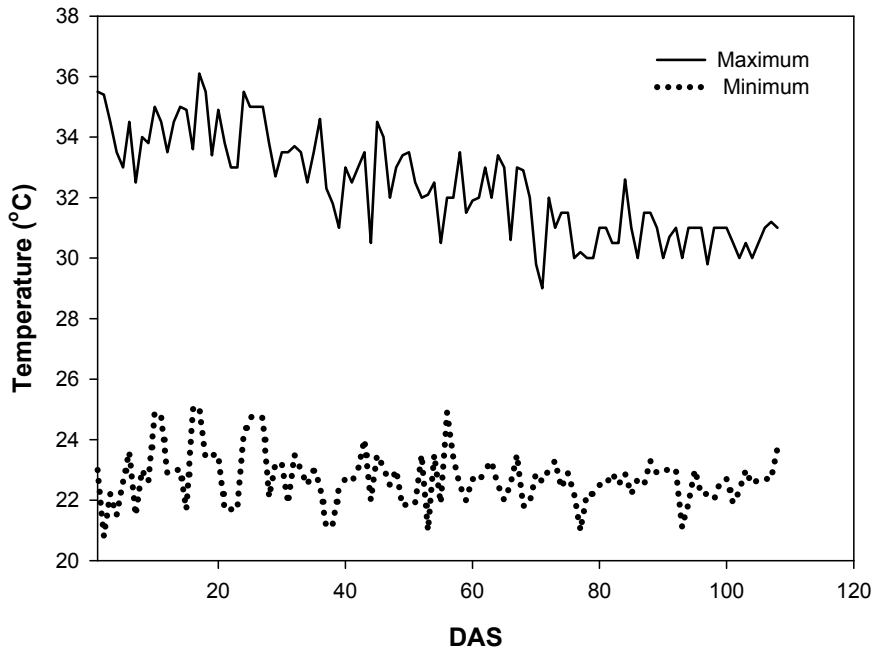


Figure 3. 4: Minimum and maximum temperatures during major season in Ejura (2008).

Figure 3.4 shows maximum temperatures to be quite high in April (35.7°C) at the beginning of the season and gradually reducing (about 31°C) toward the end of the season in August. There was more variability in the minimum temperature at the beginning of the season than towards the end (Figure 3.5).

3.1.2 Vegetation

The vegetation in this region is typical for the transitional zone. The southern part of the region is covered with moist semi-deciduous forest. The northern part is generally covered with Guinea savannah and consists of small deciduous fire-resistant branching trees that do not usually form a closed canopy and are often widely scattered. The predominance of savannah vegetation in the area is largely attributable to the increase in the rate of shifting cultivation and bush fallowing in the district. The climatic conditions together with the topographical layout are favorable conditions for the cultivation of food crops such as *Discorea species* (yam), *Manihot esculenta* (cassava), *Zea mays* (maize), etc in the transition zone.

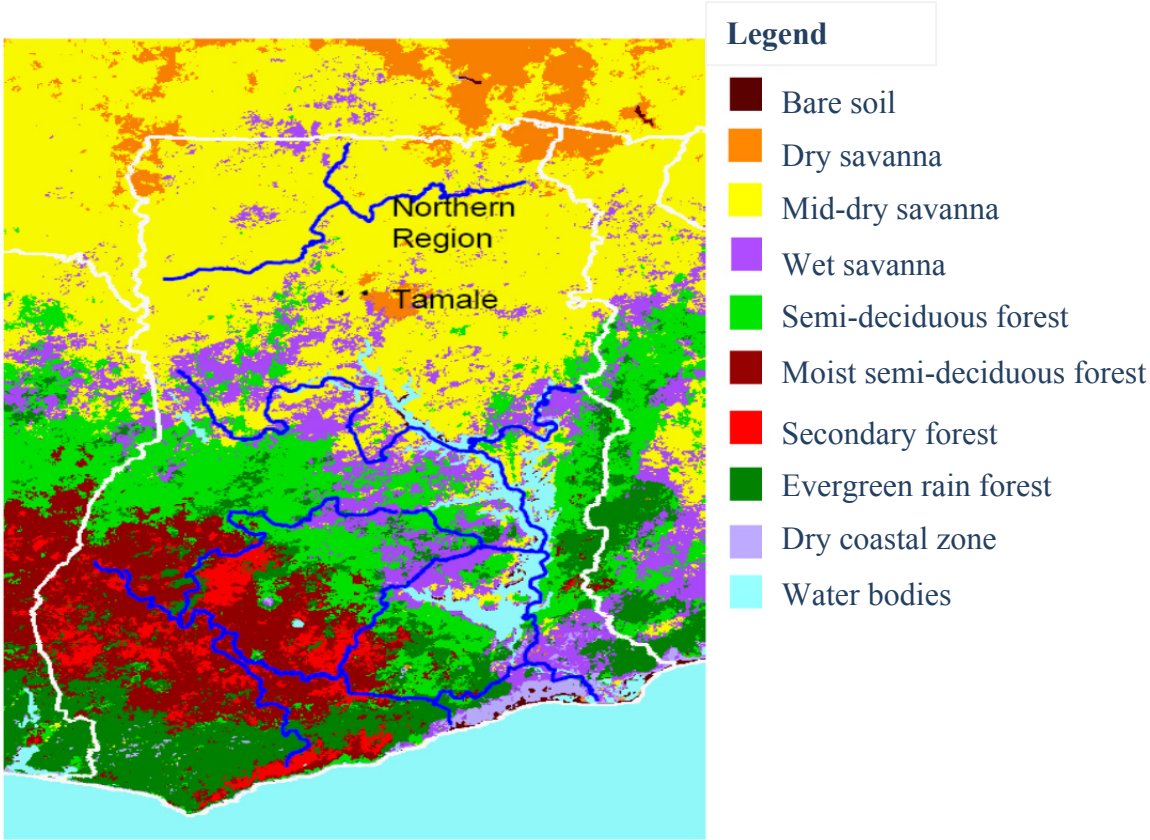


Figure 3. 5: Vegetation map of Ghana (Menz and Bethke, 2000)

3.1.3 Geology and soil

The Ejura area is generally characterized by gently dipping or flat-bedded topography on shales, mudstone and sandstone which are easily eroded. At Ejura, both Lixisols and

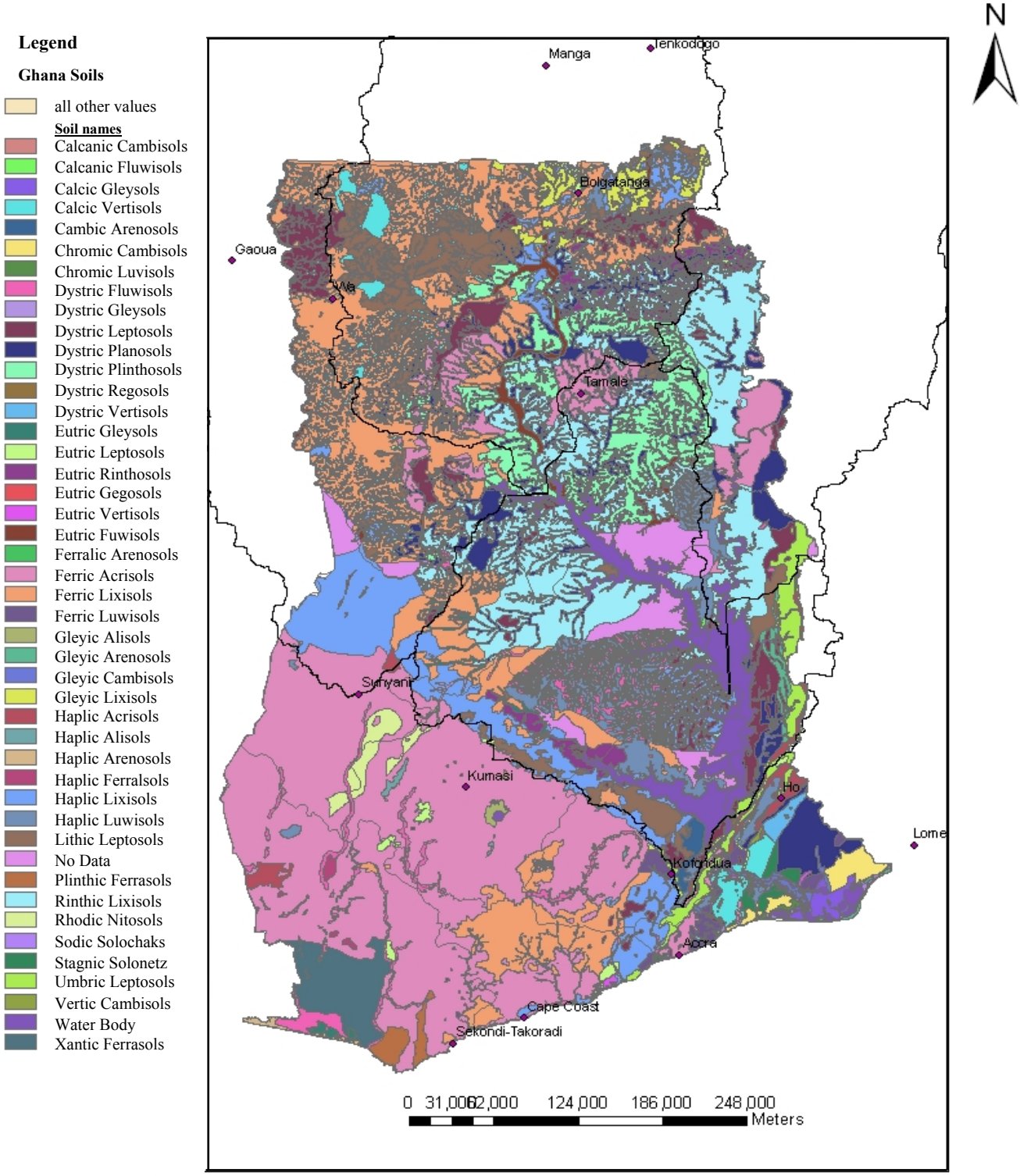


Figure 3. 6: Soil map of Ghana showing the Volta Basin (Source: Ghana at a Glance, 1971).

Plinthosols are found. However, Lixisols are more commonly found than Plinthosols (Figure 3.7). The normal profile of a Lixisol consists of about 30 cm of dark brown to brown, fine sandy loam overlying, from 30-152 cm, reddish brown to reddish yellow, fine sandy loam to fine sandy clay loam (Adu and Mensah-Ansah, 1995). They are moderately well supplied with organic matter and plant nutrients. Moisture holding capacity is moderately good and this soil is easily tilled by machines and by hand. This soil type supports the cultivation of food and cash crops. Root tubers such as yam, cocoyam and cassava as well as cereals such as maize and legumes such as groundnut and cowpea do well on it. This explains why maize and yam are the two major crops grown in the district (Adu and Mensah-Ansah, 1995).

The patches of Plinthosols have humus, fine, sandy loam topsoil approximately 12 cm or less in thickness, over brown to light yellowish brown, fine sandy loam containing abundant ironstone concretions and large boulders or iron pan. They are poorly drained, medium to light textured and subject to seasonal water logging or flooding for varying periods. They generally become thoroughly dry during the dry seasons (Adu and Mensah-Ansah, 1995).

3.1.4 Topography and drainage

Ghana is generally classified as a lowland country because it mostly lies below 300 m.a.s.l. (Walker, 1962). In the Sekyedumasi district where Ejura is the capital, the landscape in the southern part is gently rolling with valleys and hilltops. On average, the valleys have a depth of about 135 m, whilst the peaks rise to about 315 m.a.s.l. The highest point in the district is made up of a range of hills in the eastern part passing through Ejura and Mampong, forming part of the Kintampo-Koforidua range. Examples of the hills found in the district include: Kwasi Mahu Hills (1,350 m), Ejurachem Scarp (1, 000 m) and Dente Scarp (rock outcrop), with a greater part of the district's land being a scarp.

On the other hand, the northern part is undulating and fairly flat with heights ranging from 150-300 m. Ejura is located at an altitude of about 225 – 250 m. The district is dissected and well-drained by a number of rivers, streams and their tributaries. Major rivers are the Affram, Akobaa, Chirade, Bresua whilst minor rivers include

Aberewa, Yaya and Baba (ESDA, 2006) (http://www.ghanadistricts.gov.gh/districts, cited on September 2009).

3.1.5 Agriculture and land tenure system

The people in this district are mostly migrant workers from the three northern regions (Upper East, Upper West and Northern Region). The type of land tenure in this community thus plays a very important role and greatly influences the total land cropped. In communities where land tenure is more flexible, farmers are able to put more land under cultivation than communities where land tenure is very restricted. A survey conducted by Codjoe (2004) revealed that 22% of the farmers are tenant farmers, 14% communal land owners, and 41% family land owners. In the district, 72.1% of the people are mainly farmers (Codjoe, 2004).

3.1.6 Soil sampling and characterization

Before sowing, initial soil sampling was carried out in each of the fields. In the first type of sampling, composite soil samples (5) were taken by driving a soil auger into the soil, and samples were taken at different soil depths (0-15, 15-30, 30-45, 45-60, 60-90 and 90-100 cm) and placed into sampling bags. In the second type of sampling, 3 soil profile pits of 1-m depth were dug at each experimental site for model parameterization. The generic horizons of the profiles and soil types were classified using the FAO guidelines. The profiles were then sampled at the same intervals as in the core sampling method. Samples were air-dried, ground and passed through a 2-mm sieve. The samples were kept in polythene bags for future routine physical and chemical analysis. Initial ammonium and nitrate concentrations were determined for the different profiles by taking soil samples and placing them in an ice box to keep them cool. They were immediately sent to the Soil Research Institute laboratory in Kumasi for analysis.

3.2 Soil chemical analysis

3.2.1 Soil pH

The pH of the soil was determined in a 0.01*M* $CaCl_2$ solution using an 8120 Weicheim, Germany, pH meter and a soil to solution ratio of 1:2.

3.2.2 Soil organic carbon determination

Soil organic carbon (SOC) was determined by a modified Walkley-Black procedure as described by Nelson and Sommers (1982). The organic carbon was oxidized by a known concentration of potassium dichromate (0.166 *M*) solution added in excess. The excess unreacted dichromate was titrated with 0.5 *M* ammonium iron (II) sulphate in a redox reaction using a diphenylamine indicator.

3.2.3 Determination of soil total nitrogen

Soil total nitrogen was determined using the micro Kjeldahl distillation and titration method (Bremner and Mulvaney, 1982). A 1 g soil sample was weighed into a digestion flask, 5 ml concentrated sulphuric acid and few drops of 30 % hydrogen peroxide were added with selenium to serve as catalyst. The entire content was then digested. The use of this method converts organic nitrogen to ammonium sulphate and the resultant solution made alkaline by the addition of 5 ml of 40 % sodium hydroxide and ammonia distilled into 2 % boric acid and titrated with standard hydrochloric acid.

3.2.4 Available phosphorus

The available soil P was determined using a Pye Unicom spectrophotometer at 880 nm wavelength in absorbance after extraction with Bray P-1 extractant and molybdate/ascorbic acid reduction. The Bray P-1 extractant is made up of 0.03 *M* NH_4F and 0.25 *M* HCl (Bray and Kurtz, 1945).

3.2.5 Exchangeable calcium

Exchangeable bases (Ca, Mg, K, and Na) content in the soil were determined in 1.0 *M* ammonium acetate extract (Thomas, 1982).

To determine calcium (Ca), 10 ml of the extract was transferred into an Erlenmeyer flask. A 10-ml potassium hydroxide solution was added after which 1 ml triethanolamine was added. A few drops of potassium cyanide solution and a few crystals of cal-red indicator were added. The mixture was titrated with a 0.02 *M* EDTA (ethylene diamine tetra-acetic acid) solution from a red to a blue end point.

3.2.6 Determination of exchangeable calcium and magnesium

To determine exchangeable Ca and Mg, 10 ml of the extract was transferred to an Erlenmeyer flask and 5 ml of an ammonium chloride-ammonium hydroxide buffer solution was added followed by addition of 1 ml triethanolamine.

A few drops of potassium cyanide and Eriochrome Black T solutions were then added. The mixture was then titrated with 0.02 *M* EDTA solution from a red to a blue end point.

3.2.7 Determination of exchangeable potassium and sodium

Flame photometry method was used to determine potassium (K) and sodium (Na) in the soil extract. To determine K and Na, standard solutions of 0, 2, 4, 6, 8, and 10 ppm K and Na were prepared by diluting appropriate volumes of 100 ppm K and Na in volumetric flask using distilled water. Reading of the flame photometer for the standard solution was done and standard curve constructed. Potassium and sodium concentrations in the soil extract were read from the standard curve.

The calculations were as follows:

$$\text{Exchangeable K (cmol/kg soil)} = \frac{Graph\ reading \cdot 100}{39.1 \cdot w \cdot 10} \quad (3.1)$$

$$\text{Exchangeable Na (cmol/kg soil)} = \frac{Graph\ reading \cdot 100}{23 \cdot w \cdot 10} \quad (3.2)$$

Where: W = weight of air – dried sample soil in grams
39.1 = mole of potassium
23 = mole of sodium

3.2.8 Exchangeable acidity

The titration method was used to determine exchangeable acidity (Al and H) after extracting with a 0.1 *M* KCl (Thomas, 1982).

3.2.9 Effective cation exchange capacity

Effective cation exchange capacity (ECEC) was calculated by the summation of exchangeable acidity and exchangeable basic cations.

3.3 Soil physical analysis

3.3.1 Determination of initial soil water content

Initial soil water content was determined using two methods. The first method was done in-situ using a moisture meter (ML2x with HH2). The second type was done using the gravimetric method.

3.3.2 Bulk density (ℓ_b)

Bulk density was determined using a bulk density ring to take soil samples. Samples were then oven dried at 105 °C for 24 hours, and the dried weight recorded. Bulk density was calculated by dividing the oven-dried soil mass by volume of the cylinder (Landon, 1991) as:

$$\text{bulk density } \ell_b \text{ (g cm}^{-3}) = \frac{M_{2-M_1}}{V} \quad (3.3)$$

Where M_2 = Mass of the core cylinder + oven dried soil
M_1 = Mass of empty core cylinder
V = Volume of core cylinder (πr^2h).

3.3.3 Particle size analysis

The composition of primary soil particles (clay, silt and sand) were determined by their settling rates in an aqueous solution using the hydrometer method. This method is based on the dispersion of soil aggregates using a sodium hexa-meta-phosphate solution and subsequent measurement based on the changes in suspension density (Landon, 1991). The samples were pre-treated with hydrogen peroxide to remove organic matter before shaking with a dispersion agent (sodium hexa-meta-phosphate). The soils were then classified into the different textural classes using a computer program (Gerikis and Baer, 1999).

3.3.4 Determination of Drained Upper Limit

The Drained Upper Limit (DUL) was determined using the method described in APSRU (1999). An area was pounded until Saturated. Plastic sheeting was used to line the bank of the pond to limit lateral water movement. The water was allowed to drain until drainage ceased. Installed access tubes (2 at each pond) in the area were read at 15 cm interval when drainage stopped (48-72 hours). Four core soil samples within each pounded area were also taken and the moisture content determined using the gravimetric method.

3.3.5 Determination of Lower Limit (LL) or plant wilting point

The lower limit was determined using the method given by APSRU (1999). This was done by covering a small plot within the planted area with a rain shelter when the plants were at tasseling stage until the death of the plants from water stress was observed. Soil moisture content was then determined using both gravimetric and volumetric methods at 15 cm intervals. The soil moisture at this point was considered the lower limit of the crop.

3.4 Soil moisture monitory

3.4.1 In-situ soil moisture monitoring using volumetric method

Soil moisture was routinely measured weekly when the plants were one month old until maturity. Due to the large treatment size in the experiment for model evaluation and lack of enough access tubes, some treatments were selected where soil water was monitored throughout the growth of the crop. Access tubes were installed in 10 plots and five treatments (Table 3.1) with two replicates at each site (Ejura farm and Agricultural College).

Table 3. 1: Treatments with access tubes for soil moisture monitory

Treatment Combination	N	P (kg ha^{-1})	K
N1P1(control)	0	0	60
N3P1	80	0	60
N4P1	120	0	60
N3P2	80	30	60
N3P3	80	60	60
N4P3	120	60	60

However for the model parameterization experiments, soil moisture was measured in all plots. A profile probe (PR 1; Delta-T Devices, Cambridge, England) was used to measure the soil moisture. Four sensors were arranged at 10-cm depth intervals down to 40 cm, while a further two were placed at 60 cm and at 100 cm, respectively (Figure 3.8).

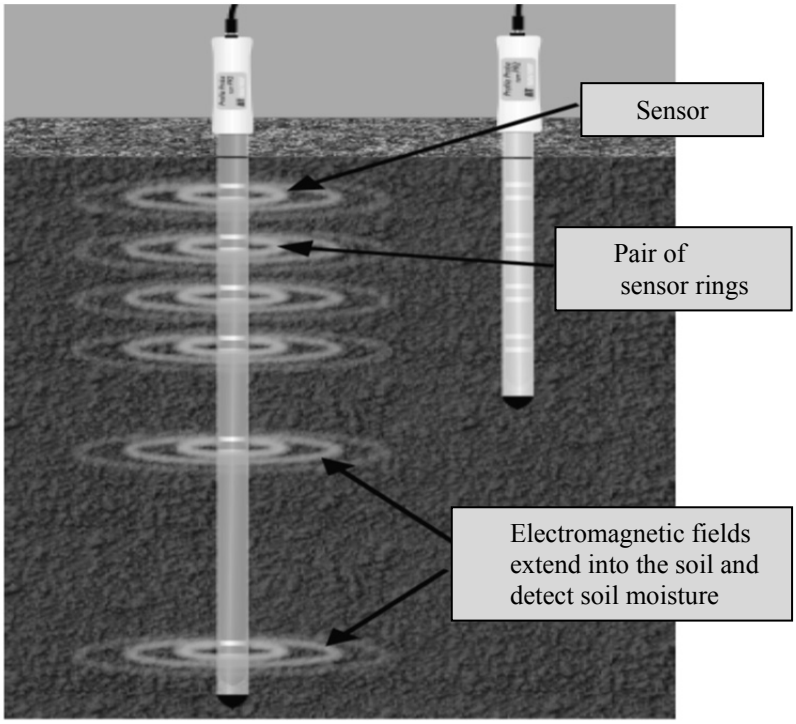


Figure 3. 7: Diagram of soil profile Delta-T showing the sensors. (Source: http://www.delta-t.co.uk/groups, cited on 23 July 2009).

Three readings in each tube were taken by rotating the probe through 120° each time; the three small screw heads were used for this purpose. The calibrated conversion formulae for mineral soils, supplied by the manufacturer, were used to obtain volumetric soil moisture from the millivolt data recorded by the sensors.

3.4.2 Measuring soil water content using gravimetric method

Soil moisture content was measured at the beginning of the experiment, at flowering and at physiological maturity using the gravimetric method. A soil auger was used to take soil samples at 15-cm intervals till 100 cm depth. Each sample was replicated three

times. These were weighed and oven dried at 105 °C. The gravimetric water content (θm) was converted to volumetric water content (θv) as

$$\left(\frac{Mw-Ms}{Ms}\cdot 100\right)\cdot \mathrm{BD} \qquad (3.4)$$

Where: Mw = mass of wet soil, Ms = mass of dry soil, BD = bulk density

3.5 Land preparation

The Euro farm site had a one year fallow with cultivation of cowpea during the previous year of the establishment of the experiment. Continuous cultivation of maize for the past 6 years was done at the Agricultural College site before the establishment of the experiments. The land was prepared by spraying the fields with Glyph sate (Round-up) at 1.5 kg air. (active ingredient) ha^{-1} two weeks before ploughing to kill the weeds. The fields were ploughed using a disc plough and harrowed to level them. The fields were then laid out by pegging to obtain the required plot sizes and spaces between plots. Two days after sowing, pre-emergence chemical weed control consisting of a combination of Pendimethalin and Atrazine at 1.5 kg a.i.ha^{-1} and 1.0 kg a.i. ha^{-1}, respectively, were sprayed.

3.6 Experiment for model parameterization

To parameterize the APSIM crop model for the study area, experimental plots of 6 m x 5 m (30 m^2) were established for two seasons (April – August and August – November, 2008) and two maize cultivars (Obatanpa and Dorke) with 120 kg N ha^{-1} in the form of ammonium sulphate, and 60 kg P ha^{-1} in the form of triple super phosphate (P_2O_5) laid out in a randomized complete block design (RCBD) with three replicates. Supplementary watering of about 14 mm was done using watering cans when necessary to prevent water stress. Thus optimum conditions were provided for plant growth. Row spacing was 75 cm between rows (inter-row) and 40 cm within rows (intra-row). Seeds were sown at a depth of about 5 cm. The plots were separated from each other by a distance of 2 m to prevent cross contamination of treatments between plots.

3.7 Field experimental layout and treatment for model evaluation

To evaluate the model, field experiments were conducted using two maize cultivars (Obatanpa and Dorke) at Ejura during the major and minor season in 2008. Site selection was carried out based on differences in soil fertility and organic matter levels. Twelve different application rates of inorganic fertilizer (Table 3.2) were used as treatments in a randomized complete block design (RCBD) with three replicates in each experiment. During the major season, the soil type used for the experiments was Haplic Lixisol. However during the minor season one experiment (Agricultural College site) was established on a Pisoplinthic Lixisol and the other (Ejura farm site by to the major season plots) on a Haplic Lixisol.

An equal amount of K was applied in all treatments, with four levels of N and three levels of P (Table 3.2). The source of N, P and K were ammonium sulphate, triple super phosphate (P_2O_5) and muriate of potash (K_2O), respectively. Plot size, seeding depth and row spacing were the same as in the experiment for model parameterization.

Table 3. 2: Experimental treatments with different fertilizer levels

Treatment combination	N	P (kg ha^{-1})	K
N1P1(control)	0	0	60
N2P1	40	0	60
N3P1	80	0	60
N4P1	120	0	60
N1P2	0	30	60
N2P2	40	30	60
N3P2	80	30	60
N4P2	120	30	60
N1P3	0	60	60
N2P3	40	60	60
N4P3	80	60	60
N4P3	120	60	60

3.8 Fertilizer application

The full rate of P and K with 50 % of the N rate were applied at 10 days after sowing (DAS) in the respective plots. The fertilizers were applied using the band placement method, spaced 5 cm from each plant. The other 50 % of the N fertilizer was applied at 45 DAS as practiced by the farmers. Farmers apply full rate of P and K fertilizer with

50 % rate of N 10 – 14 days after sowing and top-dress of the other 50 % N at 45 days after sowing. Weeding was regularly done to keep the fields free of weeds.

3.9 Test crop

The test crop in the experiment was maize (*Zea mays* L.). Two cultivars of maize (Obatanpa and Dorke), which are known to be medium- and early-maturity cultivars, respectively, were obtained from the Crop Research Institute in Fumesua near Kumasi and sown during the major and minor season in 2008. Dorke is known to be more drought tolerant than Obatanpa.

3.10 Field measurement of crop parameters

Measurements taken in the course of the experiment included time series biomass sampling, LAI and soil moisture measurement. At maturity, yield and yield components were determined.

3.10.1 Date of emergence of plants

Date of emergence was determined by marking and observing three rows of 3-m length in randomly selected plots. The emerged seedlings were counted at 2-day intervals until emergence ceased (at least 50 %).

3.10.2 Date of flag leaf

Two rows after the border row from each side of each plot were selected and tagged. Plants in these rows were observed and date of flag leaf appearance was recorded**.**

3.10.3 Days to 50 % tassel

For this observation, plants from the tagged rows were observed and the date of 50 % tasseling noted. The average number of days taken to 50 % tasseling was calculated from the date of sowing.

3.10.4 Days to 50 % silking

The same tagged rows in each plot were kept under observation, and the number of days to 50 % silking and average days to silking were calculated from the date of sowing.

3.10.5 Days to physiological maturity

Plants from the tagged rows were observed and the days to physiological maturity were recorded.

For model parameterization, thermal time (growing degree days) was calculated according to Gallagher *et al.* (1983). Thermal time (Tt) is calculated as a function of mean temperature above a base temperature (Tb).

$$Tt = \frac{\sum Tmax + Tmin}{2} - Tb \qquad (3.5)$$

where Tb is base temperature taken as 8 °C for maize

3.10.6 Leaf area index

Measurements of leaf area index (LAI) were made nondestructively with a canopy analyzer (LAI-Sun scan) in the center of each plot (three measurements were averaged to give one LAI value per plot) at 2-week intervals in both seasons. Crop management was similar in both seasons, and measurements were taken between 7:00 am and 12:30 pm each day of measurement.

3.10.7 Sampling of plant biomass

Time series sampling of plant biomass was carried out for each treatment by random sampling of 6 plants from each plot (the central portion of each plot was reserved for final harvest) at 34 and 55 days after sowing (DAS) during both seasons. Border plants were not included in the sampling. Plants were cut at ground level, kept in sampling bag and weighed. Samples were oven dried at 70 °C for 48 hours, weighed, ground and analyzed for N and P.

3.11 Grain yield and yield components

At harvest, a 3 m x 3 m area was harvested in all plots for determination of potential grain yield and total aboveground biomass of maize, and the yields calculated in gram per square meter. Plants were harvested at physiological maturity, cobs separated from

the stalk, and fresh weight of both parts recorded. Six plants (stover) representative of each plot were sub-sampled, weighed and oven dried at 70 °C until constant weight and the weight recorded. Six randomly selected cobs representative of the yield were taken, weighed, dried and shelled.

The shelling percentage was calculated as the weight of maize grain (mg) divided by the weight of the cob (mc) and expressed as percentage: A sample of thousand grains was randomly taken from each plot and the weight recorded. Sub-samples of both grain and stover were ground and sent to the laboratory for chemical analysis for N and P uptake as described above.

The apparent nitrogen recovery (ANR) was calculated as:

$$\% \text{ N recovery} = \frac{N\ uptake_{\ fert} - N\ uptake_{\ control}}{N\ fertilzer\ applied} \cdot 100 \qquad (3.6)$$

The harvest index (HI) was calculated as the ratio of grain yield to total biomass, and expressed in percentage.

3.12 Chemical analysis of plant samples

The dried maize shoot samples and grain in all experiments were ground and analyzed for total N and P as follows:

3.12.1 Plant total nitrogen

To determine the total N in plants, ground samples were digested with a mixture of concentrated H_2SO_4, selenium powder, potassium sulphate and hydrogen peroxide using a micro Kjeldahl digestion system (Anderson and Ingram, 1996). The solution was then distilled and titrated with standard 0.02 *M* hydrochloric acid. The total N content and the total biomass dry weight were used to calculate the total N uptake.

3.12.2 Determination of total phosphorus

Total P in plant was determined using the wet digestion procedure as described for total N. After the digestion, the molybdate/ascorbic acid colorimetric method was employed

to determine total P concentration. The total P content and the total biomass dry weight were used to calculate total P uptake.

3.13 Statistical analysis

The general linear model (GLM) analysis of variance (ANOVA) was used to compare yield, stover and total biomass data from the different treatments and also between the varieties using SPSS version 17. The Tukey test for pairwise comparison of means was used to identify significant differences.

3.14 APSIM crop simulation model overview

Crop simulation models are state-of the-art technology that enables users or researchers to estimate the growth, development and yield of crops using management strategies and environmental factors as input parameters (Mavromatis et al., 2001). A framework is provided by the model that uses a range of component modules. These modules, which are plugged into one main model (e.g., APSIM, CropSyst, CERES and DSSAT) engine, can be managerial or biological, environmental and economic (Jones et al., 2001; Keating et al., 2003). The models are built such that they use in-built algorithms that express the correlation between plant growth processes (transpiration, photosynthesis, physiological development, biomass growth and partitioning, and nutrient and water uptake) and environmental driving forces (e.g., daily temperature, photoperiod and available soil water). In the APSIM model, there is integration of cultivar-specific genetic coefficients which estimate growth and development on daily basis and response of plants to environmental factors such as weather, soil and management practices (Boote et al., 1998). The Maize module has 11 crop stages and 9 phases (time between stages). Commencement of each stage is determined by accumulation of thermal time except during the sowing to germination period which is driven by soil moisture. The phase between emergence and floral initiation is composed of a cultivar-specific period of fixed thermal time, commonly called the basic vegetative or juvenile phase. Between the end of the juvenile phase and floral initiation the thermal development rate is sensitive if the cultivar is photoperiod sensitive (for further details see the documentation of APSIM Maize under http://www.apsim.info/Wiki/Maize.ashx.

Crop simulation models have the ability to simulate yields of a range of crops in response to nutrients and crop rotation sequence. For example, they have been used in Zimbabwe and Kenya to simulate the effect of P on maize and bean production and N use efficiency (Whitbread et al., 2004; Delve et al., 2009), climate forecast applications (Meinke et al., 1996; Chen et al., 2010), simulating water and nutrient dynamics in fallows systems (Probert et al., 1998; Asseng et al., 2000) on a short- and long-term basis, thereby providing insights into the impact of management strategies on the productivity due to soil fertility losses and erosion (Malone et al., 2007).

A flexible working environment is provided by the APSIM model which enables users to choose from a set of modules from a suite of crop, soil and utility modules to configure specific model (Table 3.3). The strengths (crop yield in relation to management factors) and weaknesses (system aspect of cropping) of earlier models such as CERES, GRO (Godwin and Singh, 1998; Ritchie et al., 1998) and DSSAT were considered in the building of the APSIM model. The model relied on other models such as CENTURY (Parton et al., 1987), EPIC (Williams, 1983) and NTRM (Shaffer et al., 1983), for long-term dynamics of soil resources while recognizing the limited sensitivity of their generic crop models to weather input (Steiner et al., 1987).

Table 3. 3: Major modules in APSIM

Module type	Module name
Biological	Maize, cowpea, chickpea, mungbean, soyabean, peanut, navybean, fababean, stylo pasture, lucerne, cotton (OzCot)[a], native pasture (GRASP), hemp, pigeonpea[b], FOREST[c]
Environmental	soilN, soilP, soilWat, solutes, soil pH, manure[b], residue, erosion, SWIM[c]
Management	manager, fertilizer, irrigate, accumulate, operations, canopy, micromet, clock, report, input, met (weather)

[a] *In association with CSIRO Plant Industry*
[b] *In association with ICRISAT*
[c] *In association with CSIRO Land and Water*
Source: Adapted from Jones et al., 2001

The important modules in APSIM are the soilP, soilN, and soilWAT modules. The SoilP module describes the availability of P in the soil in terms of labile P pool and fluxes into and out of this pool. SoilN deals with the dynamics and transformation of both carbon (C) and N on layer basis in the soil. Soil organic C is differentiated in two

pools, “biom” the more labile and “hum” the less labile form. Flows between pools are calculated in terms of C, while the corresponding N is determined by the CN ratio of the receiving pool. The water balance and solute movements within APSIM model is handled by the soil WAT. It is a cascading layer model, which owes much of its precursors to CERES and PERFECT (Littleboy et al., 1992) as well as to the algorithms for redistributing water within the soil profile. It simulates on a daily time basis and water characteristics specified in terms of wilting point, (LL), drained upper limit (DUL) and saturated (SAT) volumetric water contents of each soil layer. Processes adopted from PERFECT include the influence of crop residues and crop cover on runoff and potential evaporation. The motivating factor for the incorporation of a P routine in crop modules was as a result of many soils on which subsistence crops grown are deficient in both N and P, with potential sources of N and P being manure and compost. For models to be useful in these environments, the supply of both N and P is crucial. A routine was therefore incorporated into the crop modules that limit growth and development of crop under P-limiting conditions with a soilP module specifying P supply from the soil. A detail of the module is reported in Keating et al., (2003).

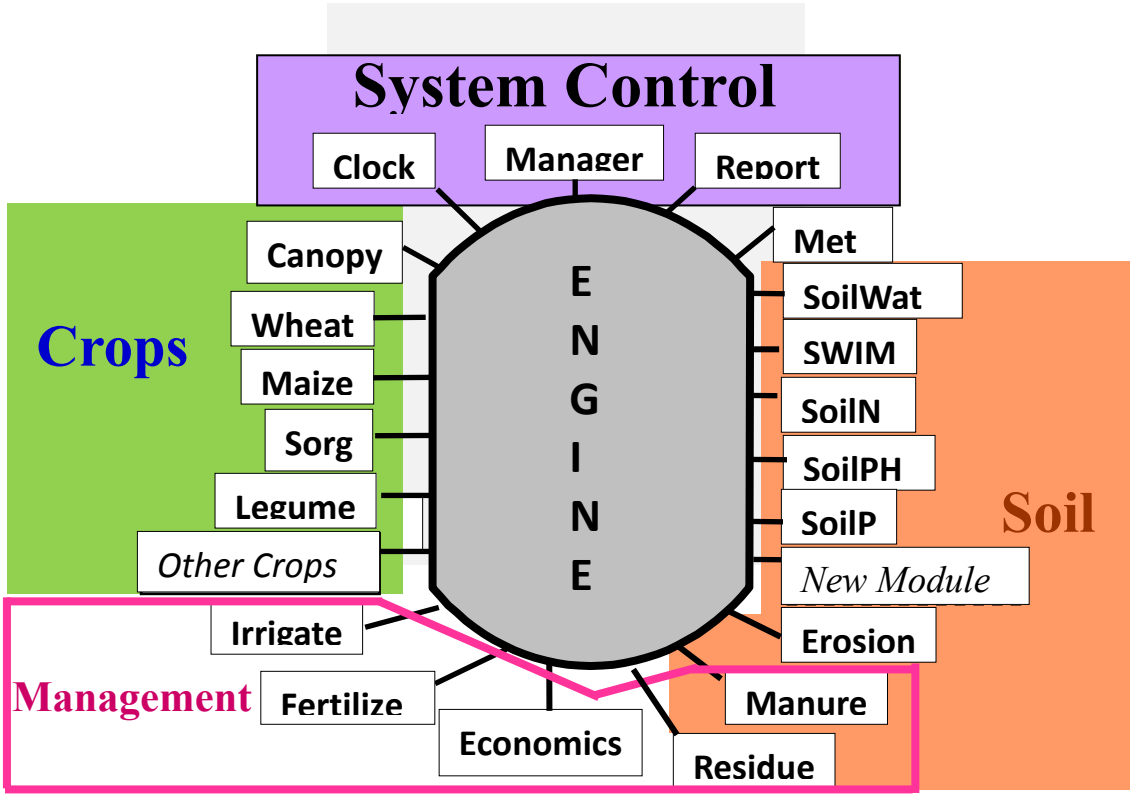


Figure 3. 8: APSIM framework (after APSRU 2010 cited on 23 January, 2010).

3.15 Model parameterization

Generally, crop simulation models need some form of parameterization before they can be used in an area other than where they were originally made, especially when the model is to be used to predict future climate change scenarios. Model parameterization involves modifying sensitive input parameters, within an acceptable range in an attempt to match model output to measured data based on a predefined objective function.

In this study, the crop (APSIM-Maize), soilN2 (soil nitrogen), soilP (soil phos phorus), and soilWat (soil water), modules were linked with APSIM 6.1 for the simulations. The manager and weather (met) modules were also included. Crop management module information such as date to sow and date and amount of fertilizer applied is dealt with in the manager module. Daily weather data (rainfall amount, minimum and maximum temperature and solar radiation) for the study area was used in the met module for both model parameterization and evaluation. The daily weather data is a vital input parameter as all processes are driven by its variables.

To simulate crop yield for phenology, biomass and grain yield, the model was first parameterized by using two sets of data for two maize cultivars collected during field experimentation in the major and minor seasons 2008 under optimum conditions (120 kg N ha^{-1} and 60 kg P ha^{-1}). The growth and yield data were used as input parameters to parameterize the maize module. Thermal time accumulations were derived using the algorithm described in Jones and Kiniry (1986) with observed phenology and weather data. Each set of data was used to estimate the genetic coefficient related to thermal time accumulations for the critical growth stages.

The maize cultivars used in the experiment had not been previously modeled with APSIM. As a short- (Dorke) and medium-season duration cultivar (Obatanpa), the parameter set selected was SC709, a late-maturing hybrid from Zimbabwe for Obatanpa and hybrid 511 from Kenya for Dorke. To improve the fit of the maturity date and yield simulated by the model with known harvest dates and yield of Obatanpa cultivar, the only change made to the parameter file for the cultivar was to increase the thermal time between flowering stage and maturity (tt_flower_to_maturity) from 760 to 830. In addition, the maximum head grain number (head_grain_no_max) was reduced from 600 to 520, and the grain growth rate (grain_gth_rate) from 9 to 8. For the second cultivar (Dorke), no change was made to adjust the date of maturity. The

only change made was a reduction of the head grain maximum number (head_grain_no_max) from 450 to 420 and of the grain growth rate (grain_gth_rate) from 10.5 to 8. With the use of the soil data, management data and weather data, APSIM model was run and predicted tasseling date, biomass and yield which were compared to measured values.

Table 3. 3: Genetic coefficients used for modeling maize in APSIM

Coefficient	Definition
tt_emerg_to_endjuv	Thermal time accumulation from seedling emergence to end of juvenile phase (°C days)
Photo_crit 1	Critical photoperiod 1
Photo_crit 2	Critical photoperiod 2
Photo_slope	Extent to which growth is affected by photoperiod increase beyond photo_crit 1 and 2
tt_flower_to_maturity	Thermal time accumulation from flowering to maturity (°C days)
tt_flag_to_flower	Thermal time accumulation from flag stage to flowering (°C days)
tt_flower_to_start_grain	Thermal time accumulation from flowering to start grain filling (°C days)

3.16 Sensitivity analysis

Sensitivity analysis is done on a model to determine how sensitive the output of the model is to changes in the input parameters in order to understand the behavior of the model. If a small change in an input parameter results in relatively large changes in the output, then the outputs are said to be sensitive to that parameter. This implies that the particular parameter concerned has to be determined more accurately. Models in general have several parameters, and the user has to parameterize the model by adjusting the parameter based on certain criteria to obtain a best fit between the model output and measured data. Knowing the input parameters (N and P in this study) that are sensitive to the model output, the focus was on these parameters during the parameterization process, hence saving time. Sensitivity analysis helps the user to determine, in order of priority, the parameters that show the highest contribution to the output variability (Lenhart et al., 2002).

3.17 Model evaluation

To evaluate the APSIM model, data from the experiments for model evaluation for both major and minor seasons were used. The treatments comprised of four levels of N application (0, 40, 80 and 120 kg ha^{-1}) in the form of ammonium sulphate, and three levels of P (0, 30 and 60 kg ha^{-1}) in the form of triple super phosphate given a total of twelve treatments combination. An equal amount of K was applied to all treatments in the form of muriate of potash (K_2O). The model was run for two sites for each season. During the major season, the soil type used in running the model was Haplic Lixisol. However during the minor season a Pisoplinthic Lixisol was used to run the model for one site and a Haplic Lixisol for the other site. For easy identification of the sites, the Ejura farm location for the major season experiment is referred to as Expt. 1, the Agricultural College major season site as Expt. 2, the Ejura farm and Agricultural College minor season sites as Expt. 3 and 4, respectively.

Sowing density was 6.7 plants m^{-2} and sowing done on 21 and 24 April 2008 during the major season for Expt. 2 and 1, respectively. In the minor season, sowing occurred on August 9 and 10 for Expt. 3 and 4, respectively. During the model evaluation process, measured data on the date of emergence, date to tasseling, maturity date, grain yield, total DM, harvest index, grain N uptake, total N uptake, total P uptake, and soil moisture were compared with simulated values.

Table 3. 4: Haplic Lixisol properties used for APSIM model evaluation in Experiment 1 and 3 in Ejura, Ghana.

Soil depth	1	2	3	4	5	6	7	8	9
Soil water parameters									
Layer thickness (mm)	150	150	150	150	150	150	150	150	150
BD (g cm^{-3})	1.50	1.55	1.54	1.54	1.44	1.50	1.40	1.40	1.40
SAT [cm cm^{-1}]	0.401	0.388	0.387	0.394	0.398	0.409	0.457	0.457	0.461
DUL [cm cm^{-1}]	0.180	0.145	0.145	0.175	0.237	0.232	0.233	0.238	0.278
Soil C parameters									
Organic C (%)	1.1	0.68	0.51	0.46	0.42	0.38	0.28	0.28	0.28
finert[a]	0.30	0.50	0.60	0.75	0.90	0.99	0.99	0.99	0.99
fbiom[b]	0.035	0.025	0.015	0.01	0.01	0.01	0.01	0.01	0.01
Soil P parameters									
Labile P (mg/kg)	12.7	6.5	3.4	2.0	1.7	1.5	0.9	0.9	0.9
P sorption[c] (mg/kg)	50	125	150	200	200	200	200	200	200

1, 2, 3, ...9: Soil depth at 150 mm interval, BD, bulk density; SAT, volumetric water content at saturation; DUL, drained upper limit.

[a] *Finert defines the proportion of the soil organic matter that is not susceptible to decomposition; Fbiom*

[b] *is the proportion of the decomposable soil organic matter that is initially present in the more rapidly decomposing pool. Sorption*

[c] *is the P sorbed at a concentration in solution of 0.2 mg l^{-1}*

Table 3. 5: Haplic Lixisol properties used for APSIM model evaluation in Experiment 2 in Ejura, Ghana.

Soil layer	1	2	3	4	5	6	7	8	9
Soil water parameters									
Layer thickness (mm)	150	150	150	150	150	150	150	150	150
BD (g cm^{-3})	1.63	1.61	1.63	1.64	1.54	1.50	1.45	1.45	1.45
SAT [cm cm^{-1}]	0.365	0.368	0.350	0.358	0.394	0.409	0.457	0.457	0.457
DUL [cm cm^{-1}]	0.147	0.145	0.145	0.175	0.237	0.232	0.233	0.233	0.233
Soil–C parameters									
Organic C (%)	0.58	0.55	0.51	0.46	0.42	0.38	0.34	0.34	0.34
finert[a]	0.30	0.50	0.60	0.75	0.90	0.99	0.99	0.99	0.99
fbiom[b]	0.035	0.025	0.015	0.01	0.01	0.01	0.01	0.01	0.01
Soil P parameters									
Labile P (mg kg^{-1})	9.4	4.8	2.3	1.8	1.4	1.1	1.0	1.0	1.0
P sorption[c] (mg kg^{-1})	50	150	200	200	200	200	200	200	200

Table 3. 6 Plinthosol properties used for APSIM model evaluation in Experiment 4 in Ejura, Ghana.

Soil layer	1	2	3	4	5	6	7	8	9
Soil water parameters									
Layer thickness (mm)	150	150	150	150	150	150	150	150	150
BD (g cm^{-3})	1.57	1.55	1.58	1.56	1.56	1.66	1.73	1.73	1.73
SAT [cm cm^{-1}]	0.384	0.392	0.381	0.389	0.266	0.254	0.232	0.232	0.232
DUL [cm cm^{-1}]	0.130	0.133	0.42	0.150	0.067	0.065	0.051	0.051	0.051
Soil–C parameters									
Organic C (%)	0.55	0.53	0.40	0.40	0.35	0.04	0.04	0.04	0.04
finert[a]	0.30	0.50	0.60	0.75	0.90	0.99	0.99	0.99	0.99
fbiom[b]	0.035	0.025	0.015	0.01	0.01	0.01	0.01	0.01	0.01
Soil P parameters									
Labile P (mg kg^{-1})	9.1	5.5	4.5	3.4	1.4	1.1	1.0	1.0	1.0
P sorption[c] (mg kg^{-1})	75	150	400	400	400	400	400	400	400

BD: Bulk density; SAT: volumetric water content at saturation; DUL: drained upper limit;

[a] *Finert defines the proportion of the soil organic matter that is not susceptible to decomposition; Fbiom*
[b] *is the proportion of the decomposable soil organic matter that is initially present in the more rapidly decomposing pool.*
[c] *Sorption is the P sorbed at a concentration in solution of 0.2 mg l^{-1}*

3.18 Evaluation of model performance

Statistical methods were used for assessing the performance of the crop simulation model in comparison with the observed/field measured data. The closeness of the relationships between observed (O) and simulated (P) crop yields was estimated using:

1. The coefficient of determination, (R^2), which can be interpreted as the proportion of the variance in the observed data that is attributable to the variance in the simulated data.
2. Root mean square error (RMSE)

$$\text{RMSE} = [n^{-1} \sum (yield_{sim} - yield_{meas})^2]^{0.5} \tag{3.7}$$

Where: n is the number of replications of each planting date experiment, sim and meas denote simulation and measured yield, total biomass or any parameter compared for each replicate.

3. The median unbiased absolute percentage error, MdUAPE (%), calculated as

$$\text{MdUAPE} = 100 \cdot \text{Median}\left[\frac{|Simulated_i - Observed_i|}{0.5(Observed_i - Simulated_i)}\right] \tag{3.8}$$

4. The modified coefficient of efficiency, E_1, calculated as

$$E_1 = 1 - \frac{\sum_{i=1}^{n} |Observed_i - Simulated_i|}{\sum_{i=i}^{n} |Observed_i - Mean_{obs}|} \tag{3.9}$$

Where: $E_1 = 1$ describes a perfect fit of observed and simulated data, whilst $E_1 = 0$ indicates that the simulated data describe the observations as well as the average of the observed data.

3.19 Climate change scenarios of MM5/ECHAM4

To assess the impact of climate change on maize production in this study, climate data (future) simulated with General Circulation Model (GCM) ECHAM4 and downscaled using the regional climate model MM5 (Mesoscale Model) were used. The MM5 climate data was obtained from ALUCCSA (Adaptation of land use to climate change

in Sub-Sahara Africa) project of Georg-August University in Göttingen in collaboration with the Institute for Meteorology and Climate Research, Atmospheric Environmental Research (IMK-IFU), Garmisch, Germany. Pennsylvania State University in cooperation with the National Center for Atmospheric Research, USA, is source of the MM5 model, which is a community mesoscale model. According to Grell et al. (1995), MM5 is a non-hydrostatic or hydrostatic (Version 2 only), terrain-following sigma-coordinate model designed with initial and lateral boundary conditions to simulate or predict mesoscale and regional-scale atmospheric circulation.

The ALUCCSA project runs for MM5 used initial and lateral boundary conditions derived from ECHAM4, and run for the years 2001-2050 using A1B and B1 future climate scenarios. A1B foresees a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, with a rapid introduction of new and more efficient technologies without relying too heavily on one particular source of energy.

The B1 storyline sees a convergent world with the same global population that peaks in mid-century and declines thereafter, as in the A1 scenario, but with a rapid change in economic structures toward a service and information economy, with reductions in material intensity and the introduction of clean and resource-efficient technologies. The emphasis is on global solutions for economic, social and environmental sustainability, including improved equity, but without additional climate initiatives.

The ALUCCSA simulation was based on the parameterization done by the GLOWA-Volta project using IS92a scenarios (Jung, 2006) and 0.5^{o} x 0.5^{o} gridded monthly observational dataset from the East Anglia Climate Research Unit (CRU), UK. For the parameterization, the effects of sulphate aerosols were not considered, as they are considered the largest source of errors within the IS92a scenario.

In the GLOWA Volta project, two time slices of 10 years each (1991-2000 and 2030-2039) with ECHAM4 for the West African region were simulated and downscaled with the MM5 for the Volta Basin. The MM5 was parameterized with long-term observed mean climate data. Details of the ECHAM4 and MM5 setup and simulations can be obtained from Jung (2006) and Kunstmann and Jung (2003).

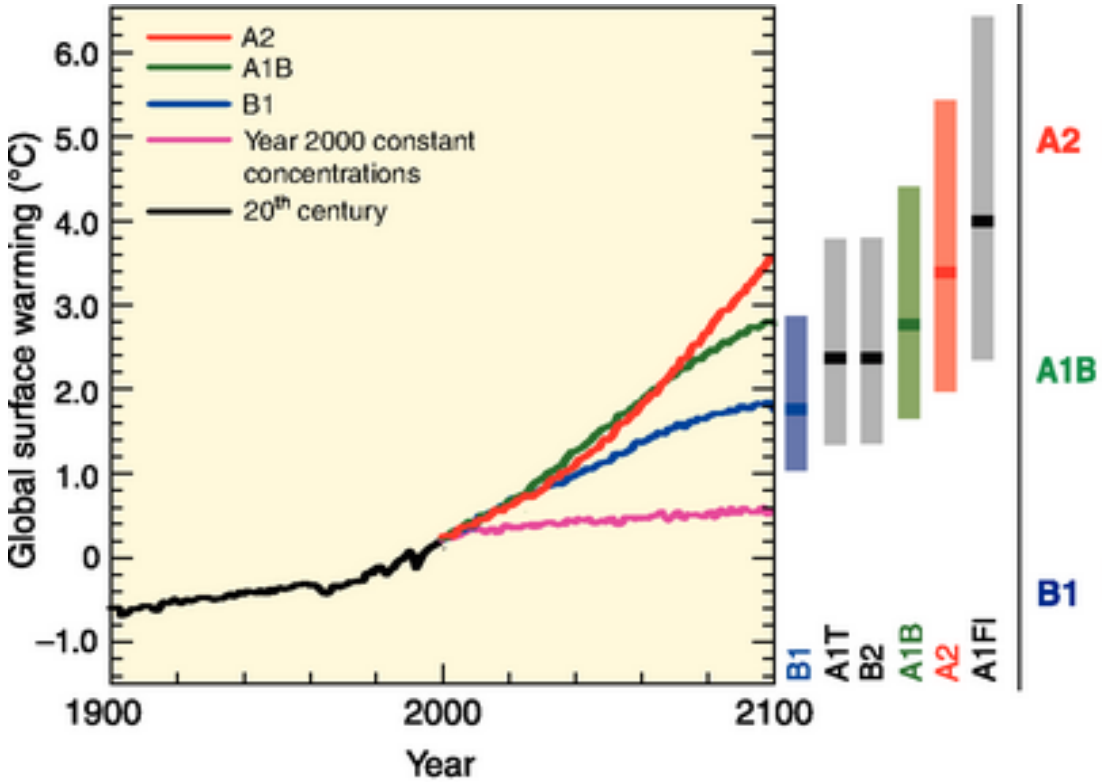


Figure 3. 9: Multi-model global averages of surface warming (relative to 1980-1999) for the SRES scenarios A2, A1B and B1, shown as continuations of the 20th century simulations. The orange line is for the experiment where concentrations were held constant at year 2000 values. The bars in the middle of the figure indicate the best estimate (solid line within each bar) and the likely range assessed for the six SRES marker scenarios at 2090-2099 relative to 1980-1999. (Source: IPCC synthesis report 2007)

Source: http://www.ipcc.ch/publications_and_data/ar4/syr/en/figure-3-2.html

Results of the GLOWA-Volta climate studies show good agreement in mean annual, monthly and seasonal temperatures between ECHAM4-simulated climate and the CRU dataset for the period 1961-1990. There was, however, a slight overestimation of temperature by ECHAM4 for the Sahara region in the wet season and for southern West Africa in the dry season. For the same period, ECHAM4 rainfall amounts are comparable to the CRU data, but the maximum values are generally low (Jung, 2006).

A perfect agreement was obtained between the MM5 simulated mean monthly temperatures and the observed. However, the model underestimated temperatures in the dry season nearly everywhere in the Volta Basin. The correlation obtained between MM5 simulated mean monthly rainfall and the observed was much weaker compared to

that of temperature. There was a strong underestimation of rainfall (up to 80 %) along the coast and an overestimation in the Sahel zone (10-30 %) (Jung, 2006).

A comparison of MM5- and ECHAM4-simulated temperature and rainfall revealed a pronounced positive deviation in the MM5 temperature values from those of ECHAM4, but the change in temperature between the present and future time slices was found to be nearly the same for both models (Jung, 2006).

To assess the reliability of the MM5 data for the future climate scenarios for analysis of impacts of climate change on resources in the Volta Basin, the MM5 simulated mean monthly rainfall for the present time slice (1991-2000) were compared with the results of 30-year (1971-2000) mean monthly observed rainfall within the basin (Figure 3.10).

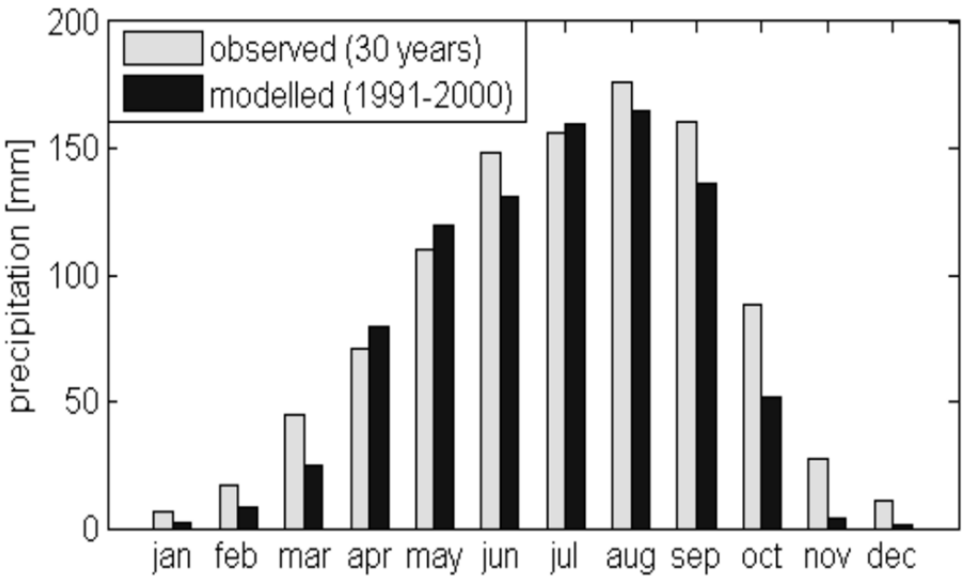


Figure 3. 10: MM5-simulated mean monthly precipitation versus long-term observed mean monthly rainfall in the Volta Basin (Jung, 2006).

A fairly good agreement was observed between MM5 simulated data (1991-2000) and the observed (1971-2000) for mean monthly rainfall (Figure 3.10). Over the Volta Basin, the MM5 gave an overall increase of 44.7 mm (5.1 %) in mean annual rainfall between the two time slices and a mean temperature increase of 1.2 °C (Jung, 2006). However, under the A1B scenario, the average temperature is predicted to increase by 1.6 °C in Ejura and rainfall to decrease by about 19% by the year 2050.

3.20 Scenarios used in assessing impact of climate change on maize

To assess the impact of climate change and variability on maize yield, three scenarios were considered during the simulation. These were (i) Maize-maize bimodal simulation (simulation of maize during major and minor seasons) for 21 years, (ii) Maize-cowpea simulation (maize during major season and cowpea during minor season), and (iii) maize-fallow rotation (maize during major season and fallow during minor season). The sowing window used was 15 March to 10 May and sowing at 50 mm soil depth. Apart from the maize-maize simulation where both seasons and both varieties were simulated, all other scenario considered only Obatanpa and major season yield.

3.21 Socio-economic Survey

A social survey was conducted to ascertain the farmers' awareness of climate change and variability and the possible adaptation strategies taken to mitigate the impacts. To achieve this, structured and semi-structured questionnaires were designed and administered. The survey was carried out between February and October 2009 using quantitative (to assess trends and patterns in the individual's behavior) and qualitative (to understand the reasons of the individual) methods. A total of 180 farmer households were randomly sampled from 4 farming communities (Ejura town, Teacherkrom, Aframso and Dromankuma) in the Sekyedumase District of the Ashanti region of Ghana.

A meeting was first arranged with extension officers in the villages to inform them about the survey, and solicit their assistance in organizing the farmers in order to administer the questionnaire. Before the questionnaire (Appendix 1) was administered, a pre-test was carried out with adjustments made to improve unclear questions and incorporate additional important factors. In the first pre-test, the author was assisted by two extension officer trainees from the Ejura Agricultural College, while the actual survey was carried out with the assistance of 8 extension officers and extension trainees. The survey collected a wide range of information including the socio-economic situation of the farmers. Structured and unstructured questionnaires were used to interview farmers asking whether they had noticed long-term changes in mean temperature, mean rainfall, and vegetation cover over the past 20 years. Questions about adaptation and the constraints to adaptation were also posed.

For selecting important socio-economic factors that contribute to increased agricultural activities in Ghana and in particular in the Sekyedumase district, different literature sources were consulted (DFID, 2001; Drechsel and Zimmerman, 2005; Kelly, 2006; Oduro and Osei-Akoto, 2008). Livelihood assets, for example, describe categories of a property that a farmer has that determine his livelihood and influence his living standard (DFID, 2001).

Three broad categories were used to assess factors that contribute to the farmers' perception and adaptation to climate change. These include:

1. Access to services, i.e., markets and agricultural extension assistance
2. Household characteristics, e.g., gender, education,
3. Household assets, i.e., income, housing type, etc.

Regression analysis with the logit model was employed due to the nature of the decision variable, i.e., whether climate change is perceived or not and whether adaptation is practiced or otherwise. For such a dichotomous outcome, the logit model is the most appropriate. The logistic model considers the relationship between a binary dependent variable and a set of independent variables, whether binary or continuous. The logistic model for '*k*' independent variables ($x_i, x_2, x_3 \ldots, x_k$) is given by

$$Logit\, P(x) = \alpha + \sum_{i=1}^{k} \beta_i x_i \qquad (3.10)$$

Where Exp(β_i) indicates the odds ratio for a person having characteristics *i* versus not having *i*, while β_i is the regression coefficient, and α is a constant.

4 RESULTS

4.1 Initial soil properties

The results of chemical and physical analyses of the soil at the experimental sites in 2008 are presented in Tables 4.1-4.3. The soil used in Ejura farms for both experiments were the same. Table 4.1 presents the average of soil analysis in the two seasons.

Table 4. 1: Characteristics of Haplic Lixisol at Ejura farm in 2008 wet season.

Soil depth (cm)	0-15	15-30	30-45	45-60	60-75	75-90	90-100
Soil parameters							
Total N (mg g^{-1})	0.13	0.08	0.03	0.04	0.03	0.02	0.03
Available P (mg kg^{-1})	12.70	6.54	3.43	2.04	1.72	1.5	0.91
Available K (mg kg^{-1})	180	130	100	120	94	84	73
pH	5.05	5.61	5.71	5.78	5.86	6.03	6.12
Ca (cmol (+) kg^{-1})	4.2	5.0	4.3	3.9	3.8	3.7	3.7
Mg (cmol (+) kg^{-1})	1.8	1.6	1.4	1.4	1.6	1.9	1.2
ECEC (cmol (+) kg^{-1})	6.5	8.2	5.3	5.7	6.3	6.6	6.1
K (cmol (+) kg^{-1})	0.3	0.4	0.3	0.3	0.3	0.3	0.2
Organic C (%)	1.1	0.7	0.5	0.5	0.4	0.4	0.3
BS (%)	96.4	98.4	97.6	97.7	98.3	98.4	98.4
Bulk density (g cm^{-3})	1.50	1.55	1.54	1.54	1.44	1.50	1.40
Sand (%)	62.7	60.5	59.8	45.9	34.1	29.5	29.4
Silt (%)	33.2	33.4	33.1	37.5	38.8	42.5	41.5
Clay (%)	4.1	6.1	7.1	16.6	27.1	27.1	29.1

Table 4. 2: Characteristics of Haplic Lixisol at Agricultural College in Ejura during the major season, 2008.

Soil depth (cm)	0-15	15-30	30-45	45-60	60-75	75-90	90-100
Soil parameters							
Total N (mg g^{-1})	0.03	0.03	0.02	0.02	0.02	0.02	0.03
Available P (mg kg^{-1})	9.4	4.8	2.3	1.8	1.4	1.1	1.1
Available K (mg kg^{-1})	85	85	85	89	107	101	132
pH	4.75	4.73	4.71	4.76	4.22	4.07	4.07
Ca (cmol (+) kg^{-1})	0.5	0.7	0.7	1.1	2.0	1.9	2.1
Mg (cmol (+) kg^{-1})	0.3	0.3	0.3	0.9	1.2	1.1	0.8
ECEC (cmol (+) kg^{-1})	1.7	2.0	1.6	2.7	4.3	4.3	4.3
K (cmol (+) kg^{-1})	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Organic C (%)	0.58	0.55	0.51	0.46	0.42	0.38	0.34
BS (%)	59.9	54.4	59.9	89.1	70.3	70.9	70.4
Bulk density (g cm^{-3})	1.63	1.61	1.63	1.64	1.54	1.50	1.45
Sand (%)	77.8	76.2	74.8	64.2	52.2	51.6	52.5
Silt (%)	18.1	20.7	22.1	29.7	30.8	32.3	30.4
Clay (%)	4.1	3.1	3.1	6.1	17.1	16.1	17.1

Table 4. 3: Characteristics of Plinthosol at Agricultural College in Ejura during the minor season, 2008.

Soil depth (cm)	0-15	15-30	30-45	45-60	60-75	75-90	90-100
Soil parameters							
Total N (mg g^{-1})	0.11	0.1	0.06	0.08	0.11	0.10	0.10
Available P (mg kg^{-1})	8.3	5.6	3.4	3.1	3.6	2.9	3.5
Available K (mg kg^{-1})	63	67	40	40	50	40	30
pH	4.72	4.76	4.90	4.92	4.73	4.88	4.71
Ca (cmol (+) kg^{-1})	0. 7	0.8	1.1	0.8	1.1	1.1	0.8
Mg (cmol (+) kg^{-1})	0.4	0.3	0.5	0.3	0.3	0.3	0.3
ECEC (cmol (+) kg^{-1})	1.4	1.4	2.1	1.3	1.9	1.8	1.6
K (cmol (+) kg^{-1})	0.1	0.1	0.1	0.1	0.1	0.1	0.1
BS (%)	80.6	80.1	90.3	85.0	87.0	80.5	77.4
Organic C (%)	0.55	0.53	0.40	0.40	0.35	0.04	0.04
Bulk density (g cm^{-3})	1.57	1.55	1.58	1.56	1.56	1.66	1.73
Sand (%)	76.6	74.7	72.2	68.4	66.4	65.8	70.7
Silt (%)	21.4	23.3	23.7	25.4	26.5	28.2	25.3
Clay (%)	2.1	2.1	4.1	6.1	7.1	6.1	4.1

Haplic Lixisol is formed over weathered Voltaian sandstone on middle-slope and gentle sloping topography. The soil is deep, well grained, and brown in color with humus-stained topsoil overlapping a thick brown clayey sub-soil. Data in Table 4.1 – 4.3 indicate that soils at these sites are generally acidic at the more sandy sites (Agricultural College) than at Ejura farms as reflected also in the base saturation. The recorded total N value in the top 15 cm layer was low (0.13 for Ejura farm site and 0.03 at Agricultural College during major season). Plant available P can be rated as medium and K as rather high according to Page et al. (1982). Similarly, the percent organic carbon (1.1 and 0.36) is rated very low according to Landon (1996).

4.2 Phenology

4.2.1 Crop development

Plant emergence was not affected by treatment in all 4 experiments. The thermal time expressed in growing degree days (GDD) of crop growth (maize) from sowing to day of 50 % tasseling (Appendices 2 and 3) during the major season (experiments 1 and 2) ranged from 1090 to 1152 °C days for the Obatanpa cultivar and 1032 to 1094 °C days for Dorke. During the minor season (experiments 3 and 4), the GDDs from sowing to

tasseling ranged from 1038 to 1114 °C days for Obatanpa and 983 to 1058 °C days for Dorke. On average, Obatanpa took more days to tassel (56) than Dorke (53) explaining the difference in GDDs.

Thermal days to maturity varied from 2031 to 2074 °C days and 1790 to 1851 °C days during the major season for Obatanpa and Dorke, respectively. During the minor season, GDDs maturity ranged from 2012 to 2073 °C days and 1771 to 1849 °C days for Obatanpa and Dorke, respectively.

4.2.2 Days to 50% tasseling

The effect of site on days to 50 % tasseling was significant ($p < 0.01$) with an average of 1 day early tasseling at the Ejura farm site than at the Agricultural College site for both seasons possibly reflecting the slower growth on the more acidic soil.

Seasonal effect (Expt. 1 vs. 3) showed a slower development of crop by delaying days to 50 % tasseling by an average of 2 days during the minor season (57 days) compared to the major season (55 days) for Obatanpa. The same number of days difference (2 days) was observed in Dorke cultivar (52 vs. 54).

The effects of N, P, and cultivar on days to 50 % tasseling are presented in Table 4.4 and 4.5. Cultivar, N and P significantly ($p < 0.01$) affected days to 50 % tasseling in all four experiments. Obatanpa cultivar took more days (56) to tassel compared to the Dorke cultivar (53). The number of days to tasseling significantly ($P < 0.01$) increased by an average of 3 days with increased N stress in all experiments. The effect of P was similar, delaying tasseling by 1 day if inadequately supplied. There were no interactive effects of N and P except for experiment 3 where the effect of N was for the different cultivars (Table 4.4). In Expts. 1 and 2, the number of days to tasseling in Obatanpa ranged from 54 to 57 between treatments which corresponds to 17 June, the earliest and 20 June the latest. More days to tasseling were needed in experiments 3 and 4 with days to 50% tasseling ranging from 55 to 58 days and 55 to 59 days, respectively.

Table 4. 4: Effect of cultivar, N and P fertilizer on days to 50 % tasseling

Effects	Expt. 1	Expt. 2	Expt. 3	Expt. 4
			F-probability	
N	**	**	**	**
P	**	**	**	**
Cultivar	**	**	**	**
N*P	NS	NS	NS	NS
N*cultivar	NS	NS	**	NS
P*cultivar	NS	NS	NS	NS
N*P*Cultivar	NS	NS	NS	NS

*NS = Not significant; *, ** = Significant at 0.05 and 0.01, respectively; Expt.= experiment*

4.2.3 Days to maturity

The effect of treatments on days to maturity of the maize crop is presented in Appendices 2 and 3. There were no sites or seasonal effect. However, plants took on average 1 more day to mature during the minor season (Expt. 3) (99.2) compared to the major season (Expt. 1) (98.4).

The effect of cultivar on number of days to maturity was highly significant ($p < 0.01$) in all experiments (Table 4.5) with Obatanpa taking more days (105.4) to mature than Dorke (93.4).

Table 4. 5: Effect of cultivar, N and P fertilizer on days to maturity of maize crop.

Effects	Expt. 1	Expt. 2	Expt. 3	Expt. 4
			F-probability	
N	**	**	**	**
P	**	*	**	**
Cultivar	**	**	**	**
N*P	NS	NS	NS	NS
N*cultivar	NS	NS	NS	NS
P*cultivar	NS	NS	NS	NS
N*P*Cultivar	NS	NS	NS	NS

NS = Not significant; *, ** = Significant at 0.05 and 0.01, respectively

Days to maturity significantly decreased with increased N rates for the Obatanpa maize cultivar (Appendix 2). Days to maturity ranged from 104 to 105 in Experiment 1 with the earliest occurring in 120 kg N ha^{-1} fertilizer application. There was no significant difference between days to maturity at different P levels. In Expt.2, days to maturity ranged from 104 (3 August) to 106 (5 August). The plants in

experiment 4 took the highest number of days to mature (105 to 107 days) compared to the other experiments.

Similar trends were observed for the Dorke cultivar where N significantly ($p < 0.01$) decreased days to maturity (Appendix 3). Plants in Expt. 1 matured earlier (91 to 93 days) followed by Expt. 2 (92 to 94 days) with Expt. 4 showing the highest number of days to mature (93 to 96 days 8 to 11 November). For both varieties, maturity was delayed most at 0 and 40 kg N ha^{-1} in all experiments.

4.3 Effect of N and P inorganic fertilizer on total biomass accumulation and nutrient uptake

4.3.1 Maize dry matter accumulation at 34 days after sowing (DAS)

There was a slow growth of maize at the start of the season in all experiments, which later picked up. The effect of treatments on dry matter (DM) accumulation at 34 DAS in all four experiments are presented in Appendices 4 and 5. Dry matter accumulation of maize 34 DAS was 4.6 % higher at the Ejura farm compared to Agricultural College ($p < 0.01$).

The ANOVA showed that DM accumulation of maize at 34 DAS was 18.6 % higher ($p < 0.01$) during the major season than during the minor season (Expt.1 vs. Expt.3). In all four experiments, Dorke had significantly ($p < 0.01$) higher biomass than Obatanpa with percentage difference of 16.4, 13.2, 14.3 and 8.3 in Experiments 1, 2, 3 and 4, respectively. Dorke showed improved growth over Obatanpa due to its faster growth rate and a shorter period to complete its life cycle.

Maize DM accumulation was significantly influenced by inorganic N ($p < 0.01$) and P ($p < 0.05$) fertilizer in both cultivars ranging from 63 g m^{-2} (control) to 77g m^{-2} (N3P3) in Expt. 1 and 62g m^{-2} (N1P1) to 77 g m^{-2} (N4P3) in Expt. 2. Dry matter accumulation in experiments 3 and 4 ranged from 52. g m^{-2} (N1P1) to 67 g m^{-2} (N4P2) and 49 g m^{-2} (N1P1) to 63 g m^{-2} (N4P2), respectively in Obatanpa cultivar.

Dry matter accumulation followed a similar trend in Dorke. Nitrogen and P had a significant ($p < 0.01$) effect in all experiments except for Expt. 1, where P did not show a significant effect. There was, however, no interactive effect between N and P on DM accumulation at 34 DAS which ranged from 44.9 g m^{-2} in the control (N1P1) in Expt. 4 to a maximum of 92.8 g m^{-2} (N4P2) in Expt. 1.

4.3.2 Maize dry matter accumulation at 55 days after sowing

At 55 DAS, DM production was 12.4% higher on Ejura farm compared to Agricultural College ($p < 0.01$). Dry matter accumulation during the major season (Expt. 1) was significantly ($p < 0.01$) higher by 14 % compared to the minor season (Expt. 3).

The ANOVA (Table 4.6) showed significant cultivar effects, with Dorke producing a higher average biomass (5.9 %) than Obatanpa except for Experiment 4. However, the cultivars reacted differently to the application of N in the case of Expt. 4, and also to P (4.7 and 4.8) with Dorke being more responsive to N than Obatanpa.

Table 4. 6: Effect of cultivar, N and P on dry matter accumulation 55 days after sowing in Ejura, Ghana.

Effects	Expt. 1	Expt. 2	Expt. 3	Expt. 4
			F-probability	
N	**	**	**	**
P	*	**	**	**
Cultivar	**	**	**	NS
N*P	**	**	**	**
N*cultivar	*	**	**	**
P*cultivar	NS	NS	NS	**
N*P*Cultivar	NS	NS	NS	*

*NS = Not significant; *, ** = Significant at 0.05 and 0.01, respectively*

The interactive effect of N and P on maize DM accumulation 55 DAS was significant in all experiments for 3 levels of N for Obatanpa (Table 4.7). Mean DM accumulation in Experiment 1 ranged from 269 (control) to 457g m^{-2} (N4P3). The application of inorganic N fertilizer significantly ($p < 0.01$) increased aboveground DM by 18.3, 29.3 and 33.6 % over the control. Significant differences in DM accumulation at 55 DAS were observed between 0 kg P ha^{-1} and 30 and 60 kg ha^{-1} at all levels of N with the exception of the control (0 kg N ha^{-1}). There was, however, no significant difference in DM accumulation between 30 and 60 kg P ha^{-1}. Thus, beyond 30 kg P ha^{-1}, other factors (other soil nutrients or environmental factors or both) were limiting DM production. The application of 60 kg P ha^{-1} increased plant DM accumulation by 4.0, 21.4, 10.7 and 11.2 % over those without P fertilizer application for the four levels of N. In Experiment 2, mean DM production ranged from 231 in the control (N1P1) to 434g m^{-2} with the application of 120 kg N ha^{-1} and 60 kg P ha^{-1} (N4P3) and 223 to 376 g m^{-2}

in the N1P1 and N4P2 respectively in Expt. 3. Experiment 4 showed the lowest DM accumulation ranging from 120 in N1P1 to 321 g m^{-2} in N3P3. Thus, DM production was in the order of Expt. 1 > Expt. 2 > Expt. 3 > Expt. 4 in a decreasing order.

Table 4.7: Dry matter accumulation of Obatanpa maize cultivar at 55 days after sowing at Ejura, Ghana.

Treatment combinations	N applied (kg ha^{-1})	P applied	Expt. 1	Expt. 2	Expt. 3	Expt. 4
			DM (g m^{-2})			
N1P1	0	0	269	231	223	120
N1P2	0	30	285	284	258	218
N1P3	0	60	281	281	265	227
N2P1	40	0	330	298	273	227
N2P2	40	30	401	376	356	309
N2P3	40	60	419	390	364	312
N3P1	80	0	381	355	321	246
N3P2	80	30	418	414	354	292
N3P3	80	60	427	424	376	331
N4P1	120	0	406	358	316	256
N4P2	120	30	444	422	373	294
N4P3	120	60	457	434	362	317
Effects			F-probability			
N			**	**	**	**
P			**	**	**	**
N * P interaction			**	*	**	**

*Expt. 1 = Ejura farm major season; Expt. 2 = Agric college major season; Expt. 3 = Ejura farm minor season; Expt. 4 = Agric college minor season; NS = Not significant; *, ** = Significant at 0.05 and 0.01, respectively*

Similar observations were made for Dorke (V2) DM accumulation at 55 DAS. Nitrogen and P mineral fertilizer productivity significantly and interactively re-enforced each other (Table 4.8). Experiment 2, located at Agricultural College had the most DM of 488g m^{-2} in N4P3 while the lowest of 338 g m^{-2} in N4P3 was recorded in Experiment 4. There was no significant difference in the controls of all experiments. Dry matter production was in the order of experiment 1 > 2 > 3 > 4.

Table 4. 8: Dry matter accumulation of Dorke maize cultivar at 55 days after sowing at Ejura, Ghana.

Treatment combinations	N applied	P applied	Expt. 1	Expt. 2	Expt. 3	Expt. 4
	(kg ha^{-1})		Dry matter (g m^{-2})			
N1P1	0	0	278	264	235	114
N1P2	0	30	296	284	283	222
N1P3	0	60	304	300	285	252
N2P1	40	0	369	332	300	185
N2P2	40	30	439	414	370	289
N2P3	40	60	435	420	378	320
N3P1	80	0	396	381	351	209
N3P2	80	30	458	461	383	292
N3P3	80	60	475	475	422	325
N4P1	120	0	411	396	352	212
N4P2	120	30	468	474	405	323
N4P3	120	60	472	487	412	338
Effects			F-probability			
N			**	**	**	**
P			**	**	**	**
N * P interaction			*	**	**	NS

*NS = Not significant; *, ** = Significant at 0.05 and 0.01, respectively.*

4.3.3 Plant nitrogen uptake at 55 days after sowing

Site effect on plants N uptake at 55 DAS was highly significant ($p < 0.01$) with the Ejura farm site (Expt. 1 and 3) having a higher average N uptake (6.5 g m^{-2}) than the Agricultural College site (Expt. 2 and 4) with 5.7 g m^{-2}.

Seasonal effect significantly ($p < 0.01$) influenced N uptake at 55 DAS. During the major season (Expt. 1) maize plant N uptake was higher by 16.6 % than the minor season (Expt. 3).

The ANOVA showed a significant ($p < 0.01$) cultivar, N and P effect (Table 4.9) on biomass N uptake at 55 DAS in all experiments. Higher N levels (3.3 %) were found in Dorke than in Obatanpa cultivar.

Nitrogen uptake followed the same trend as in DM production. Nitrogen uptake of Obatampa (V1) maize at 55 DAS is shown in Figure 4.1. Nitrogen and P and their positive interaction significantly affected N uptake in three experiments for all levels of N in the Obatampa cultivar (V1). Generally, Expt. 1 had the highest N uptake ranging from 3.9 to 9.4 g m^{-2}. The application of 60 kg P ha^{-1} increased N uptake by 5.7,

11.3, 18.1 and 14.6 % over those without P fertilizer application for 0, 40, 80 and 120 kg N ha^{-1}. In Expt. 2, N uptake followed a similar trend to that in Expt. 1.

Table 4. 9: Effect of cultivar, N and P on maize N uptake at 55 days after sowing at Ejura, Ghana.

Effects	Expt. 1	Expt. 2	Expt. 3	Expt. 4
			F-probability	
N	**	**	**	**
P	**	**	**	**
Cultivar	**	**	**	**
N*P	**	**	**	**
N*cultivar	NS	*	NS	NS
P*cultivar	NS	NS	NS	NS
N*P*Cultivar	NS	NS	NS	NS

NS = Not significant; *, ** = Significant at 0.05 and 0.01, respectively.

Total N uptake ranged from 3.3 to 9.4 g m^{-2} with 120 kg N ha^{-1} and 30 and 60 kg P ha^{-1} having the highest uptake. In Expt. 3, N3P3 treatment had the highest N uptake (7.9 g m^{-2}) followed by N3P2 with 7.8 g m^{-2}. Experiment 4 had the lowest N uptake reflecting the poorer quality of the soil. There was, however, no interactive effect of N and P. Nitrogen uptake ranged from 1.8 (N1P1) to 6.7 g m^{-2} (N3P3 and N4P3).

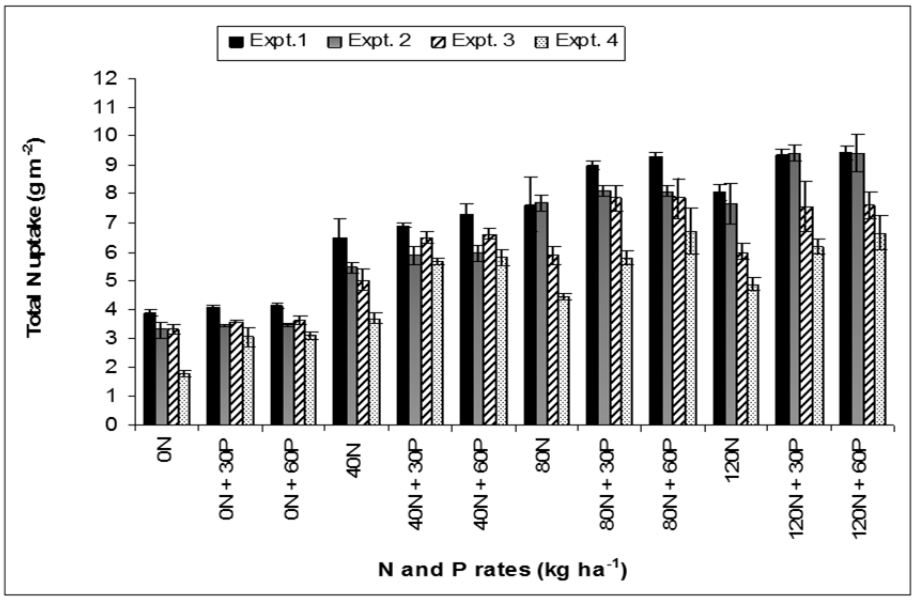


Figure 4. 1: Effect of N and P fertilizer on aboveground plant N uptake of Obatampa maize cultivar at 55 DAS at Ejura, Ghana, 2008.

Nitrogen uptake of the Obatampa maize cultivar at 55 DAS in the different treatments was linearly and positively correlated (graph not shown) with total DM production in all experiments.

In Expt. 1, N uptake ranged from 4 (N1P1) to 10 g m^{-2} (N4P2 and N4P3), while in Expt. 2, N uptake ranged from 3 to 10 g m^{-2}. There were no significant differences in N uptake between Expt. 1 and 2. Expt. 4 had the least N uptake ranging from 2 (N1P1) to 7 g m^{-2} (N4P3), while 4 (N1P1) to 8 g m^{-2} (N4P2 and N4P3) were observed in Expt. 3.

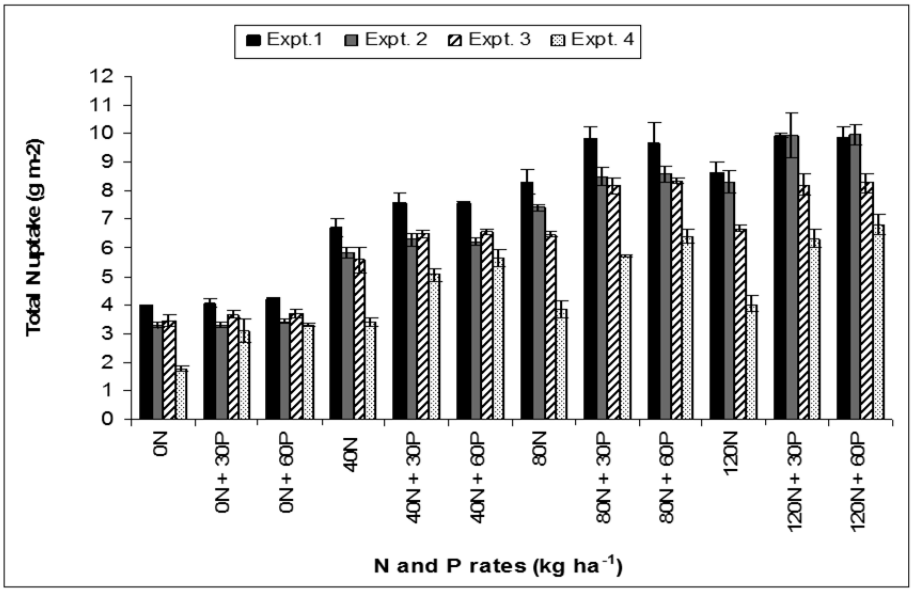


Figure 4. 2: Effect of N and P fertilizer on N uptake on aboveground biomass of Dorke maize variety 55 days after sowing at Ejura, Ghana, 2008.

4.3.4 Phosphorus uptake at 55 days after sowing

The site effect on biomass P uptake 55 DAS was highly significant ($p < 0.01$), with the Ejura farm (Expts. 1 and 3) having the highest average value (0.5 g m^{-2}) than Agricultural College (Expts. 2 and 4) having the least (0.4 g m^{-2}).

The seasonal effect on P uptake 55 DAS was significant ($p < 0.01$), with higher P uptake (0.5 g m-2) during the major season (Expt. 1) than during the minor season (0.4 g m^{-2}), representing a 16.4 % increased P uptake over the minor season.

The ANOVA showed that there was only a significant difference in P uptake between the two cultivars in Expt. 4.

Table 4. 10: Effect of cultivar, N and P on maize P uptake at 55 days after sowing at Ejura, Ghana.

Effects	Expt. 1	Expt. 2	Expt. 3	Expt. 4
			F-probability	
N	**	**	**	**
P	**	**	**	**
Cultivar	NS	NS	NS	**
N*P	**	**	NS	NS
N*cultivar	NS	NS	NS	NS
P*cultivar	NS	NS	NS	NS
N*P*Cultivar	NS	NS	NS	NS

*NS = Not significant; *, ** = Significant at 0.05 and 0.01, respectively.*

The uptake of P as influenced by the different treatments is shown in Figure 4.3and 4.4 for Obatampa and Dorke, respectively. Phosphorus uptake of both maize cultivars was influenced by the application of N and P. There was, however a positive interaction of N and P only in the main season (Expts. 1 and 2) as shown in Table 4.10. There was no significant difference in P uptake between 30 and 60 kg P ha^{-1} at all levels of N in except for Expt. 4. In Expt. 1, P uptake in Obatanpa ranged from 0.4 g m^{-2} (N1P1) to 0.7 g m^{-2} (N4P3), while in Expt. 2 values ranged from 0.3 g m^{-2} (N1P1) to 0.6 g m^{-2} (N2P2 N2P3 N3P2 N3P3 N4P2 and N4P3). Experiment 4 had the lowest P uptake with values ranging from 0.1 to 0.4 g m^{-2} followed by those of Expt. 3 ranging from 0.3 to 0.5 g m^{-2}.

Similar trends were observed for P uptake by Dorke at 55 DAS (Figure 4.4) as in Obatampa in all experiments. In Expt. 1, P uptake ranged from 0.37 (N1P1) to 0.67 g m^{-2} (N4P3) while 0.27 (N1P1) to 0.65 g m^{-2} (N4P3) was observed in Expt. 2. Experiment 4 had the lowest P uptake ranging from 0.13 (N1P1) to 0.39 g m^{-2} (N2P3).

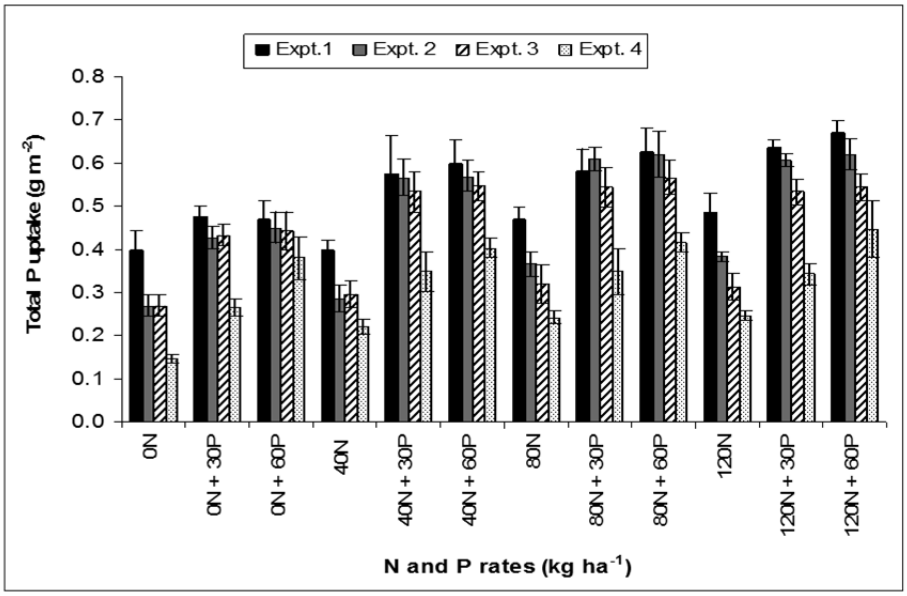


Figure 4. 3: Influence of N and P fertilizer on P uptake by aboveground biomass of Obatampa maize variety 55 days after sowing at Ejura, Ghana, 2008.

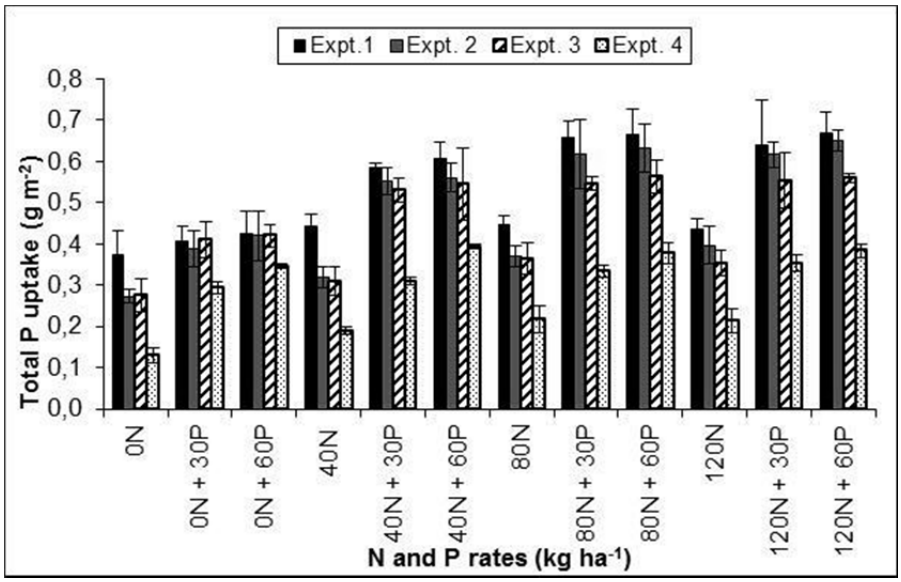


Figure 4. 4: Influence of N and P fertilizer on P uptake by aboveground biomass of Dorke maize variety 55 days after sowing at Ejura, Ghana, 2008.

4.4 Maximum leaf area index (LAI)

Leaf area index (LAI) values steadily increased and reached a maximum value at tasseling stage in all experiments; and thereafter declined. Due to the large number of treatments, only maximum LAI is presented. Site effect on maximum LAI was significant ($p < 0.01$) with higher maximum LAI obtained on Ejura farm (9.6%) than at Agricultural College.

Significant cultivar effects ($p < 0.01$) on maximum LAI were observed between the two cultivars, with higher values for Obatanpa (2.67) than for Dorke (2.61). The seasonal effect on maximum LAI observed in Expts. 1 and 3 was also significant ($p < 0.01$). A higher average value (2.9) was observed in the major season (Expt. 1) compared to the value (2.6) in the minor season (Expt. 3).

Nitrogen and P positively affected LAI and with a strong interactive effect. The effect of N was greatly enhanced by the addition of P (Tables 4.11 and 4.12). The interactive effect of N and P was more obvious in Obatanpa cultivar, with maximum LAI ranging from 1.38 (control in Expt. 4) to highest of 3.35 (N4P2 in Expt. 1). In Dorke, maximum LAI ranged from 1.30 (in the control) to 3.29 (N3P2 in Expt. 2).

Table 4. 11: Influence of N and P fertilizer on maximum leaf area index (LAI) of Obatanpa maize cultivar at Ejura, Ghana, 2008.

Treatment combinations	N applied (kg ha^{-1})	P applied (kg ha^{-1})	Expt.1	Expt. 2	Expt.3	Expt.4
			Maximum LAI			
N1P1	0	0	2.38	2.13	2.20	1.38
N1P2	0	30	2.54	2.31	2.41	2.29
N1P3	0	60	2.56	2.42	2.47	2.36
N2P1	40	0	2.41	2.42	2.28	1.57
N2P2	40	30	2.89	2.89	2.95	2.72
N2P3	40	60	3.03	2.94	2.88	2.85
N3P1	80	0	2.80	2.56	2.18	1.51
N3P2	80	30	3.33	3.16	3.20	2.72
N3P3	80	60	3.34	3.19	3.24	2.86
N4P1	120	0	2.91	2.35	2.34	1.67
N4P2	120	30	3.35	3.30	3.21	2.80
N4P3	120	60	3.33	3.28	3.27	2.86
Effects			F-probability			
N			**	**	**	**
P			**	**	**	**
N * P interaction			**	**	**	**

*NS = Not significant; *, ** = Significant at 0.05 and 0.01, respectively.*

Table 4. 12: Influence of N and P fertilizer on maximum LAI of Dorke maize cultivar at Ejura, Ghana, 2008.

Treatment combination	N applied	P applied	Expt.1	Expt.2	Expt.3	Expt.4
	(kg ha^{-1})			Maximum LAI		
N1P1	0	0	2.36	2.11	2.07	1.30
N1P2	0	30	2.58	2.38	2.37	2.23
N1P3	0	60	2.64	2.49	2.41	2.27
N2P1	40	0	2.51	2.36	2.32	1.53
N2P2	40	30	2.97	2.86	2.75	2.56
N2P3	40	60	3.00	2.97	2.83	2.71
N3P1	80	0	2.65	2.62	2.21	1.49
N3P2	80	30	3.14	3.29	3.00	2.67
N3P3	80	60	3.20	3.25	3.11	2.72
N4P1	120	0	2.78	2.47	2.14	1.52
N4P2	120	30	3.22	3.26	3.02	2.67
N4P3	120	60	3.19	3.19	2.96	2.72

Effects	F-probability			
N	**	**	**	**
P	**	**	**	**
N * P interaction	NS	*	NS	NS

*NS = Not significant; *, ** = Significant at 0.05 and 0.01, respectively.*

4.5 Grain yield

Maize grain yields at final harvest are presented in Tables 4.14 and 4.15.

The ANOVA showed a significant site effect ($p < 0.01$) on grain yield with higher yields at the Ejura farm than at Agricultural College. The Ejura farm site (Expts. 1 and 3) produced 13 % (41.6 g m^{-2}) and 17% (49.7 g m^{-2}more grain yields than the Agricultural College site during the major and minor season, respectively.

The seasonal effect on grain yield was highly significant ($p < 0.01$) with a 10.9 % (354.5 vs. 314.9g m^{-2}) higher grain yield in the major season (Expt. 1) than in the minor season (Expt. 3).

The average across-sites cultivar effect on grain yield was significant, with Obatanpa producing a 12.6 % higher grain yield than Dorke. Obatanpa produced 15 % (52.7 g m^{-2}), 14 % (44.3 g m^{-2}), 11 % (33.8 g m^{-2}) and 10 % (25.8 g m^{-2}) more grain than Dorke (Table 4.13) in Expts. 1, 2, 3 and 4, respectively.

Table 4. 13: Effect of cultivar, N and P fertilizer on maize grain yield at Ejura, Ghana.

Effects	Expt. 1	Expt. 2	Expt. 3	Expt. 4
			F-probability	
N	**	**	**	**
P	**	**	**	**
Cultivar	**	**	**	**
N*P	**	**	**	**
N*cultivar	NS	**	**	**
P*cultivar	**	NS	**	NS
N*P*Cultivar	NS	NS	NS	NS

*NS = Not significant; *, ** = Significant at 0.05 and 0.01, respectively*

Generally, N significantly increased grain yield of Obatanpa maize at all levels of N, but there was no effect of N beyond 80 kg N ha^{-1} if there was no P application. Grain yield in Expt. 1 (Ejura farm major season) responded positively to N application with yields ranging from 162.4 g m^{-2} in N1P1 (control) to a maximum yield of 495 g m^{-2} in N4P2, representing an increase of 67 %.

There was a significant increase ($p < 0.01$) in grain yield when N was applied irrespective of the application of P. There was no significant response to P beyond 30 kg ha^{-1}. Significant ($P < 0.01$) interactive effects of N and P mineral fertilizer on grain yield were observed. With 30 kg P ha^{-1} grain yield increased by 0.0, 19.8, 21.4 and 20.4 % at 0, 40, 80 and 120 kg N ha^{-1}, respectively, over those without P application.

In Expt. 2, N and P significantly increased ($p < 0.01$) grain yield at all levels of N over the control. The positive interactive effect of N and P was also significant ($p < 0.01$) as well. Application of N fertilizer increased grain yields ranging from 126 in N1P1 to 460 g m^{-2} in N4P3. Phosphorus positively influenced grain yield by increasing yields by 12.1, 63.4, 122.3 and 94.0 g m^{-2} compared to those without P fertilizer application, representing an 8.8, 21.0 27.3 and 20 % increment at N1, N2, N3 and N4, respectively.

In Expt. 3, N and P and their interactive effect significantly increased grain yield at all levels of N, and ranged from 129 g m^{-2} in the control (N1P1) to a maximum of 456 g m^{-2} in N4P3There was a significant response to P ($p < 0.01$) in grain yield at all levels of N except the zero N.

Table 4. 14: Effect of nitrogen and phosphorus fertilizer on Obatanpa maize grain yield at Ejura during the major and minor season, 2008.

Treatment combination	N (kg ha^{-1})	P	Expt. 1	Expt. 2	Expt. 3	Expt. 4
			yield (g m^{-2})			
N1P1	0	0	162	126	129	92
N1P2	0	30	162	133	128	113
N1P3	0	60	170	138	136	122
N2P1	40	0	287	239	254	166
N2P2	40	30	363	301	321	267
N2P3	40	60	381	302	356	294
N3P1	80	0	376	326	327	265
N3P2	80	30	481	426	420	365
N3P3	80	60	490	448	451	377
N4P1	120	0	395	356	369	301
N4P2	120	30	495	460	447	388
N4P3	120	60	491	450	455	399
Mean			355	309	316	262
Effects			F-probability			
N			**	**	**	**
P			**	**	**	**
N * P			**	**	**	*

*Expt. 1 = Ejura farm major season; Expt. 2 = Agric college major season; Expt. 3 = Ejura farm minor; Expt. 4 = Agric college minor season; NS = Non-significant; *, ** = Significant at 0.05 and 0.01, respectively,*

Table 4. 15: Effect of nitrogen and phosphorus fertilizer on Dorke grain yield at Ejura during the major and minor season 2008.

Treatment combination	N (kg ha^{-1})	P	Expt. 1	Expt. 2	Expt. 3	Expt. 4
			Grain yield (g m^{-2})			
N1P1	0	0	118	107	122	82
N1P2	0	30	124	123	126	103
N1P3	0	60	134	121	126	122
N2P1	40	0	262	211	214	152
N2P2	40	30	296	259	297	262
N2P3	40	60	328	281	308	282
N3P1	80	0	334	277	282	223
N3P2	80	30	397	344	372	329
N3P3	80	60	416	366	401	341
N4P1	120	0	368	311	319	252
N4P2	120	30	427	383	418	334
N4P3	120	60	419	391	402	356
Mean			302	264	282	236
Effects			F-probability			
N			**	**	**	**
P			**	**	**	**
N * P interaction			*	*	**	**

*NS = Non-significant; *, ** = Significant at 0.05 and 0.01, respectively.*

With the application of N2P2, grain yield was almost equal to that with N3, and the application of N3P3 produced higher grain yield than N4 application. The same trend in grain yield with the application of N and P and their interactive effect ($p < 0.05$) was observed in Expt. 4. In general, higher grain yields were observed in Expt. 1 than Expt. 2, 3 and 4 for the same cultivar (Table 4.14).

Nitrogen and P significantly increased grain yield at all levels of N in all experiments in Dorke cultivar (Table 4.15) and mutually re-enforced their effect ($p < 0.01$). In Expt. 1, grain yields ranged from 118 g m^{-2} in the control (N1P1) to a maximum value of 427 g m^{-2} in N4P3. The application of N fertilizer increased grain yield on average by 11.6, 64.0, 71.6 and 71.8 % with N1, N2, N3, and N4, respectively. Application of P fertilizer significantly increased ($p < 0.01$) grain yield by 11.6, 20.4, 19.7 and 12.2 % over those without P at N1, N2, N3 and N4, respectively. There was, however, no significant response of P beyond 30 kg ha^{-1}.

In Expt. 2 (Agricultural College site, major season), the same trends were observed for N and P and their interactive effect ($p < 0.01$) on grain yield. Grain yield increased with P application and ranged from 107 g m^{-2} in the control (N1P1) to a maximum grain yield of 391 g m^{-2} in N4P3. The application of N2P3 produced grain yields higher than that with N3 and almost the same yield with N4.

Similarly, N and P and their interactive effect positively increased ($p < 0.01$) grain yield in Expt. 3. Experiment 4 showed a similar trend. There was, however, significant increase in grain yield from P2 and P3 application. The poor nature of the soil (low soil organic carbon and organic matter) and the high P sorption capacity probably resulted in this different behavior.

4.6 Stover yield at harvest

Maize stover yields at final harvest are presented in (Figures 4.5 and 4.6). The effect of site on stover yield at final harvest was highly significant ($p < 0.01$), with the Ejura farm site (Expts. 1 and 3) producing the highest average stover yield of 509 g m^{-2} compared to Agricultural College (452 g m^{-2}).

The seasonal effect on stover yield was significantly ($p < 0.01$) with a 2 % increase during the major season (Expt. 1) than during the minor season (Expt. 3).

Cultivar effects on stover yield were highly significant in all experiments (Table 4.16), with Obatanpa producing 7.0, 3.6, 7.6, and 10.9 % more stover than Dorke in Expts. 1, 2, 3 and 4, respectively.

Table 4.16: Effect of cultivar, N and P fertilizer on stover yield at final harvest at Ejura, Ghana, 2008.

Effects	Expt. 1	Expt. 2	Expt. 3	Expt. 4
			F-probability	
N	**	**	**	**
P	**	**	**	**
Cultivar	**	**	**	**
N*P	**	**	**	NS
N*cultivar	**	NS	NS	NS
P*cultivar	NS	**	NS	NS
N*P*Cultivar	NS	*	NS	NS

*Expt.1 = Ejura farm major season; Expt.2 = Agric college major season; Expt.3 = Ejura farm minor season; Expt.4 = Agric college minor season; NS = Non-significant; *, ** = Significant at 0.05 and 0.01, respectively.*

Obatanpa maize stover yield (Figure 4.5) responded well to the application of N and P up to 80 kg N ha^{-1} in all experiments except Expt. 4, where there was significant difference between 80 and 120 kg N ha^{-1}. The ANOVA shows a significant response ($p < 0.01$) of Obatanpa maize stover to N and P fertilizer and the interactive effect in all experiments except Expt. 4. Significant response in stover yield were observed between yield at 0 kg P ha^{-1} and the other P levels (30 and 60 kg ha^{-1}). Yield in Expt. 1 ranged from 362 in the control (N1P1) to 641 g m^{-2} with N4P3, while in Expt. 2, yields ranged from 359 g m^{-2} in the control (N1P1) to 605g m^{-2} with N4P2. The lowest yield was observed in Expt. 4, with yields ranging from 220 g m^{-2} (N1P1) to 619 g m^{-2} and 386 g m^{-2} (N1P1) to 670 g m^{-2} (N3P3) in Expt. 3.

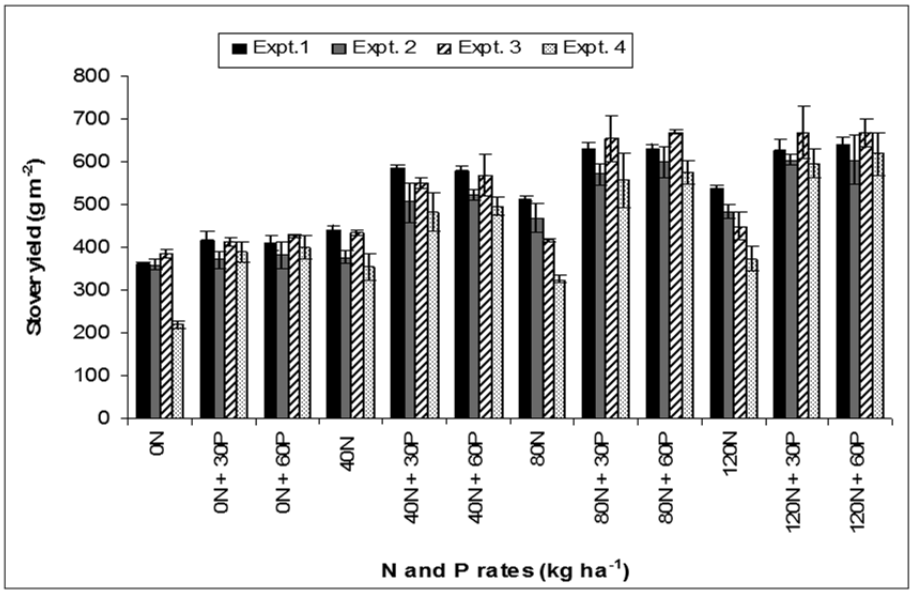


Figure 4. 5: Effect of N and P fertilizer on Obatanpa stover yield during major and minor season, 2008.

Dorke maize stover showed a significant ($p < 0.01$) response to N and P and their interactive effect in all except Expt. 4. The highest yield of 629 g m^{-2} was recorded in Expt. 2. Stover yield in Expt. 1, ranged from a minimum of 372 g m^{-2} (N1P1) to a maximum 623 g m^{-2} (N4P3) while a maximum of 624 g m^{-2} (N4P3) was recorded in Expt. 3 (N4P3). The lowest yield of 531 g m^{-2} (N3P3) was recorded in Expt. 4.

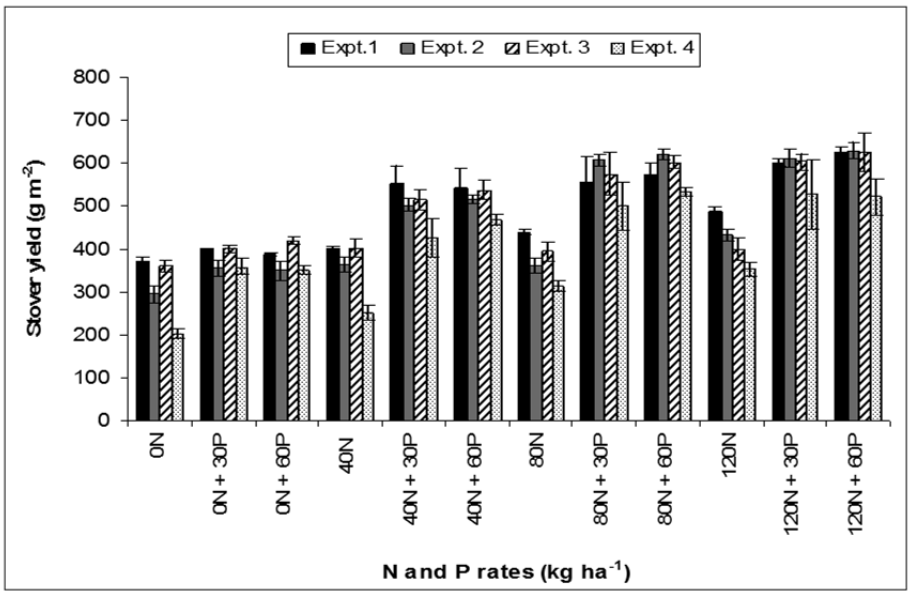


Figure 4. 6: Effect of N and P fertilizer on Dorke stover yield major and minor season, 2008.

4.7 Total dry matter production at harvest

Significant site effects ($p < 0.01$) on total dry matter (TDM) production at harvest of Obatanpa and Dorke were observed, with more average TDM production (823 g m^{-2}) at the Ejura farm site (Expts. 1 and 3) than the Agricultural College (Expts. 2 and 4) as shown in (Figures 4.7 and 4.8).

The seasonal effect on TDM was significant ($p < 0.01$) with a 4.4 % (841 vs. 805 g m^{-2}) more TDM production during the major season (Expt. 1) than during the minor season (Expt. 3). The ANOVA (Table 4.17) revealed a highly significant cultivar effect ($p <0.01$) on TDM, with more TDM production by Obatanpa than Dorke. Averaged across-experiments, Obatanpa produced 9.3 % (75.1 g m^{-2}) more TDM than Dorke.

Table 4. 17: Effect of cultivar, N and P fertilizer on total dry matter at Ejura, 2008.

Effects	Expt. 1	Expt. 2	Expt. 3	Expt. 4
			F-probability	
N	**	**	**	**
P	**	**	**	**
Cultivar	**	**	**	**
N*P	**	**	**	**
N*cultivar	**	NS	**	NS
P*cultivar	NS	*	NS	NS
N*P*Cultivar	NS	NS	NS	NS

Nitrogen and P significantly increased TDM production at all levels of N in Obatanpa maize cultivar (Figure 4.7) and re-enforced their effect ($p < 0.01$). TDM yield in Expt. 1 responded positively to N and P with yield ranging from a minimum of 525 g m^{-2} (N1P1) to a maximum of 1132 g m^{-2} (N4P3), while in Expt. 2 a maximum of 1064 g m^{-2} (N4P2) was observed. A maximum of 1123 g m^{-2} (N4P3) and 1017.7 g m^{-2} (N4P3) was observed in Expts. 3 and 4, respectively. There was no significant response to P beyond 30 kg ha^{-1}.

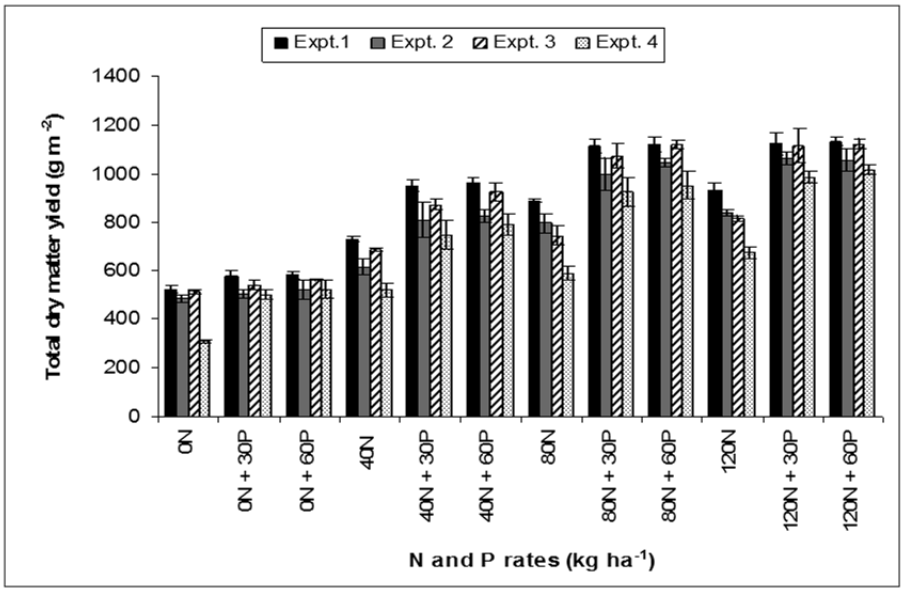


Figure 4. 7: Total dry matter yield of Obatanpa maize at different sites at Ejura, Ghana, 2008.

Similar trends were observed in Dorke TDM production, with a significant response ($p < 0.01$) to N and P. Total dry matter production was highest (1042 g m^{-2}) in Expt. 1 compared to 1019.6, 1026.2 and 877.4 g m^{-2} in experiments 2, 3, and 4, respectively (Figure 4.8).

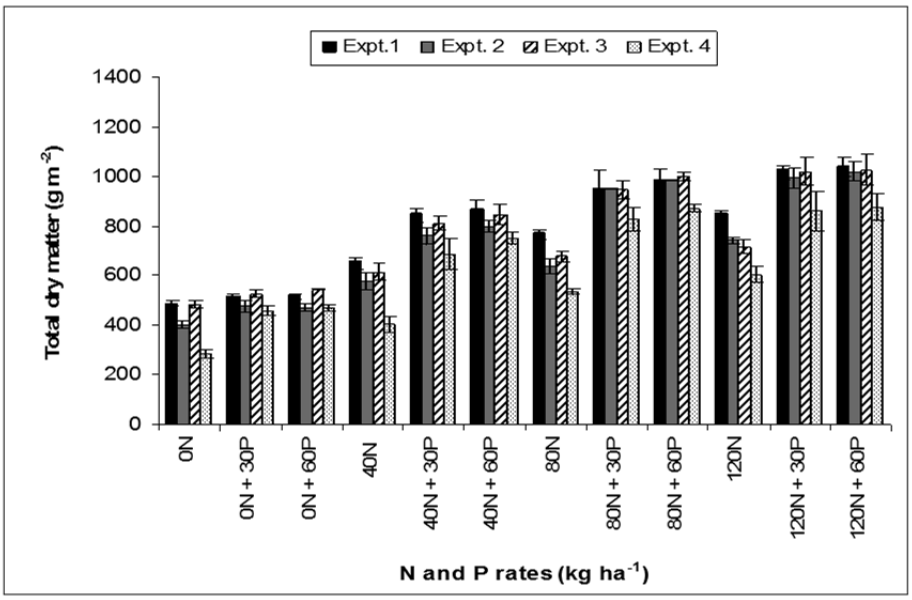


Figure 4. 8: Total dry matter yield of Dorke maize at different sites at Ejura, Ghana, 2008.

4.8 Harvest index

Harvest index (HI) shows the physiological efficiency of plants to convert the fraction of photoassimilates to grain yield. The HI computed as the ratio between maize grain yield and aboveground TDM production is presented in Tables 4.18 and 4.19.

The ANOVA showed a significant site effect ($p < 0.01$) on HI, with the highest mean HI of 0.37 at the Ejura farm (Expts. 1 and 3) compared to 0.36 at Agricultural College (Expt. 2 and 4). The seasonal effect on HI was significant ($p < 0.01$) with a 4.8 % increase in HI during the major season (Expt. 1) than during the minor season (Expt. 3).

Average across-sites, cultivar effects on HI were only significant in Ejura farm (Expts. 1 and 3) with Obatanpa (2.4 %) showing a higher HI than Dorke.

There was a significant influence of N ($p < 0.01$) on HI in all experiment at all levels of N but no effect of beyond 80 kg N ha^{-1}. There was interactive effect of N and P on HI only in Expt. 1 ($p < 0.05$) and Expt. 4 ($p < 0.01$) in the Obatanpa cultivar.

Table 4. 18: Effect of N and P fertilizer on harvest index of Obatanpa maize at Ejura, Ghana, 2008.

Treatment combination	N applied (kg ha^{-1})	P applied	Expt.1	Expt. 2	Expt.3	Expt.4
			HI (%)			
N1P1	0	0	0.31	0.25	0.25	0.30
N1P2	0	30	0.28	0.26	0.24	0.23
N1P3	0	60	0.29	0.27	0.24	0.24
N2P1	40	0	0.40	0.39	0.37	0.32
N2P2	40	30	0.38	0.37	0.37	0.36
N2P3	40	60	0.40	0.37	0.38	0.37
N3P1	80	0	0.42	0.41	0.44	0.44
N3P2	80	30	0.43	0.42	0.39	0.40
N3P3	80	60	0.43	0.43	0.40	0.40
N4P1	120	0	0.42	0.42	0.45	0.44
N4P2	120	30	0.44	0.43	0.40	0.39
N4P3	120	60	0.43	0.43	0.41	0.39
Mean			0.39	0.37	0.36	0.36
Effects			F-probability			
N			**	**	**	**
P			NS	NS	*	**
N * P interaction			*	NS	NS	**

*NS = Non-significant; *, ** = Significant at 0.05 and 0.01, respectively*

Significant effects ($p < 0.01$) of N on the HI of Dorke were observed in all experiments and all levels of N but not beyond 80 kg ha^{-1}. No interactive response of N and P on HI was observed.

Table 4. 19: Effect of N and P mineral fertilizer on harvest index of Dorke maize at Ejura, Ghana, 2008.

Treatment combination	N applied (kg ha^{-1})	P applied	Expt.1	Expt.2	Expt.3	Expt.4
			HI (%)			
N1P1	0	0	0.24	0.27	0.25	0.29
N1P2	0	30	0.24	0.26	0.24	0.22
N1P3	0	60	0.26	0.26	0.24	0.26
N2P1	40	0	0.39	0.36	0.35	0.37
N2P2	40	30	0.35	0.34	0.37	0.38
N2P3	40	60	0.38	0.35	0.37	0.38
N3P1	80	0	0.43	0.43	0.42	0.41
N3P2	80	30	0.42	0.36	0.39	0.40
N3P3	80	60	0.42	0.37	0.40	0.39
N4P1	120	0	0.43	0.42	0.44	0.41
N4P2	120	30	0.41	0.39	0.41	0.39
N4P3	120	60	0.40	0.38	0.39	0.41
Mean			0.37	0.35	0.35	0.36
Effects			F-probability			
N			**	**	**	**
P			NS	**	*	NS
N * P interaction			NS	NS	NS	NS

*NS = Non-significant; *, ** = Significant at 0.05 and 0.01, respectively.*

4.9 Grain and stover N uptake in maize at harvest

4.9.1 Grain N uptake

Grain N uptake of maize as influenced by N and P fertilizer application is presented in Figure 4.9 and 4.10. Significant site effects ($p < 0.01$) on grain N uptake were observed, with the highest average N uptake (4.7 g m^{-2}) at the Ejura farm (Expts. 1 and 3) compared to Agricultural College (Expts. 2 and 4) which had 3.9 g m^{-2}.

Seasonal effect on grain N uptake was significant ($p < 0.01$), with a 4.1 % (4.8 vs. 4.6 g m^{-2}) increase in N uptake in the major season (Expt.1) compared to the minor season (Expt. 3).

A significant cultivar effect ($p < 0.01$) on grain N uptake was observed between the two cultivars, with a higher grain N uptake in Obatanpa than in Dorke

(Table 4.20). On average, Obatanpa had a 12% higher N uptake than Dorke, with the highest difference in Expt. 1 (15 %) and the lowest in Expt. 4 (10 %).

Table 4. 20: Effect of cultivar, N and P fertilizer on grain N uptake at final harvest at Ejura, Ghana, 2008.

Effects	Expt. 1	Expt. 2	Expt. 3	Expt. 4
			F-probability	
N	**	**	**	**
P	**	**	**	**
Cultivar	**	**	**	**
N*P	**	**	**	**
N*cultivar	NS	**	*	*
P*cultivar	NS	NS	NS	NS
N*P*Cultivar	NS	NS	NS	NS

*NS = Non-significant; *, ** = Significant at 0.05 and 0.01, respectively.*

A significant ($p < 0.01$) increase in grain N uptake in Obatanpa in all experiments with the application of N and P inorganic fertilizer was observed (Figure 4.9). In Expt. 1, grain N uptake ranged from 2.2 g m^{-2} in the control (N1P1) to 7.9 g m^{-2} with N4P3. The application of 60 kg P ha^{-1} increased grain N uptake by 2, 25, 25 and 27 % at 0, 40 80 and 120 kg N ha^{-1}, respectively. There was a significant response in grain N uptake at 0 kg P ha^{-1} and the other levels of P. However, no significant response in grain N uptake was observed beyond 30 kg P ha^{-1}. The application of 80 kg N ha^{-1} and 30 kg P ha^{-1} led to a higher gain N uptake than 120 kg N ha^{-1} without P application. This translated into a higher grain yield in this treatment than 120 kg N ha^{-1} without P fertilizer.

In Expt. 2, grain N uptake ranged from 2 g m^{-2} (N1P1) to 7 g m^{-2} (N4P2). Application of 30 kg P ha^{-1} fertilizer increased grain N uptake by 6, 23, 28 and 31 % over treatments without P fertilizer for 0, 40, 80 and 120 kg N ha^{-1}, respectively. In Expt. 3, increase in grain N uptake ranged from 7 (N1P1) to 25 % (N4P2) when compared with plots without P fertilizer application. Experiment 4 showed the lowest grain N uptake, with uptake values ranging from 1.2 g m^{-2} (N1P1) to 6.1 g m^{-2} (N4P2 and N4P3). The P fertilizer significantly increased ($p < 0.01$) grain N uptake by 24, 45, 40 and 32 % compared to treatments without P for N levels of 0, 40 80 and 120 kg ha^{-1}, respectively.

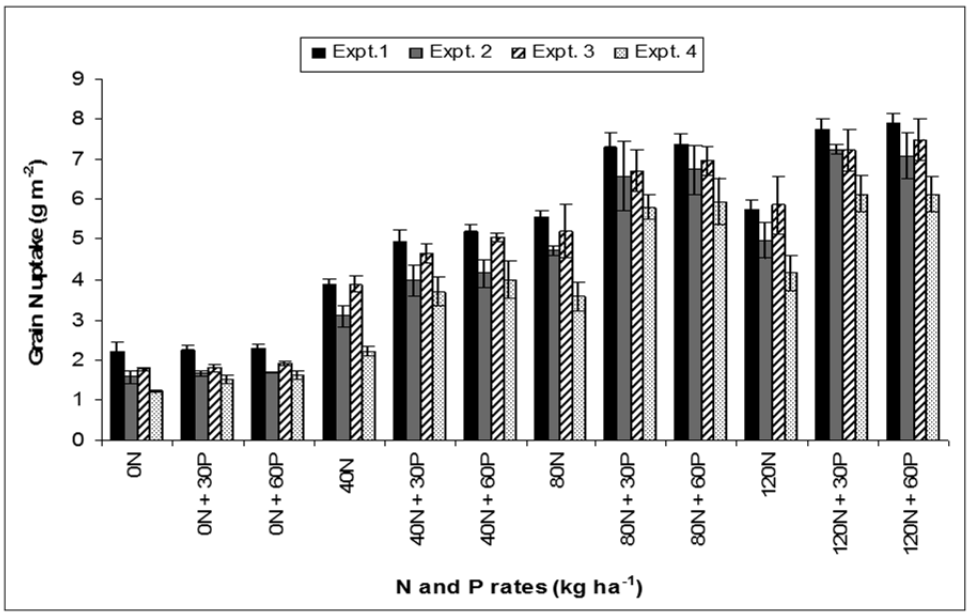


Figure 4. 9: Effect of N and P fertilizer on Obatanpa maize grain N uptake at Ejura, Ghana, 2008.

Similar trends were observed for the Dorke maize cultivar. A significant ($p < 0.01$) increase in grain N uptake in this cultivar in all experiments was observed with the application of N and P fertilizer. Grain N uptake in Expt. 1 significantly increased by 4, 20, 28 and 19 % with the application of 60 kg P ha^{-1} over those without P fertilizer

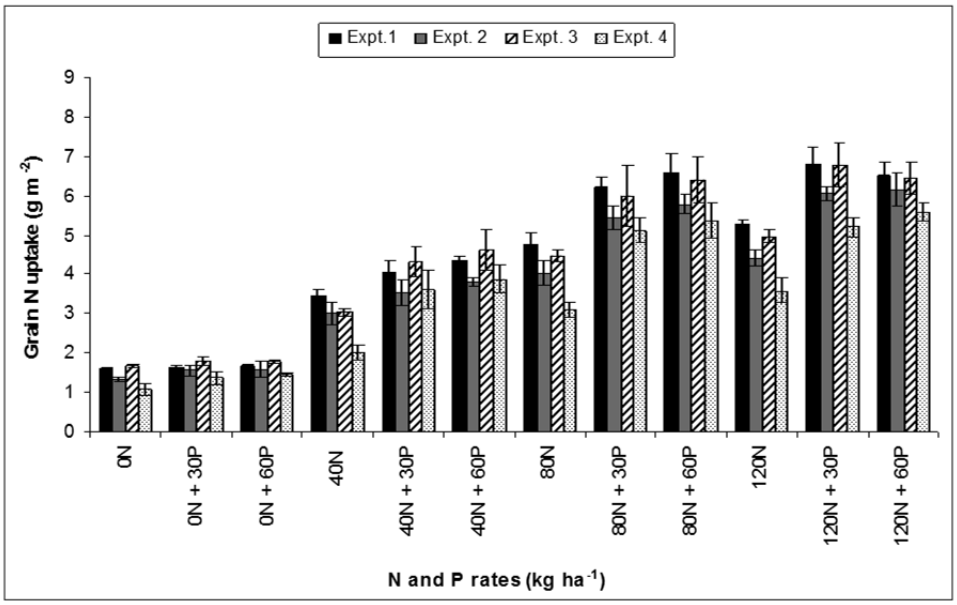


Figure 4. 10: Effect of N and P fertilizer on Dorke maize grain N uptake at Ejura, Ghana, 2008.

application at 0, 40, 80 and 120 kg N ha^{-1} respectively. In Expt. 2, application of 60 kg P ha^{-1} fertilizer increased grain N uptake in the range of 16, and 30 %. In Expt. 3 grain N uptake ranged from 1.7 g m^{-2} (N1P1) to 6.8 g m^{-2} (N4P2), representing a 75 % increase. Experiment 4 had the lowest grain N uptake with 60 kg P ha^{-1} ranging from 1.1 (N1P1) to 5.6 g m^{-2} (N4P3).

4.9.2 Stover N uptake

Stover N uptake in all experiments for the two cultivars is presented in Figures 4.11 and 4.12. The site effect on stover N uptake was highly significant ($p < 0.01$) with an average of 8.6% higher stover N uptake at the Ejura farm site than at the Agric College site.

The seasonal effect on stover N uptake was also significant ($p < 0.05$) with a 1.2 % (4.1 vs. 4.2 g m^{-2}) lower uptake during the major season compared to the minor season. There was however no significant difference between the two cultivars.

Application of N and P fertilizer significantly increased stover N uptake in Obatanpa maize in all experiments and at all levels of N except 40 kg N ha^{-1} in experiments 3 and 4, where values were not significantly difference from the control (0 kg N ha^{-1}). Positive interactive response ($p < 0.01$) of N and P was observed only in experiments 3 and 4. In Expt. 1, stover N uptake ranged from 2.8 g m^{-2} in the control to 5.3 g m^{-2} (N4P3), which represents a 47 % increment over the control. In Expt. 2, stover N uptake ranged from 2.7 g m^{-2} (N1P1) to 5.2 g m^{-2} (N4P3). Experiment 4 showed the lowest stover N uptake ranging from 1.9 (N1P1) to 5.8 g m^{-2} (N4P2 and N4P3), representing an increase of 67 %, and in Expt. 3 values ranged from 3.0 to 5.8 g m^{-2}, representing 48 % increase.

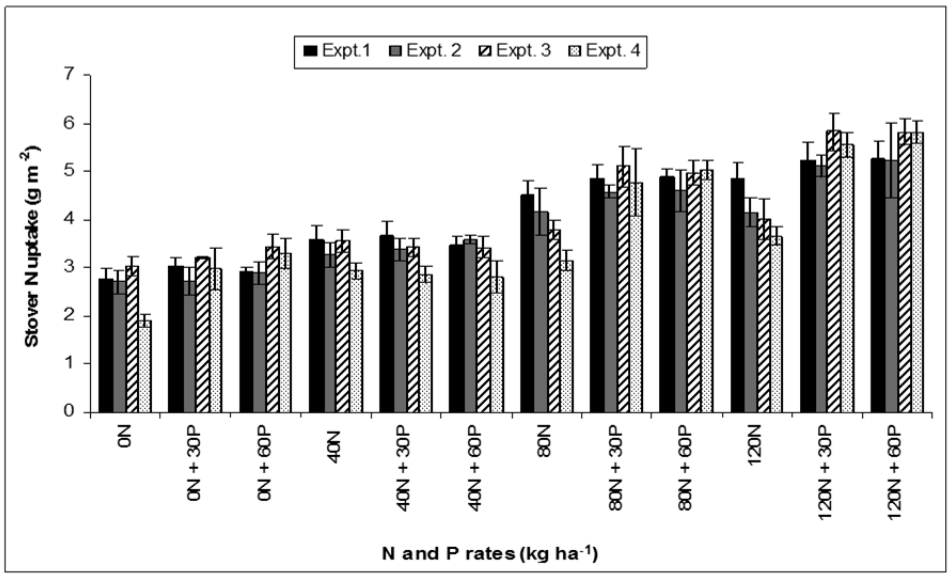


Figure 4. 11: Effect of N and P mineral fertilizer on Obatanpa maize stover N uptake at Ejura, Ghana, 2008.

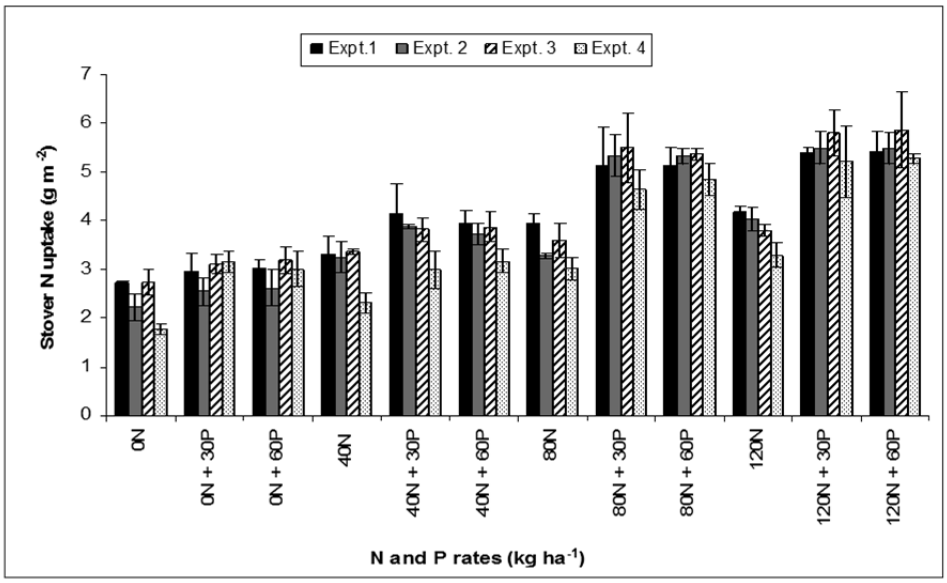


Figure 4. 12: Effect of N and P fertilizer on Dorke stover yield major and minor season, 2008.

A similar trend was observed in the Dorke maize cultivar, where the application of N and P fertilizer significantly ($p < 0.01$) increased stover N uptake over the control. Significant differences in stover N uptake were observed between uptake at 0 kg P ha^{-1} and the other P levels (30 and 60 kg P ha^{-1}). In Expt. 1, uptake ranged from 2.7 g m^{-2} (N1P1) to 5.4 g m^{-2} (N4P2 and N4P3), while the highest of 5.5 g m^{-2} (N4P2 and N4P3) was recorded in Expt. 2. Experiment 4 had the lowest values ranging from

1.8 g m^{-2} (N1P1) to 5.3 g m^{-2} (N4P3), while 5.9 g m^{-2} was recorded as the highest N uptake in Expt. 3.

4.9.3 Grain P uptake at harvest

Grain P uptake at final harvest in all experiments is presented in Figures 4.13 and 4.14. The ANOVA showed a highly significant site effect ($p < 0.01$) on grain P uptake with a higher grain P uptake at the Ejura farm site (23.3 %) than at Agricultural College.

Average across-sites, cultivar effect on grain P uptake was highly significant ($p < 0.01$), with Obatanpa showing a higher P uptake (10.5 %) than Dorke.

The seasonal effect on grain P uptake was also significant ($p < 0.01$) with a 14 % (1.0 vs. 0.8 g m^{-2}) higher uptake during the major season than during the minor season.

On average, about 65 % of the P uptake in the maize was in the grain and 35 % in the stover. This has implications for P export and soil depletion of P, as the grain is removed and eaten, which removes the largest fraction of the P taken up. In this study, P uptake by grain was significantly ($p < 0.01$) influenced by the application of N and P fertilizer at three levels of N, but there was no effect of N and P beyond 80 kg N ha^{-1} if there was no P application. Generally, grain P uptake was low. In Expt. 1, grain P uptake in Obatanpa ranged from 0.4 g m^{-2} in the control to 1.7 g m^{-2} (N4P3),

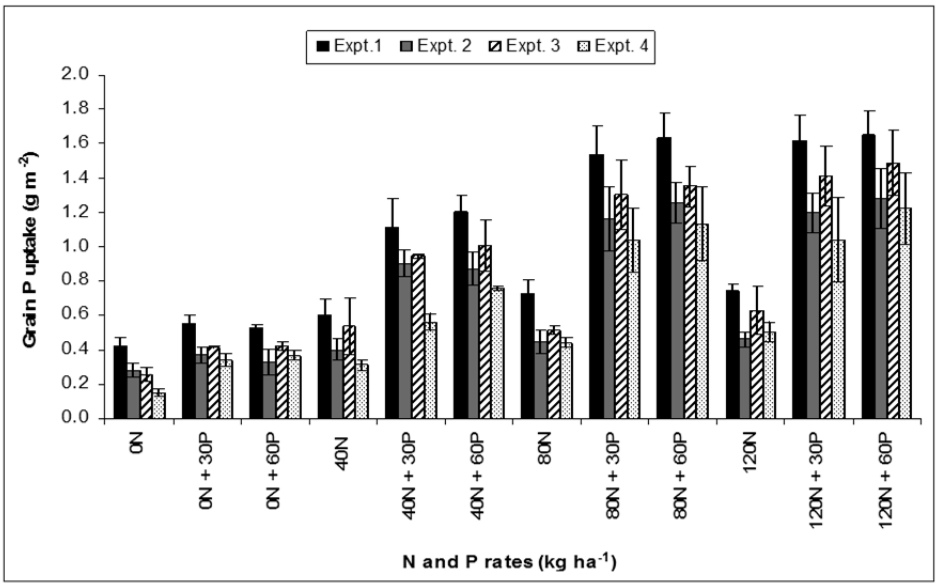


Figure 4. 13: Effect of N and P mineral fertilizer on Obatanpa grain P uptake at Ejura, Ghana, 2008.

representing a 74 % increase; in Expt. 2, values ranged from 0.3 g m^{-2} to 1.3 g m^{-2} (N3P3 and N4P3), representing a 78 % increase. Experiment 4 had the lowest grain P uptake, with values ranging from 0.2 to 1.2 g m^{-2}, while Expt. 3 had values ranging from 0.3 (N1P1) to 1.5 g m^{-2} (TN4P3), representing an 83 % increase over the control (N1P1).

Nitrogen and P significantly increase grain P uptake in Dorke cultivar (Figure 4.14) and mutually re-enforced their effect ($p < 0.01$). There was, however, no significant response of P beyond 30 kg ha^{-1}, but there was a significant response of P up to 60 kg ha^{-1} in experiment 4 reflecting the low level of extractable P. In Expt. 1, grain P uptake ranged from 0.3 g m^{-2} (N1P1) to 1.5 g m^{-1} (N4P3) while the highest of 1.1 g m^{-2} (N3P3, N4P2, and N4P3) was obtained in Expt. 2. In Expt. 3, values ranged from 0.2 g m^{-2} (N1P1) to 1.3 g m^{-2} (N3P3, N4P2 and N4P3), while the highest of 1.1 g m^{-2} (N4P3) was obtained in Expt. 4.

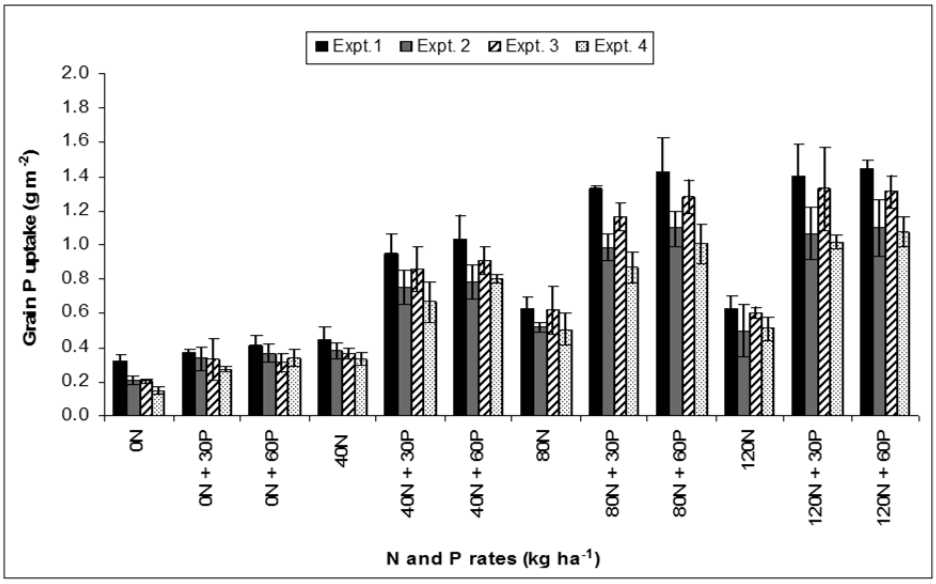


Figure 4. 14: Effect of N and P mineral fertilizer on Dorke grain P uptake at Ejura, Ghana, 2008.

4.9.4 Stover P uptake at harvest

Stover P uptake at final harvest in all experiments is presented in Figures 4.15 and 4.16. The site effect on stover P uptake was highly significant ($p < 0.01$), with a higher stover P uptake at the Ejura farm site (8.2 %) than at Agricultural College. During the major

season, there was a 3.9 % less stover P uptake at the Ejura farm site (Expt. 1) compared to the Agric College site (Expt. 2), but an increase of 18.8 % during the minor season (Expt. 3) compared to Agric College (Expt. 4).

Averaged across sites, there was no significant cultivar effect on stover P uptake. The seasonal effect was not significant, however, there was a 12 % (0.41 vs. 0.49 mg m^{-2}) less stover P uptake during the major season (Expt. 1) compared to the minor season (Expt. 3).

Phosphorus uptake by Obatanpa maize stover was significantly influenced ($p < 0.01$) by the application of N and P fertilizer. However, there was no interactive effect between N and P. In Expt. 1, there was no significant difference at 40, 80 and 120 kg N ha^{-1}. Stover P uptake ranged from 0.3 g m^{-2} (N1P1) to 0.6 g m^{-2} (N2P3). In Expt. 2, there was a significant increase at all levels of N but no significant response beyond 80 kg N ha^{-1}. The highest value of 0.6 g m^{-2} was recorded in Expt. 2 (N3P2), Expt. 3 (N4P2) and Expt. 4.

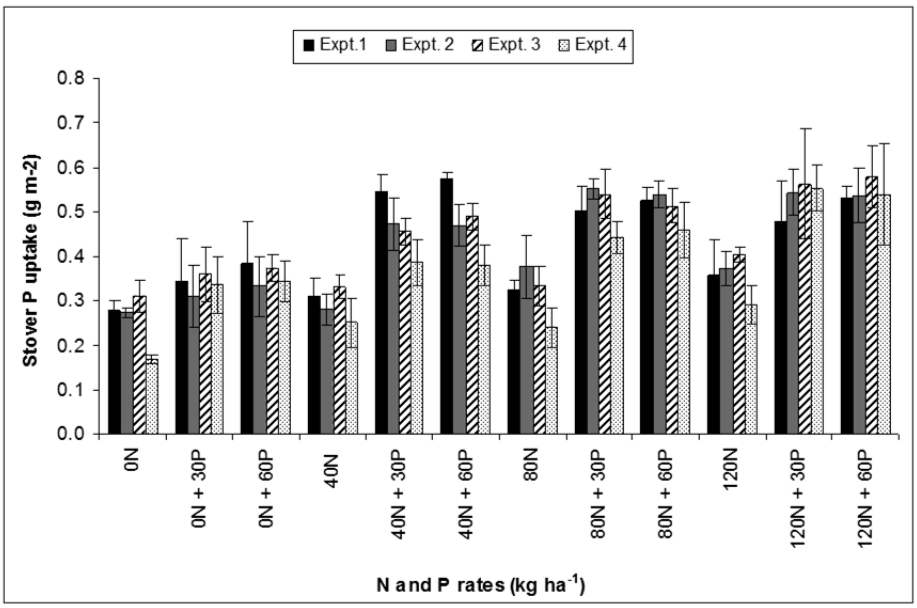


Figure 4. 15: Effect of N and P mineral fertilizer on Obatanpa stover P uptake at Ejura, Ghana, 2008.

There was no significant interactive effect between N and P on stover P uptake in the Dorke cultivar in all experiments. Significant differences were, however, observed between stover P uptake at 0 kg P ha^{-1} and the other P levels (30 and 60 kg P

ha^{-1}). In Expt. 1, stover P uptake, ranged from 0.3 g m^{-2} (N1P1) to 0.5 g m^{-2} (N4P3). The highest value of 0.7 g m^{-2} (N4P3) was observed in Expt. 3 followed by Expt. 2 and Expt. 4 (0.6 g m^{-2}).

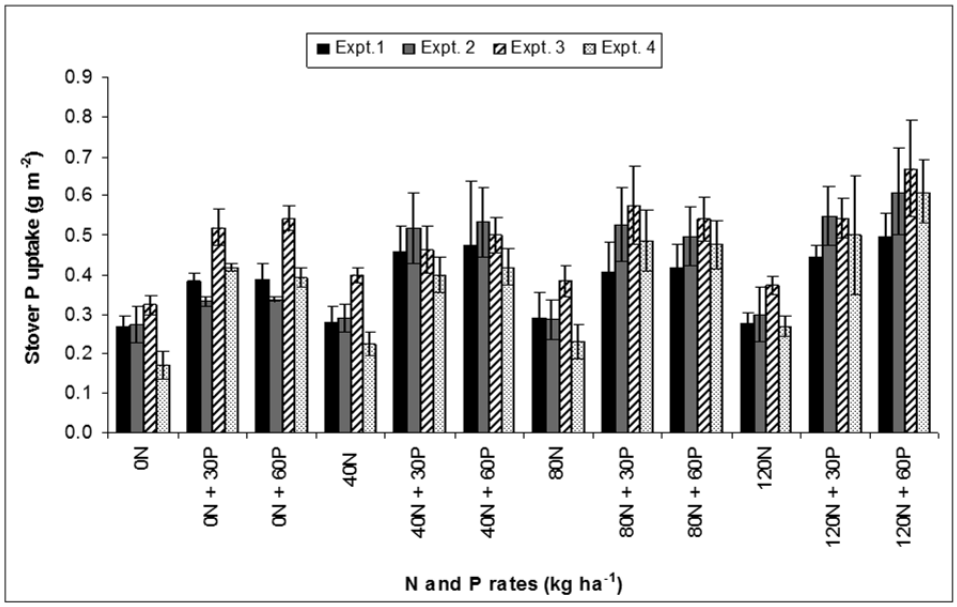


Figure 4. 16: Effect of N and P mineral fertilizer on Dorke Stover P uptake at Ejura, Ghana, 2008.

4.10 Apparent N recovery

The apparent nitrogen recovery (ANR) by maize plants from mineral fertilizer in relation to the control is presented in Figures 4.17 and 4.18. The approach used does not take into account the effect of applied N on the transformation of native soil N nor the difference in soil N exploitation as determined by the increased size of the root system of the fertilized crops. As a result, the actual N recovery by the test crop may be over-estimated. Generally, ANR in grain was higher at the Ejura farm site than at Agricultural College, while the opposite is true for ANR in stover.

The site effect on ANR was significant ($p < 0.01$) in both grain and stover with an 11.7% increase in ANR in the grain at the Ejura farm site and a 20.6 % reduction in the stover when compared to the Agricultural College site.

There was no significant seasonal effect on ANR in both grain and stover. The ANOVA revealed a significantly higher ANR in Obatanpa cultivar than in Dorke in grain; the reverse applied to stover. Averaged across sites, ANR of Obatanpa grain was 9.4 % higher than that of Dorke, while there was a 24.2 % lower in the stover.

ANR generally decreased with increasing N rates but increased with increasing P rate. ANR at 0 kg P ha^{-1} was significantly lower than for 30 and 60 kg P ha^{-1} for both cultivars. For Obatanpa, an interactive effect ($p < 0.01$) of N and P was observed only in Expt. 4 for grain ANR and in Expt. 3 and 4 for stover ANR. In Expt. 1, ANR in Obatanpa ranged from 29.5 to 73.9 % in the grain, with the highest recovery in plants which received 40 kg N ha^{-1} and 60 kg P ha^{-1} (N2P3). For the stover, this ranged from 16.9 (N2P3) to 26.1 % (N3P3). Grain ANR in plants which received 40, 80 and 120 kg N ha^{-1} increased by 43.9, 35.1 and 37.4 %, respectively, when 60 kg P ha^{-1} was applied. In Expt. 2, ANR in grain ranged from 28.5 (N4P1) to 64.9% (N2P3) and in stover from 12.0 % (N4P1) to 23.6 T (N3P3). In Expt. 3, ANR ranged from 34.0 (N4P1) to 82.2 % (N2P3), while only 8.1 to 25.9 % were obtained in the stover. The application of 60 kg P ha^{-1} increased ANR in grain by 35.7, 50.1 and 39.9% for 40 80 and 120 kg N ha^{-1} over plots that did not receive P. In Expt. 4, similar trends were observed, where ANR in grain ranged from 24.3 (N2P1) to 69.2 % (N2P3) and 14.6 to 39 % in stover.

The application of N and P fertilizer in Dorke increased ANR of aboveground biomass. In Expt. 1, ANR in grain ranged from 30.7 to 68.2 %, and in stover from 12.2 to 36.1 %. The application of 60 kg P ha^{-1} fertilizer increased ANR in grain by 31.5, 36.5 and 25.3 % for N levels of 40, 80 and 120 kg N ha^{-1}, respectively. In Expt. 2, the increase was 25.5 to 61.8 % in grain, and in stover it was 13.2 to 41.4 %. Experiments 3 and 4 showed similar values, with ANR in grain ranging from 27.3 to 73.1 % and 23.5 to 70.1 %, respectively. Apparent N recovery in stover in the same experiments ranged from 8.9 (N4P1) to 34.7% (N3P2) and 12.7 (N4P1) to 38.5 % (N3P3), respectively.

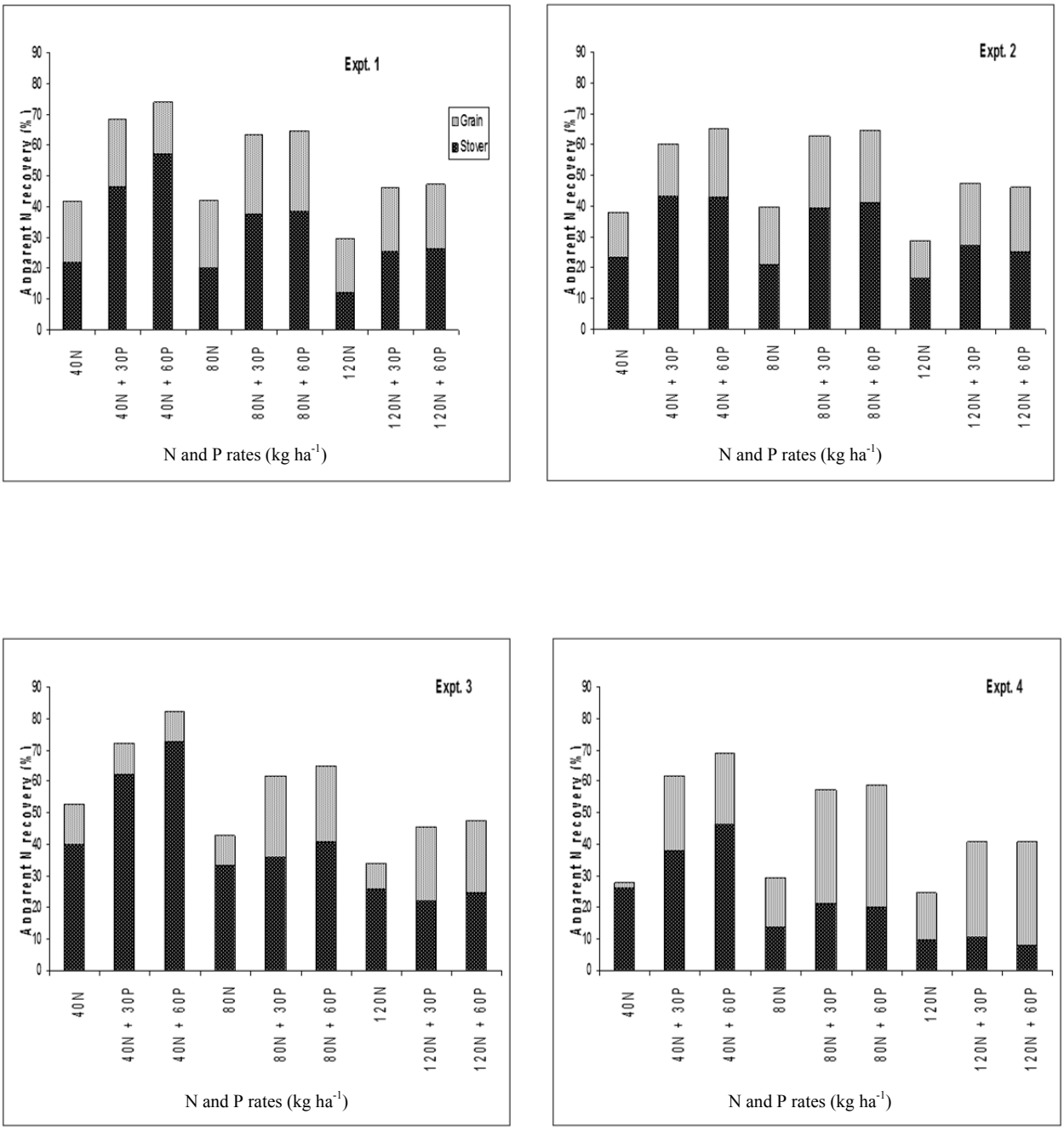


Figure 4. 17: Apparent N recovery of Obatanpa maize as affected by N and P mineral fertilizer at Ejura, Ghana, 2008.

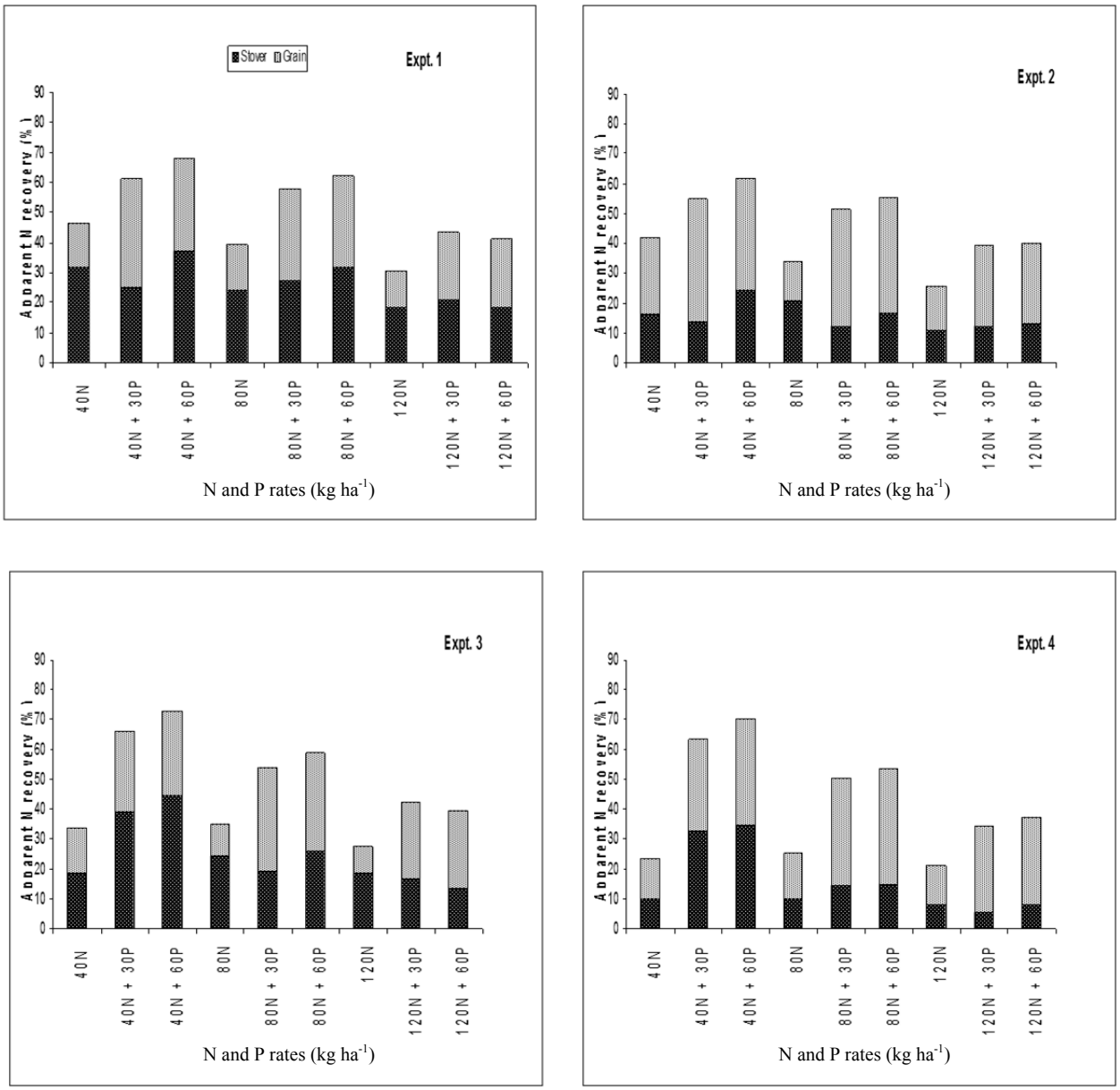


Figure 4. 18: Apparent N recovery of Dorke maize as affected by N and P mineral fertilizer at Ejura, Ghana, 2008.

4.11 Modeling maize growth and grain yield

4.11.1 Model parameterization

The APSIM-Maize model performed well in simulation of growth, phenology (Figures. 4.19a and 4.19b), grain yield and biomass (Table 4.21) during the parameterization process for both cultivars.

The model accurately predicted the number of days to flowering (tasseling) with a RMSE of 1 and 0 for the Obatanpa and Dorke cultivars, respectively. There was only a one-day difference between the observed and simulated days to tasseling for the Obatanpa cultivar. The APSIM-Maize model simulated number of days to physiological maturity for both cultivars with a RMSE of 4 and 3 days for Obatanpa and Dorke, respectively.

Table 4. 21: Observed and APSIM-simulated maize phenology, biomass production and grain yield for the model parameterization experiment.

Variable	Unit	Cultivar	Observed	Simulated	% diff.
Tasseling	day	Obatanpa	55	56	1.8
		Dorke	52	52	0
Maturity	day	Obatanpa	104	100	-4
		Dorke	92	89	-3.3
Maximum LAI		Obatanpa	3.31	2.99	-9.7
		Dorke	3.12	3.05	-2.2
Grain yield	g m^{-2}	Obatanpa	455	475	4.5
		Dorke	385	401	4.1
Total biomass	g m^{-2}	Obatanpa	1052	1063	1.1
		Dorke	1012	991	-2.0

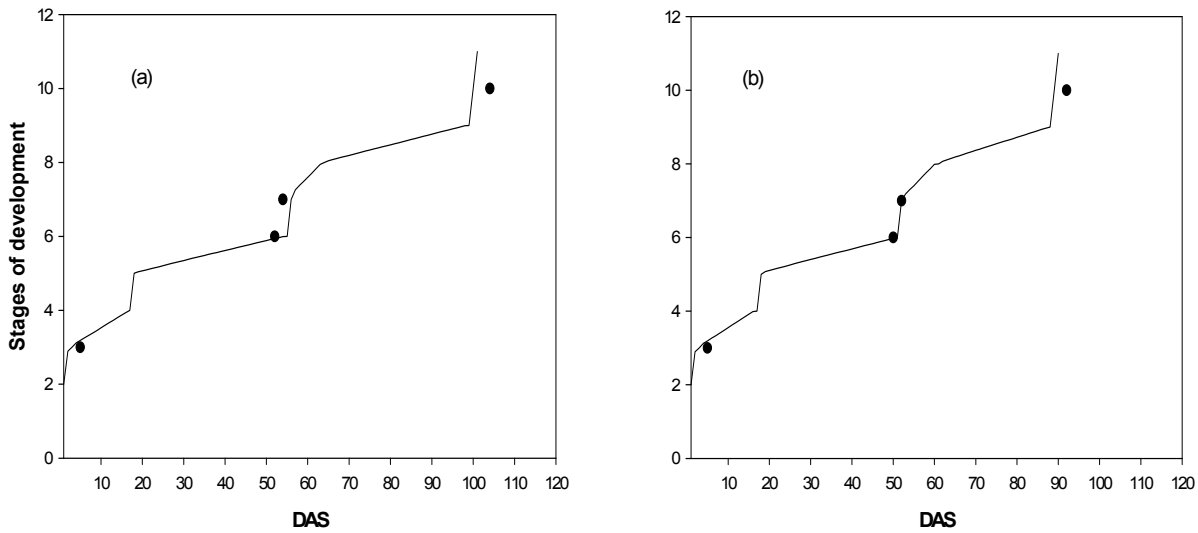


Figure 4. 19: Observed (symbol) and simulated (line) phenology of Obatanpa (a) and Dorke (b) maize cultivar from sowing to maturity for model parameterization.

4.11.2 Leaf area index

The model slightly under estimated the leaf area index (LAI) for both cultivars (Table 4.21) for both cultivars.

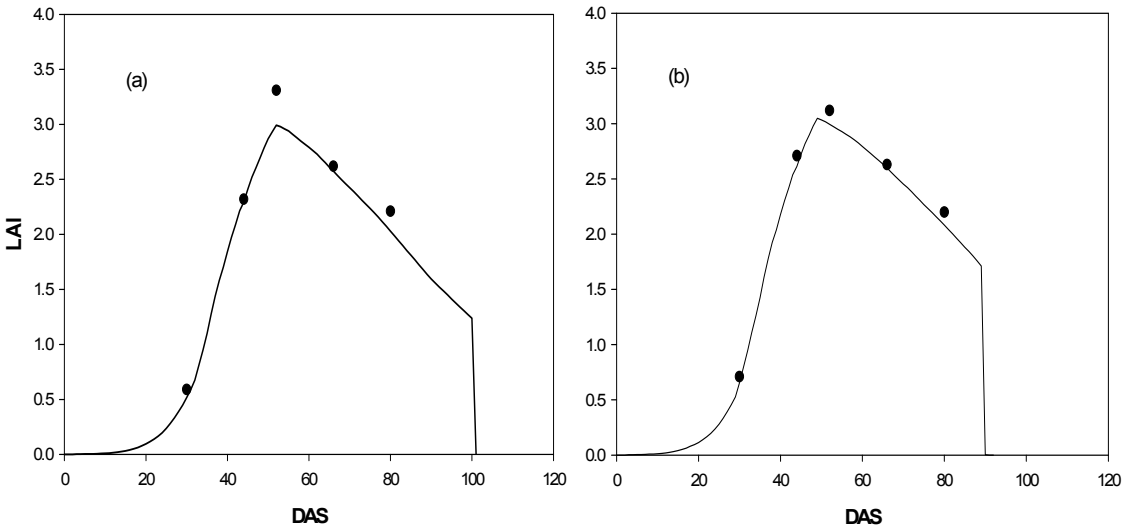


Figure 4. 20: Observed (symbol) and simulated (line) time series LAI of Obatanpa (a) and Dorke (b) maize cultivar from sowing to maturity for model parameterization.

4.11.3 Biomass accumulation

Plant biomass accumulation was accurately simulated by the model (Figure 4.21). At 55 DAS, biomass was overestimated by 2.1% in Obatanpa and underestimated by 1.6% in Dorke. However, these differences are well within an acceptable range.

Similarly, total biomass was overestimated by only 1.07% over that measured for Obatanpa and underestimated by 2.1% for Dorke cultivar compared to the measured values.

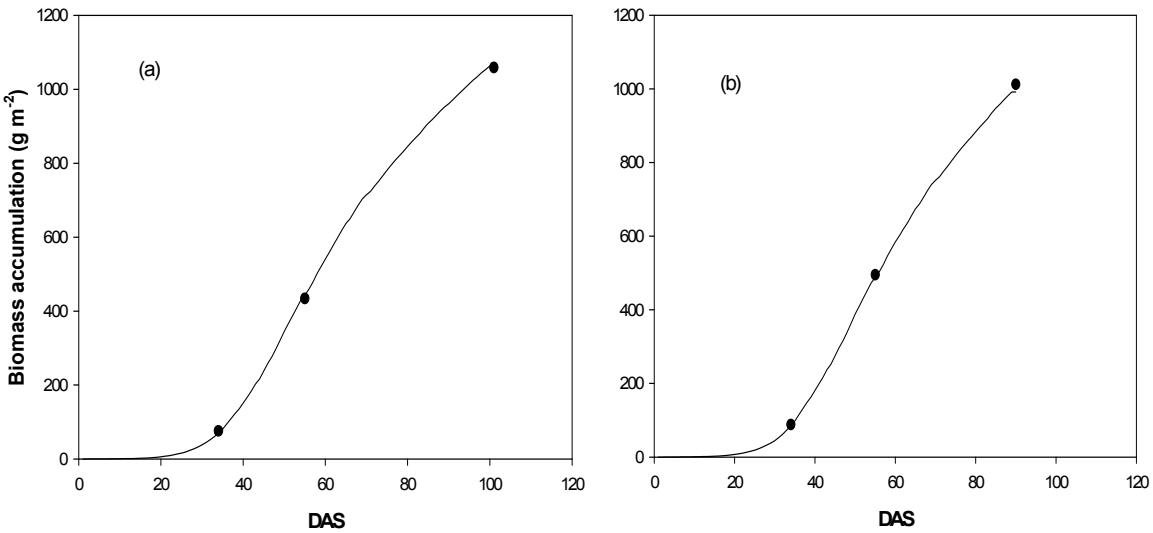


Figure 4. 21: Observed (symbol) and simulated (line) biomass accumulation of Obatanpa (a) and Dorke (b) maize cultivar from sowing to maturity for model parameterization.

Model performance in simulating grain yield was good with overestimation of grain yield by 4.5 and 4.1% for Obatanpa and Dorke, respectively. Soil moisture was well simulated. The model was able to capture the variability of rainfall as reflected in the soil moisture (Figure 4.22).

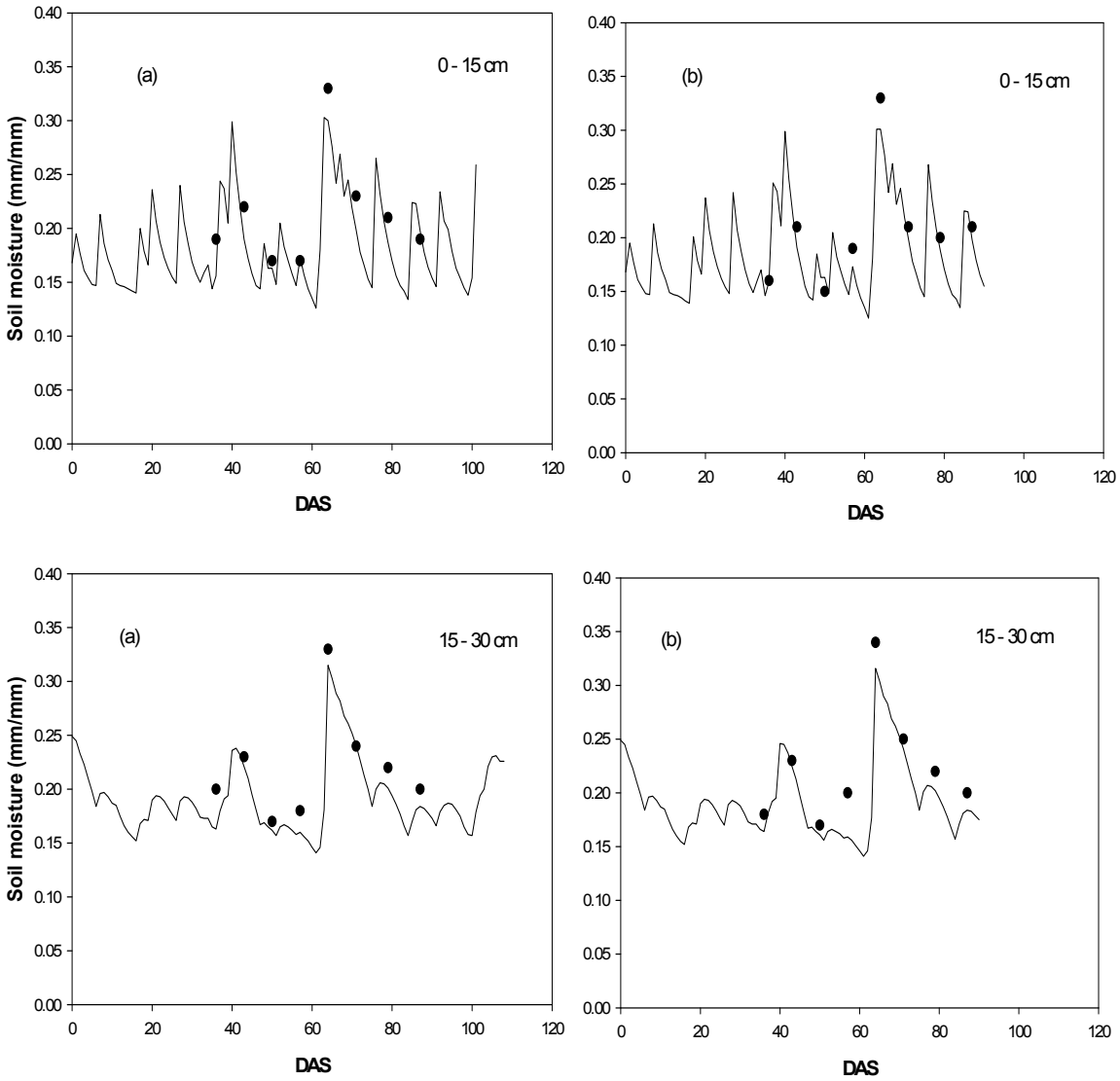


Figure 4. 22: Observed (symbol) and simulate (line) soil moisture at Agric College during parameterization for Obatanpa (a) and Dorke (b) for the top 30 cm soil depth.

4.12 Model Evaluation

The accuracy of the APSIM-Maize model simulations and performance of genetic coefficients were assessed by running the model with independent data sets collected during the major and minor seasons in 2008 for four levels of N (0, 40, 80 and 120 kg N ha^{-1}) and 3 levels of P (0, 30 and 60 kg P ha^{-1}) application at difference locations in Ejura.

4.13 Phenology

4.13.1 Days to emergence

Days to emergence was well simulated by the model with a deviation of 2 days and RMSE of 4 for both varieties.

4.13.2 Days to tasseling

Days to tasseling were delayed with increasing N stress in both cultivars in all experiments. The model closely predicted days to tasseling (Table 4.22) in the major season (experiments 1 and 2) for both varieties, with the highest deviation of 2 days in both cultivars. The model, however, overestimated days to tasseling during the minor season for both cultivars, with the highest deviation of 4 days for Obatanpa and Dorke. The model thus, simulated days to tasseling of both cultivars fairly well with an overall RMSE of 1.5 and 1.4 days for Obatanpa and Dorke, respectively.

4.13.3 Days to maturity

Similar trends were observed in the simulation of days to physiological maturity (Table 4.23) as in the simulation of days to tasseling. The APSIM-Maize model, did not show an effect of N availability on days to maturity, and predicted the same number of days to maturity at all levels of N. This indicates that the model assumes N and P stress do not affect days to maturity in maize. In general, the model was able to simulate days to maturity better at higher N levels as compared to the lower levels. The model simulated crop duration with an overall error of -4.6 % and -3.1% and RMSE values of 4.7 and 2.9 for Obatanpa and Dorke, respectively.

Table 4. 22: Comparison of simulated and observed days to tasseling at different N and P levels at Ejura, Ghana, 2008.

N and P level	Experiment 1			Experiment 2			Experiment 3			Experiment 4			Overall		
Obatanpa	Sim	Obs	Error (%)	Sim	Obs	Error (%)	Sim	Obs	Error (%)	Sim	Obs	Error (%)	Sim	Obs	Error (%)
N1P1	55	57	- 3.6	56	57	-1.8	59	58	1.7	61	59	3.3	58	58	0.0
N1P2	55	57	-3.6	56	57	-1.8	59	58	1.7	59	59	0	57	58	-0.9
N1P3	55	56	-1.8	56	57	-1.8	59	58	1.7	59	58	1.7	57	57	0.0
N2P1	55	56	-1.8	56	57	-1.8	59	57	3.4	59	57	3.4	57	57	0.9
N2P2	55	56	-1.8	56	56	0.0	59	57	3.4	59	57	3.4	57	57	1.3
N2P3	55	56	-1.8	56	56	0.0	59	56	5.1	59	56	5.1	57	56	2.2
N3P1	55	55	0.0	56	56	0.0	59	57	3.4	59	57	3.4	57	56	1.7
N3P2	55	55	0.0	56	55	1.8	59	56	5.1	59	56	5.1	57	56	3.1
N3P3	55	54	-1.8	56	55	1.8	59	55	6.8	59	56	5.1	57	55	3.9
N4P1	55	55	0.0	56	56	0.0	59	56	5.1	59	56	5.1	57	56	2.6
N4P2	55	54	1.8	56	55	1.8	59	55	6.8	59	55	6.8	57	55	4.4
N4P3	55	54	1.8	56	54	3.6	59	55	6.8	59	55	6.8	57	55	4.8
RMSE(days)		1.1			1.0			2.7			2.7			1.5	
Dorke															
N1P1	53	54	-1.9	52	54	-3.8	56	56	0.0	58	56	3.4	55	55	-0.5
N1P2	53	54	-1.9	52	54	-3.8	56	56	0.0	56	56	0.0	54	55	-1.4
N1P3	53	53	0.0	52	54	-3.8	56	55	1.8	56	56	0.0	54	55	-0.5
N2P1	53	53	0.0	52	54	-3.8	56	54	3.6	56	55	1.8	54	54	0.5
N2P2	53	53	0.0	52	53	-1.9	56	54	3.6	56	55	1.8	54	54	0.9
N2P3	53	52	1.9	52	53	-1.9	56	54	3.6	56	55	1.8	54	54	1.4
N3P1	53	52	1.9	52	53	-1.9	56	53	5.4	56	54	3.6	54	53	2.3
N3P2	53	51	3.8	52	52	0.0	56	53	5.4	56	54	3.6	54	53	3.2
N3P3	53	51	3.8	52	52	0.0	56	52	7.1	56	53	5.4	54	52	4.1
N4P1	53	52	1.9	52	53	-1.9	56	53	5.4	55	54	1.8	54	53	1.9
N4P2	53	51	3.8	52	52	0.0	56	52	7.1	56	53	5.4	54	52	4.1
N4P3	53	51	3.8	52	52	0.0	56	52	7.1	56	53	5.4	54	52	4.1
RMSE(days)		1.3			1.3			2.7			1.9			1.4	

4.13.4 Leaf area index

The APSIM-Maize model simulated the maximum LAI rather well, with better accuracy for the Dorke maize, with a RMSE values ranging from 0.08 to 0.23. The highest RMSE of 0.29 was recorded for Obatanpa in Expt. 4. In general, the model simulated LAI fairly well, with a mean coefficient of efficiency (R^2) of 0.91 and 0.94 for Obatanpa and Dorke, respectively. However, the model underestimated LAI with a mean error of 5 %.

Table 4. 23: Comparison of simulated and observed days to maturity at different N and P levels at Ejura, Ghana, 2008.

N and P level	Experiment 1			Experiment 2			Experiment 3			Experiment 4			Overall		
Obatanpa	Sim	Obs	Error (%)	Sim	Obs	Error (%)	Sim	Obs	Error (%)	Sim	Obs	Error (%)	Sim	Obs	Error (%)
N1P1	100	105	-5.0	100	106	-6.0	101	107	-5.9	102	107	-4.9	101	106	-5.5
N1P2	100	105	-5.0	100	106	-6.0	101	106	-5.0	101	107	-5.9	101	106	-5.5
N1P3	100	105	-5.0	100	106	-6.0	101	106	-5.0	101	106	-5.0	101	106	-5.2
N2P1	100	105	-5.0	100	105	-5.0	101	105	-4.0	101	106	-5.0	101	105	-4.7
N2P2	100	105	-5.0	100	105	-5.0	101	105	-4.0	101	106	-5.0	101	105	-4.7
N2P3	100	105	-5.0	100	105	-5.0	101	105	-4.0	101	106	-5.0	101	105	-4.7
N3P1	100	105	-5.0	100	105	-5.0	101	105	-4.0	101	106	-5.0	101	105	-4.7
N3P2	100	104	-4.0	100	105	-5.0	101	105	-4.0	101	105	-4.0	101	105	-4.2
N3P3	100	104	-4.0	100	104	-4.0	101	104	-3.0	101	105	-4.0	101	104	-3.7
N4P1	100	105	-5.0	100	105	-5.0	101	105	-4.0	101	106	-5.0	101	105	-4.7
N4P2	100	104	-4.0	100	104	-4.0	101	104	-3.0	101	105	-4.0	101	104	-3.7
N4P3	100	104	-4.0	100	104	-4.0	101	104	-3.0	101	105	-4.0	101	104	-3.7
RMSE(days)		4.7			5.0			4.2			4.8			4.7	
Dorke															
N1P1	90	93	-3.3	89	94	-5.6	91	95	-4.4	94	96	-2.1	91	95	-3.8
N1P2	90	93	-3.3	89	94	-5.6	91	95	-4.4	91	95	-4.4	90	94	-4.4
N1P3	90	93	-3.3	89	94	-5.6	91	95	-4.4	91	95	-4.4	90	94	-4.4
N2P1	90	93	-3.3	89	94	-5.6	91	94	-3.3	92	95	-3.3	91	94	-3.9
N2P2	90	92	-2.2	89	93	-4.5	91	93	-2.2	91	94	-3.3	90	93	-3.0
N2P3	90	92	-2.2	89	93	-4.5	91	93	-2.2	91	94	-3.3	90	93	-3.0
N3P1	90	92	-2.2	89	93	-4.5	91	93	-2.2	91	94	-3.3	90	93	-3.0
N3P2	90	92	-2.2	89	92	-3.4	91	93	-2.2	91	93	-2.2	90	93	-2.5
N3P3	90	91	-1.1	89	92	-3.4	91	92	-1.1	91	93	-2.2	90	92	-1.9
N4P1	90	92	-2.2	89	92	-3.4	91	93	-2.2	90	94	-4.4	90	93	-3.1
N4P2	90	91	-1.1	89	92	-3.4	91	92	-1.1	91	93	-2.2	90	92	-1.9
N4P3	90	91	-1.1	89	92	-3.4	91	92	-1.1	91	93	-2.2	90	92	-1.9
RMSE(days)		2.2			4.0			2.6			2.9			2.9	

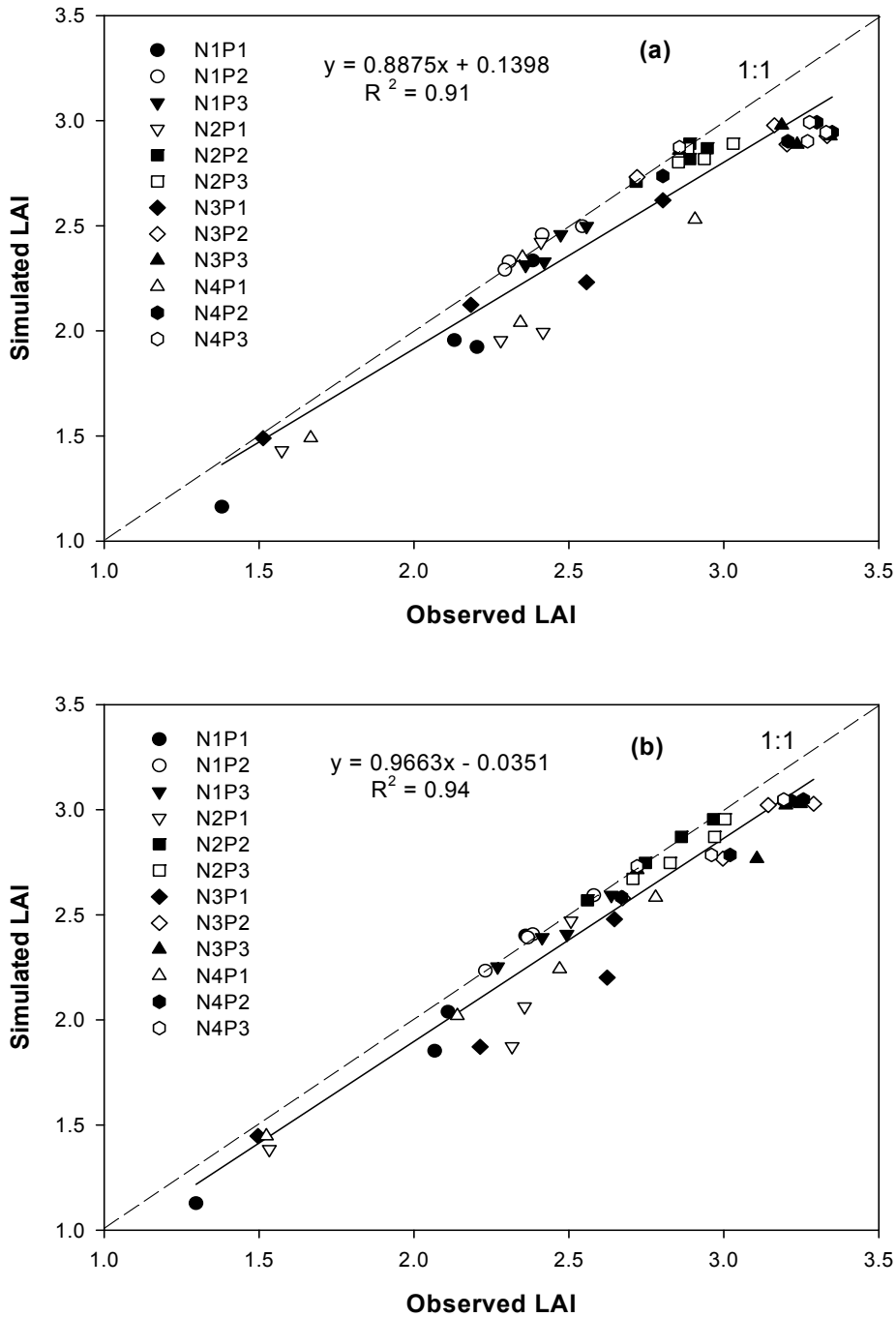


Figure 4. 23: Comparison of observed and simulated maximum LAI of Obatanpa (a) and Dorke (b) maize cultivars at Ejura, Ghana, 2008. N1, N2, N3 and N4 indicate 0, 40, 80 and 120 kg N ha^{-1}; P1, P2 and P3 are for 0, 30 and 60 kg P ha^{-1}

4.14 Grain yield

In general, the model simulated the trend of maize yield fairly well in all experiments (Figure 4.24), with RMSE values ranging from 26.1 g m^{-2} to 67.1 g m^{-2} and modified coefficiency (E1) between 0.34 to 0.80 % . The model simulated well grain yield in response to the various levels of inorganic N and P fertilizer applications (Figure 4.24), with overall coefficients of determination R^2 of 0.90 and 0.88 for Obatanpa and Dorke, respectively.

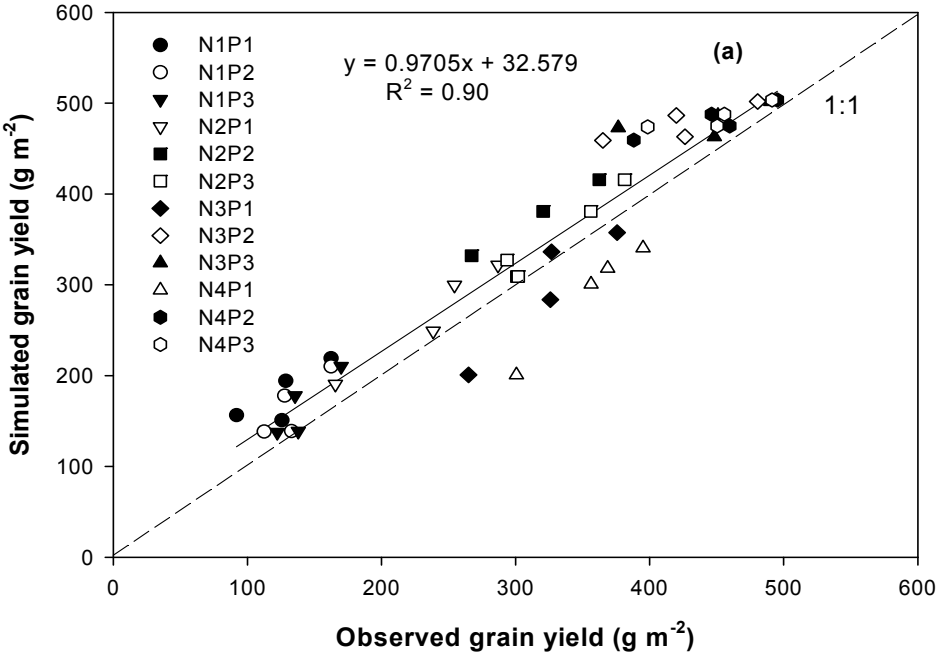
Table 4. 24: Performance of APSIM-Maize to predict maize grain yield response to inorganic N and P fertilizer.

Experiments	Number of observations	RMSE (g m^{-2})	MdUAPE (%)	E1	R^2
Obatampa					
Expt. 1	36	37.0	10	0.69	0.94
Expt. 2	36	26.1	4	0.80	0.95
Expt. 3	36	46.6	15	0.58	0.93
Expt. 4	36	67.1	21	0.34	0.82
Overall	144	46.7	14	0.63	0.90
Dorke					
Expt. 1	36	35.5	12	0.68	0.93
Expt. 2	36	27.0	5	0.75	0.93
Expt. 3	36	42.1	14	0.58	0.91
Expt. 4	36	52.8	18	0.42	0.85
Overall	144	40.5	12	0.62	0.88

Grain yields were better simulated for in experiments 1 and 2 (with MdUAPE values of 10 and 4 % for Obatanpa and 12 and 5 % for Dorke, respectively) than in experiments 3 and 4 (Table 4.24). The lowest RMSE for both cultivars was in Expt. 2 followed by experiments 1, 3 and 4 in a decreasing order. Again, the model simulated inorganic P application with zero N application best in Expt. 2.

Grain yield was fairly well predicted in experiments 1 and 2 (major season) however, it was overestimated for the minor season, with RMSE values of 46.6 and 67.1 g m^{-2} for Obatanpa and 42.1 and 52.8 g m^{-2} for Dorke, respectively. The simulated grain yield response to N and P application corresponded well with measured data with an overall MdUAPE of 14 and 12 % for Obatanpa and Dorke, respectively.

The coefficients of model accuracy R^2 were Expt. 2 > 1 > 3 > 4 in decreasing order, with Expt. 4 having the lowest average value of 0.82 and 0.85 for Obatanpa and Dorke, respectively.



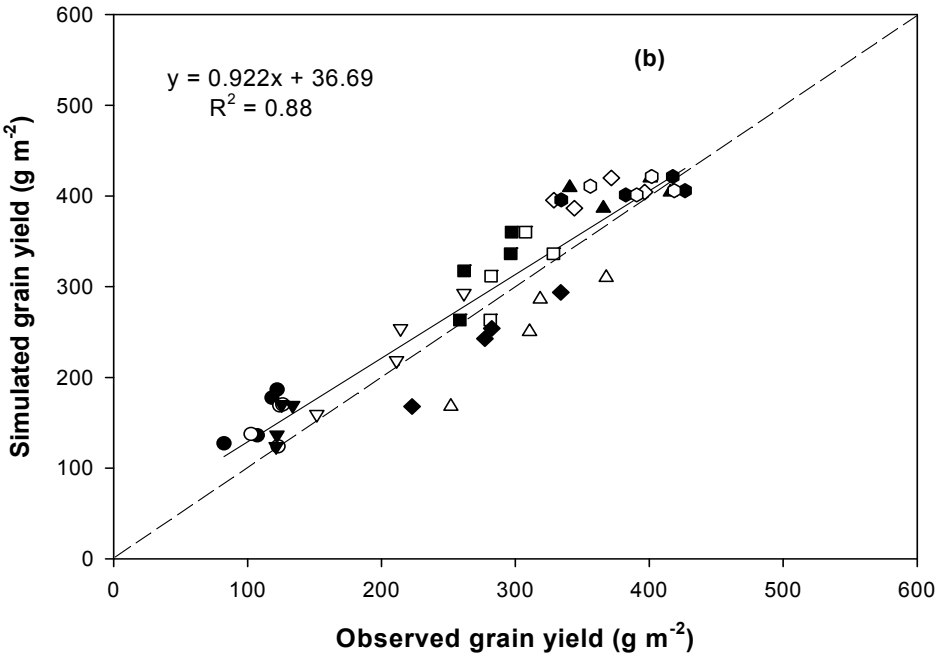


Figure 4. 24: Comparison of observed and simulated grain yield of Obatanpa (a) and Dorke (b) maize cultivars for different levels of N and P at Ejura, Ghana, 2008. (for legends see Fig. 4.23).

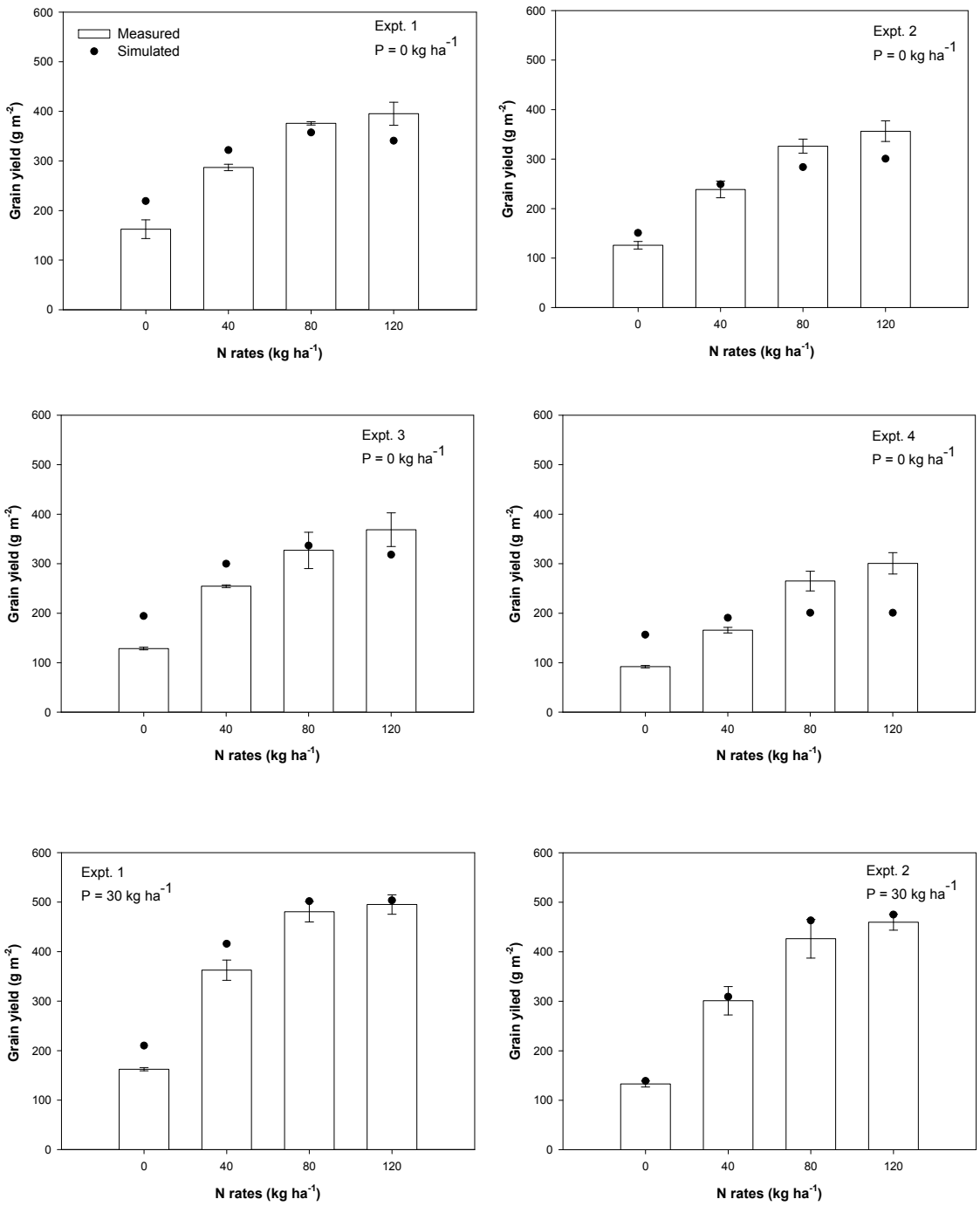


Figure 4. 25: Comparison of observed and simulated grain yield of Obatampa maize cultivar under different rates of inorganic N and P fertilizer in different experiments at Ejura, Ghana, 2008.

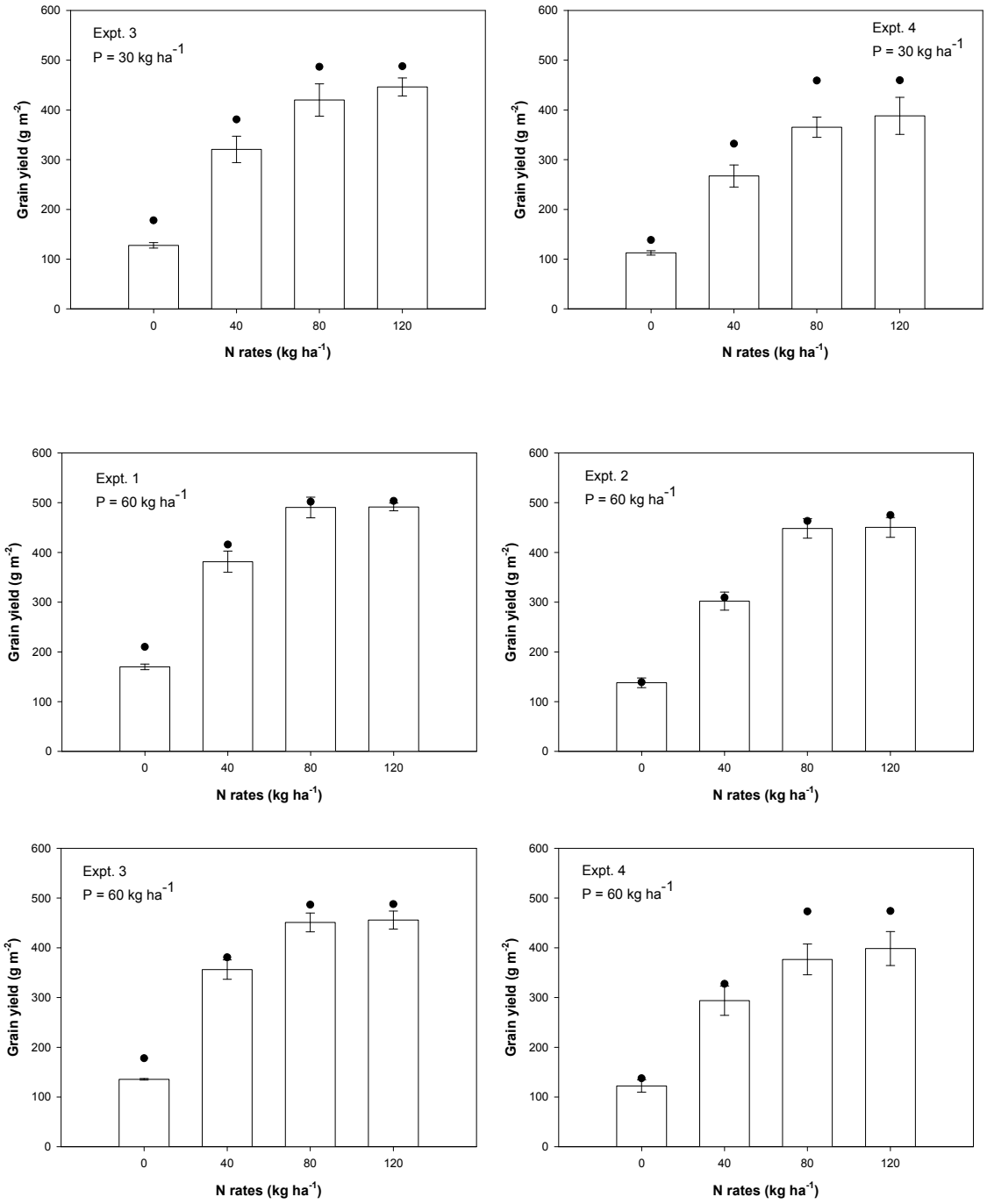


Figure 4. 26: Comparison of observed and simulated grain of Obatampa maize cultivar under different rates of N and P inorganic fertilizer in different experiments at Ejura, Ghana, 2008.

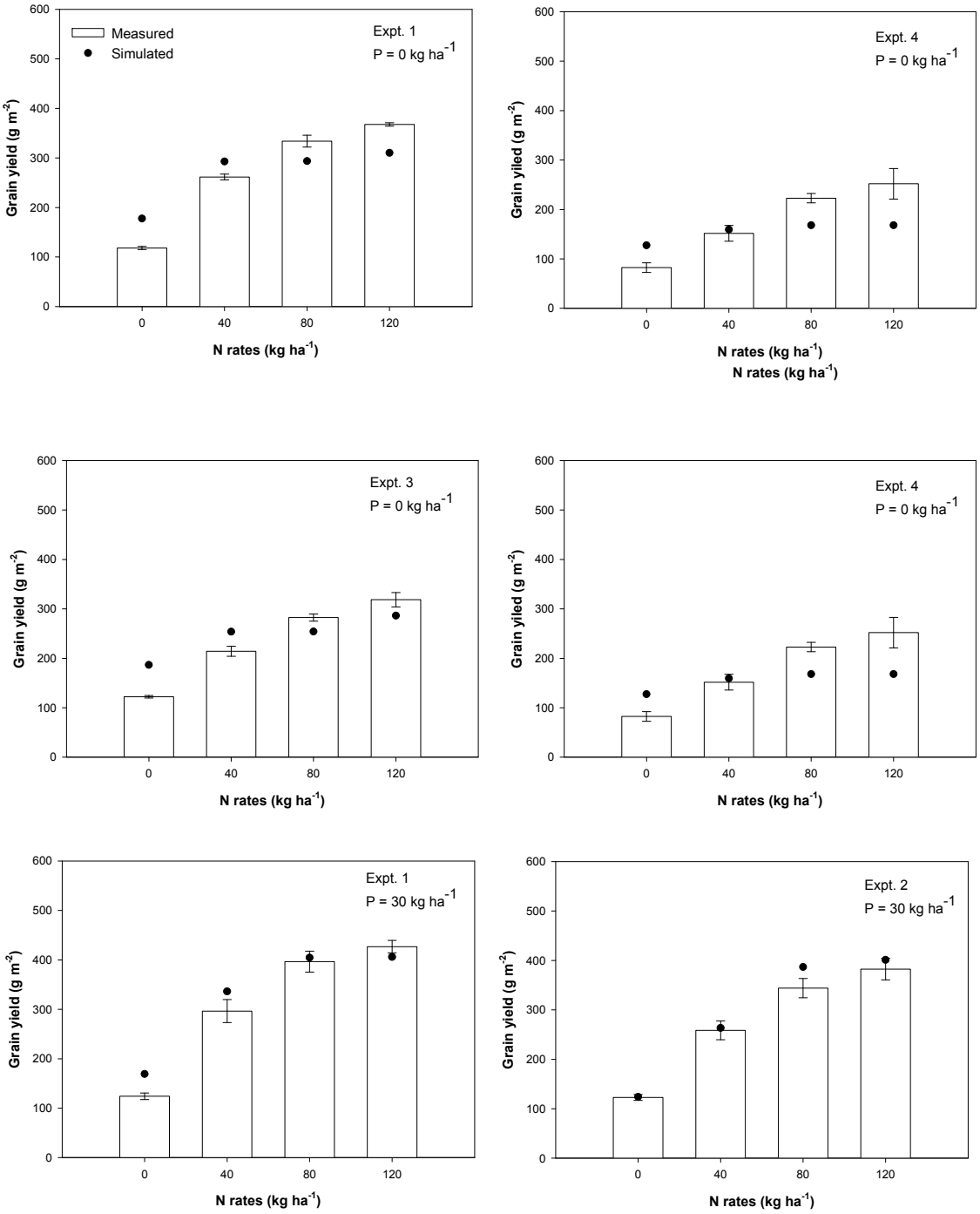


Figure 4. 27: Comparison of observed and simulated grain yield of Dorke maize cultivar under different rates of N and P inorganic fertilizer in different experiments at Ejura, Ghana, 2008.

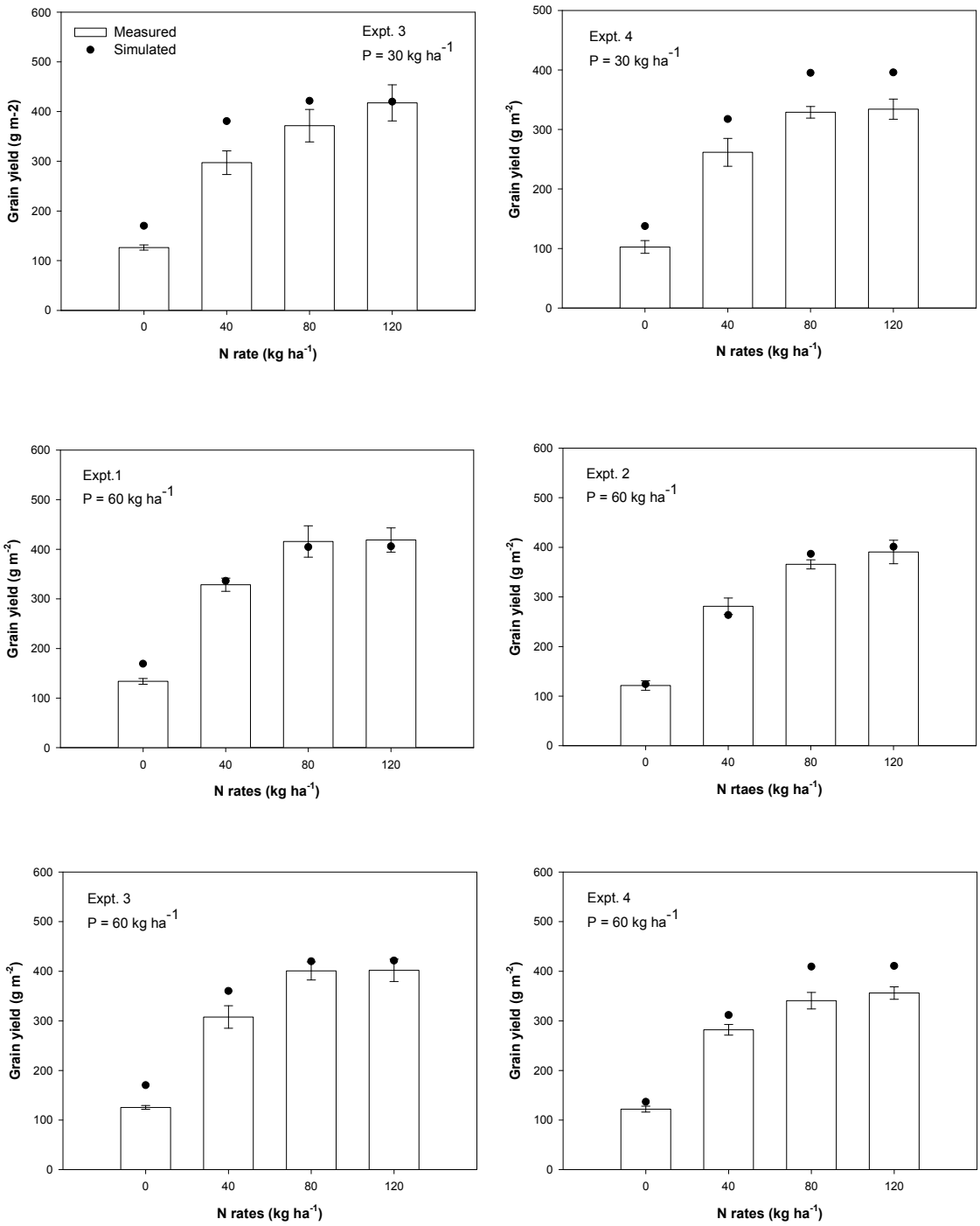


Figure 4. 28: Comparison of observed and simulated grain yield of Dorke maize cultivars for different rates of N and P inorganic fertilizer at Ejura, Ghana, 2008.

4.15 Total dry matter yield

The APSIM-Maize model simulated crop biomass development with good agreement with observed biomass data collected during the major and minor seasons of 2008. However, due to the enormity of data only the comparison of simulated and observed TDM at harvest is presented in the results (Figure 4.29). There was a good agreement between the measured and simulated TDM yield at harvest, with overall coefficient of determination (R^2) values of 0.89 and 0.91 for Obatanpa and Dorke, respectively. The overall RMSE values were 78.0 g m^{-2} and 66.1 g m^{-2}, and model coefficients of efficiency were 0.68 and 0.70 (Table 4.25) for Obatanpa and Dorke, respectively.

Table 4. 25: Performance of APSIM to simulate maize total dry matter response to inorganic N and P fertilizer.

Experiments	Number of observations	RMSE (g m^{-2})	MdUAPE (%)	E1	R^2
Obatampa					
Expt. 1	36	79.6	8	0.62	0.95
Expt. 2	36	54.9	3	0.80	0.93
Expt. 3	36	64.4	5	0.72	0.93
Expt. 4	36	104.0	13	0.52	0.89
Overall	144	78.0	7	0.68	0.89
Dorke					
Expt. 1	36	63.6	6	0.68	0.91
Expt. 2	36	48.1	3	0.81	0.95
Expt. 3	36	57.8	7	0.74	0.94
Expt. 4	36	97.1	12	0.54	0.89
Overall	144	66.1	7	0.70	0.91

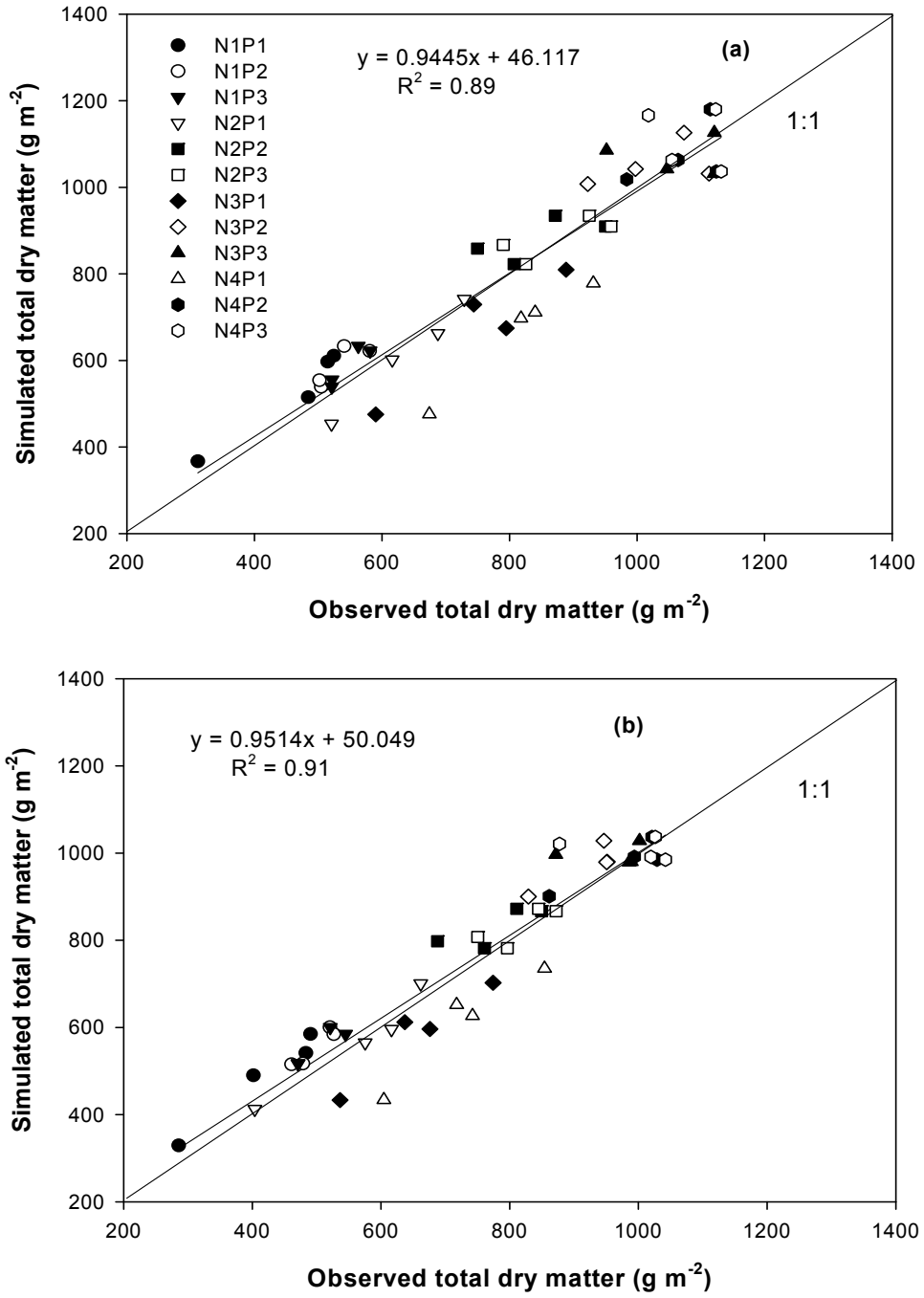


Figure 4. 29: Comparison of observed and simulated total dry matter of Obatanpa (a) and Dorke (b) maize for different treatments at Ejura, Ghana, 2008. (for legends see Fig. 4.23).

4.16 Grain N uptake Grain N uptake was calculated from grain N concentration and grain yield. The trend in model simulation of grain N uptake was similar to that in grain yield and biomass simulation. The model simulated grain N uptake rather well for

both cultivars (Figure 4.30) with RMSE values ranging from 0.59 to 1.22 g m^{-2} in Obatanpa and 0.65 to 1.47 g m^{-2} in Dorke. An overall coefficient of determination (R^2) of 0.86 and 0.82 was obtained for Obatanpa and Dorke. There was a good MdUAPE of16 and 20 % for Obatanpa and Dorke, respectively. The model, however, overestimated grain N uptake at higher N levels (80 and 120 kg ha^{-1}) in experiments 3 and 4.

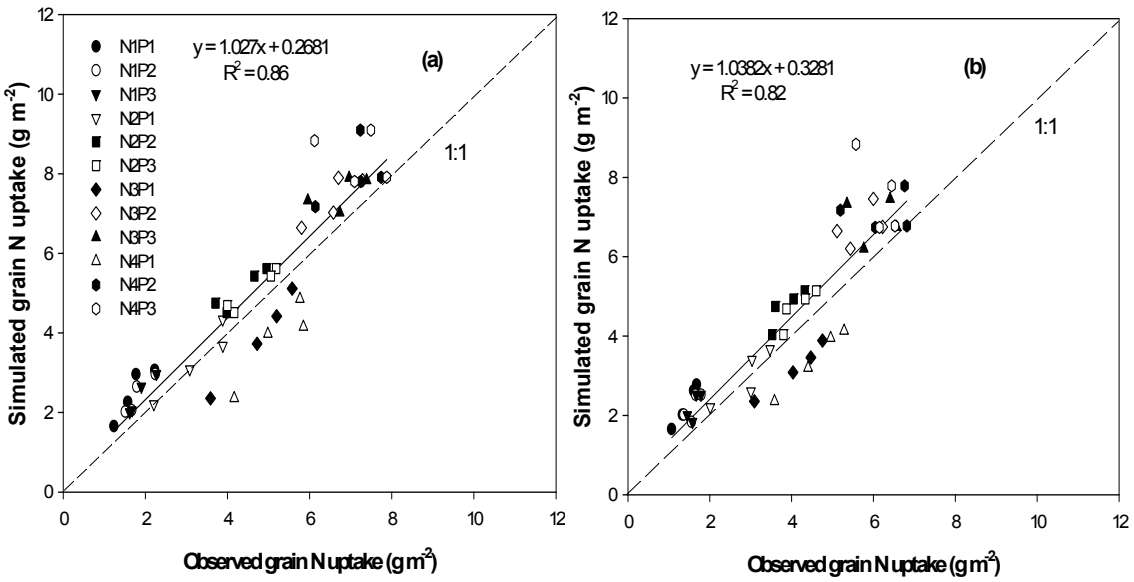


Figure 4. 30: Comparison of observed and simulated grain N uptake of Obatanpa (a) and Dorke (b) maize for different N and P fertilizer rates at Ejura, Ghana, 2008. (for legends see Fig. 4.23).

4.17 Total N uptake

The trend in total N uptake was successfully simulated by the model for both varieties for the different treatments (Figure 4.31). However, there was a slight overestimation of total N uptake by the model, with RMSE values ranging from 0.58 to 1.39 g m^{-2} and 0.73 to 1.21 g m^{-2} for Obatanpa and Dorke, respectively, with the highest variation in Expt. 4 (Table 4.26). The model effectively simulated the interactive effect of N and P. In general, the model performed well with an overall coefficient of determination (R^2) of 0.96 and a modified coefficient of model efficiency (E1) of 0.71 and 0.72 for Obatanpa and Dorke, respectively.

Table 4. 26: Performance of APSIM to predict maize total N uptake in response to inorganic N and P fertilizer.

Experiments	Number of observations	RMSE (g m^{-2})	MdUAPE (%)	E1	R^2
Obatampa					
Expt. 1	36	0.58	5	0.82	0.98
Expt. 2	36	0.71	7	0.77	0.98
Expt. 3	36	1.09	9	0.66	0.97
Expt. 4	36	1.39	13	0.56	0.93
Overall	144	0.99	8	0.71	0.96
Dorke					
Expt. 1	36	0.78	7	0.71	0.98
Expt. 2	36	0.73	5	0.77	0.97
Expt. 3	36	0.68	5	0.78	0.98
Expt. 4	36	1.21	11	0.54	0.94
Overall	144	0.88	7	0.72	0.96

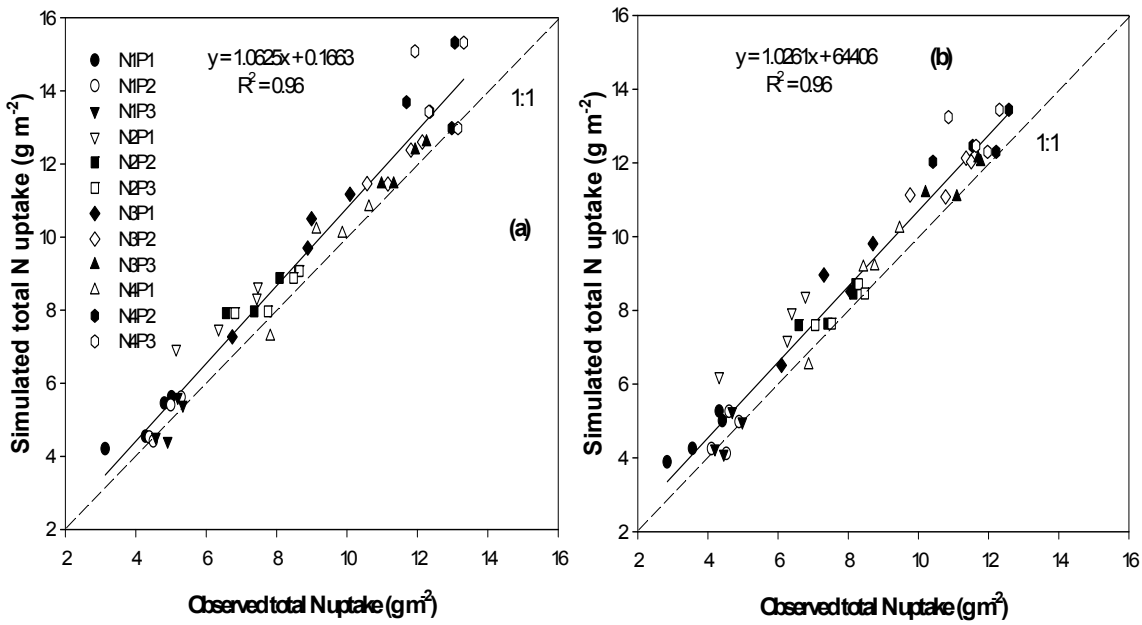


Figure 4. 31: Comparison of observed and simulated total N uptake of Obatanpa (a) and Dorke (b) maize for different N and P fertilizer rates at Ejura, Ghana, 2008 (for legends see Fig. 4.23).

4.18 Total P uptake

Similarly, total P uptake was well simulated by the model (Figure 4.32), with an overall coefficient of efficiency (R^2) of 0.86 and 0.85 for Obatanpa and Dorke, respectively.

However, the model underestimated total P uptake with an overall RMSE of 0.24 g m^{-2} (Table 4.27).

Table 4. 27: Performance of APSIM to predict maize total P uptake in response to N and P inorganic fertilizer.

Experiments	Number of observations	RMSE (g m^{-2})	MdUAPE (%)	E1	R^2
Obatampa					
Expt. 1	36	0.24	12	0.62	0.93
Expt. 2	36	0.12	7	0.80	0.95
Expt. 3	36	0.26	12	0.60	0.81
Expt. 4	36	0.31	21	0.42	0.71
Overall	144	0.24	13	0.63	0.86
Dorke					
Expt. 1	36	0.19	13	0.66	0.92
Expt. 2	36	0.15	7	0.72	0.93
Expt. 3	36	0.28	10	0.53	0.80
Expt. 4	36	0.30	21	0.37	0.75
Overall	144	0.24	12	0.58	0.85

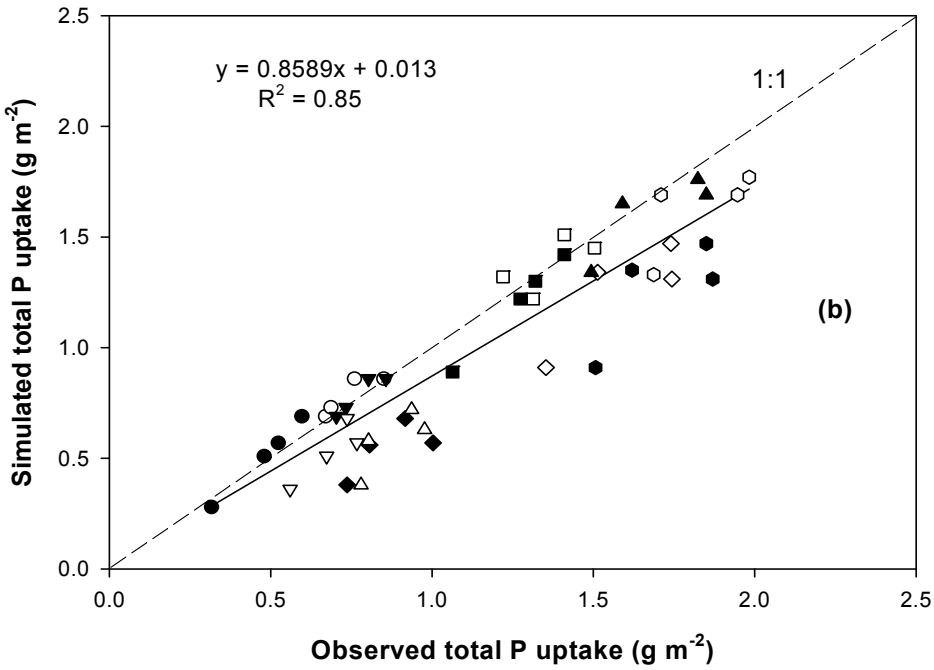


Figure 4. 32: Comparison of observed and simulated total P uptake of Obatanpa (a) and Dorke (b) maize for different N and P fertilizer rates at Ejura, Ghana, 2008. (for legends see Fig. 4.23).

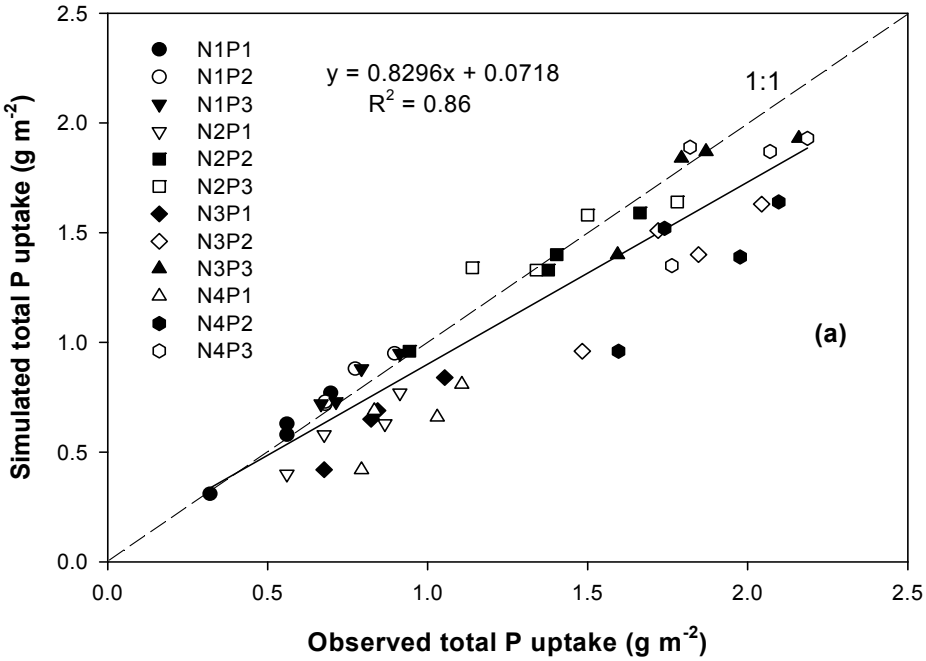


Figure 4. 33: continued

4.19 Soil water dynamics

Figure 4.33 shows the time series of simulated and measured soil moisture (on Haplic Lixisol) at Ejura farm during the major season for 120 kg N ha^{-1} and 60 kg P ha^{-1}. The dynamics of soil water content were well simulated for both seasons (minor season not presented).

As expected, changes in soil moisture were more dynamic in the top 30 cm soil layer than in the subsoil. Soil moisture uptake from 90-105 cm soil depth was negligible (graph not presented). The model accurately simulated soil moisture dynamics in the various soil profile layers but slightly underestimated soil moisture for the 0-15, 15-30 and 30-45 cm soil layers where fluctuation was greater (Figure 4.33). For the soil layers 0-15 and 15-30 cm, the RMSE was 0.032 and 0.038 mm/mm, respectively.

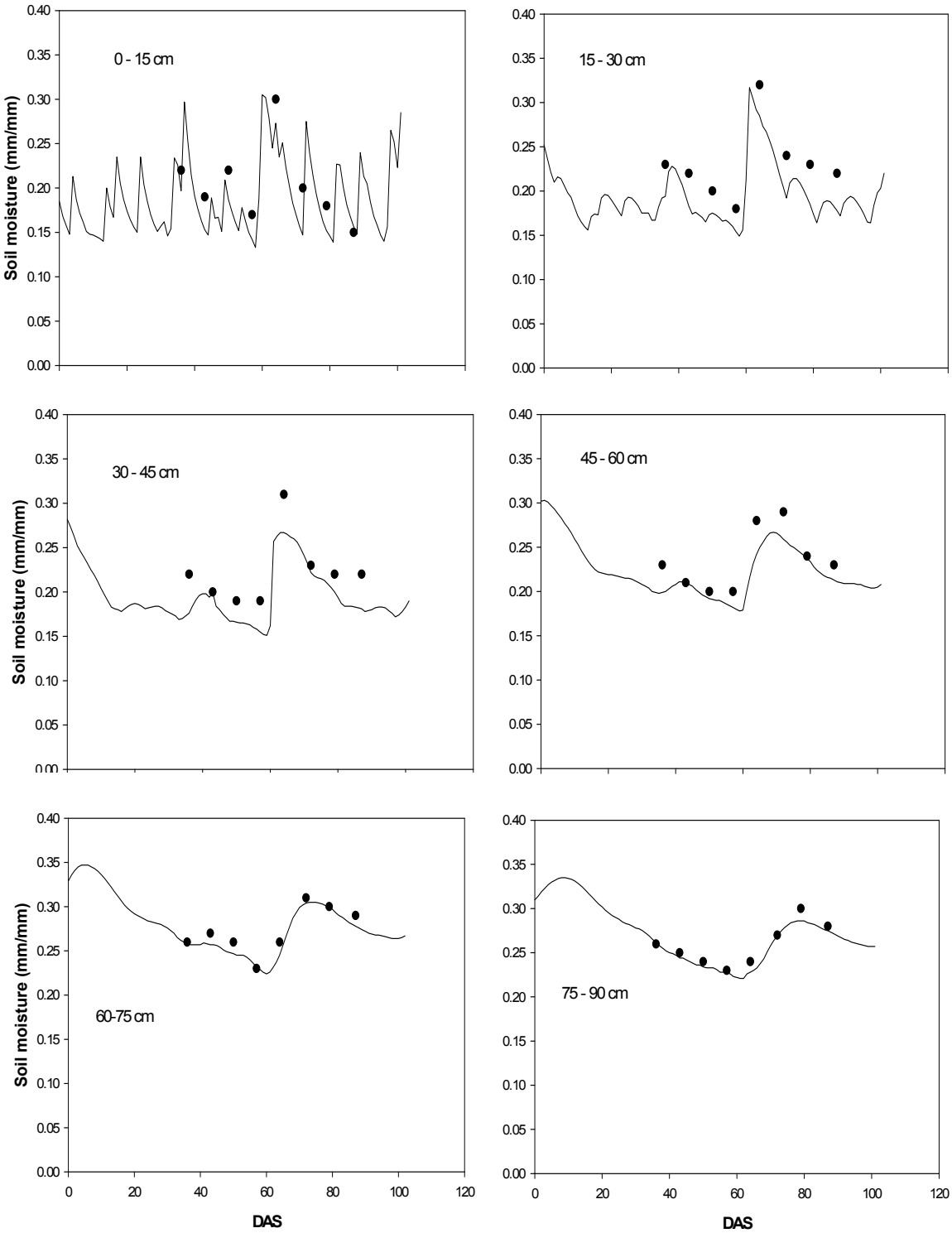


Figure 4. 34: Comparison of observed (symbol) and simulated (line) time series soil moisture on Haplic Lixisol at the Ejura farm in 120 kg N ha^{-1} and 60 kg P ha^{-1} plots from sowing to maturity.

Table 4. 28: Model parameters of maize cultivars used for simulation.

Parameters	Value	Units
Obatanpa cultivar		
Thermal time accumulation		
Duration from emergence to end of juvenile	300	^{o}C day
Duration – end of juvenile to flowering initiation	20	^{o}C day
Duration – flag leaf to flowering stage	10	^{o}C day
Duration - flowering to start of grain filling	170	^{o}C day
Duration, flowering to maturity	830	^{o}C day
Duration – maturity to seed ripening	1	^{o}C day
Photoperiod		
Day length photoperiod to inhibit flowering	12.5	H
Day length photoperiod for insensitivity	24.0	H
Photoperiod slope	23.0	^{o}C /H
Grain maximum number per head	520	
Grain growth rate	8	mg/day
Base temperature	8	^{o}C day
Dorke cultivar		
Duration from emergence to end of juvenile	285	^{o}C day
Duration – end of juvenile to flowering initiation	20	^{o}C day
Duration – flag leaf to flowering stage	10	^{o}C day
Duration - flowering to start of grain filling	170	^{o}C day
Duration, flowering to maturity	700	^{o}C day
Duration – maturity to seed ripening	1	^{o}C day
Photoperiod		
Day length photoperiod to inhibit flowering	12.5	H
Day length photoperiod for insensitivity	24.0	H
Photoperiod slope	10.0	^{o}C /H
Grain maximum number per head	420	
Grain growth rate	8	mg/day
Base temperature	8	^{o}C day

4.20 Impact of climate change on maize productivity

The impact of climate change on phenology, growth and yield of maize was assessed with the APSIM-Maize model using weather series representing both the historical (1980 -2000) and the future (2030-2050) climate assuming using A1B and B1 scenario (IPCC SRES).

4.21 Impact of climate change on the onset of the rainy season

Climate change and variability will likely result in a shift in the onset of the rainy season (Figure 4.34). Under A1B and B1 climate change scenarios, about 60 and 70 %, respectively of the years under simulation would receive the minimum amount of rainfall for sowing in the 2nd week of May (Figure 4.34) as compared to simulations with historical data, which predicts a high likelihood of sowing in the 3rd week of March. This represents a 6-week delay in sowing due to climate change by the year 2050. As a result of the shift of the major season, the seasons will be over-lapping or the minor season will be shifted towards the end of the year. In the latter case, the onset of the minor season will occur in the 3rd and 4th week of September (Figure 4.35) under A1B and B1 scenario compared to the 4th week of July and 3rd week of August according to historical data.

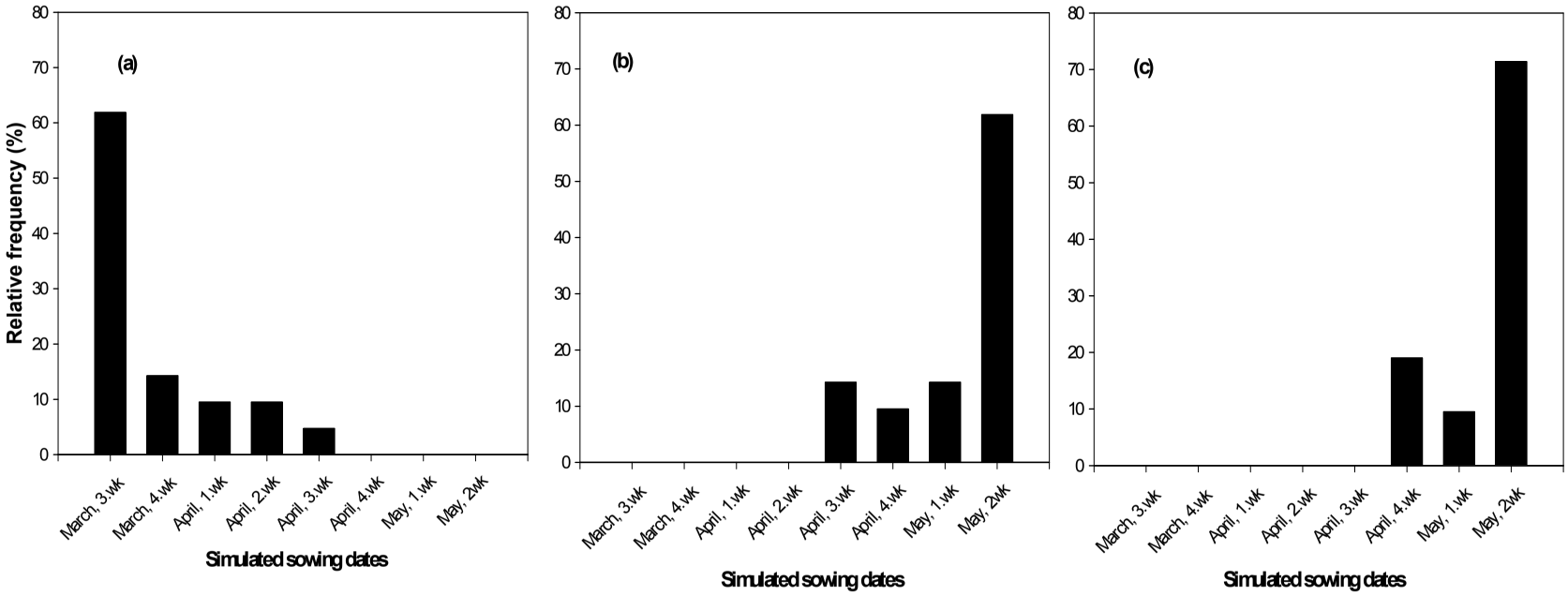


Figure 4. 35: Relative frequency (%) of simulated maize sowing dates during the major season on Haplic Lixisol at Ejura, Ghana, from historical weather data (1980-2000). (a) projected climate change (2030-2050) for scenario A1B (b) and B1 (c).

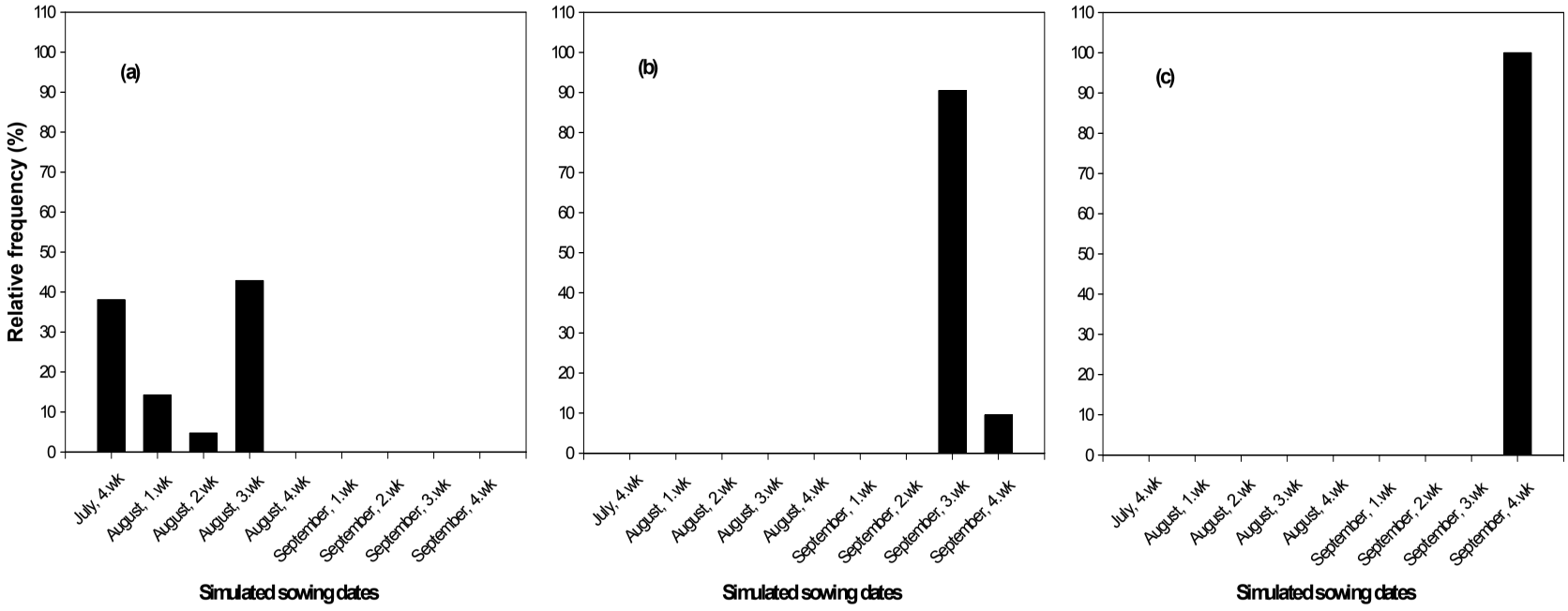


Figure 4. 36: Relative frequency (%) of simulated maize sowing dates during the minor season on Haplic Lixisol at Ejura, Ghana, from historical weather data (1980-2000) (a), projected climate change (2030-2050) for scenarios A1B (b) and B1(c).

4.22 Impact of climate change on maize grain yield

As shown in Figure 4.36, maize yield under climate change will depend significantly on the application of mineral fertilizers. Without fertilizer application, yields with historical data were about 1500 kg ha^{-1} with a wider sowing window within which the same yield can be obtained. However under climate change, yield ranged between 700 and 1100 kg ha^{-1} for both A1B (b) and B1 (c) scenarios with slightly higher yields if sowing is done earlier. There were however higher variability in yields (error bars) for earlier sowing under climate change, representing higher risk of crop loss compared to late sowing (2-week May) for Obatanpa. The same observation was made for Dorke cultivar.

Historical yields in the region range between 3530 and 3720 kg ha^{-1} with the application of 40 kg N ha^{-1} and 30 kg P ha^{-1} (Figure 4.36). As a result of the shift of the onset of the rainy season due to climate change, yields will be negatively affected with grain yield likely to reduce by an average of 55 and 34 % under A1B and B1 scenarios respectively. However, comparison of average yields for the 70 % frequency sowing dates (3rd-week March for historical data and 2nd -week of May for Climate change) indicated an average yield reduction of 49 % and 46 % for A1B and B1, respectively with high variability in yield (error bar) during the major season for Obatanpa maize cultivar (Figure 4.36). Mean grain yield under the A1B scenario varies from 1160 to 2010 kg ha^{-1}, while yields under B1 varies from 1730 to 2790 kg ha^{-1}. During the minor season, averaged across all sowing dates, climate change is likely to result in an average yield reduction of 25 and 15 % under the A1B and B1 scenarios. A similar trend in yield reduction (59 and 37 % for A1B and B1, respectively) was observed for the Dorke maize cultivar in the major season when averaged across sowing dates with historical yields ranging from 3260 to 3530 kg ha^{-1} (except for 4170 kg ha^{-1} recorded for sowing on 3rd-week of April which has a less probability of sowing on that date (Figure 4.34). The impact of climate change is likely to reduce Dorke maize yields, ranging between 900 to 1890 kg ha^{-1} and 1750 to 2450 kg ha^{-1} in A1B and B1, respectively.

Climate change is likely to also reduce the efficiency of nutrient utilization by crops. From Figures 4.37 - 4.38 and Appendix 6, it appears that, the application of 40 kg N ha^{-1} gave the same yield as that of 80 kg N ha^{-1} for both scenarios. Substantial increase in historical yields was, however, obtained with an increase in N level from 40 to 80 kg ha^{-1}.

Compared to maize-maize rotation (cultivation of maize for both seasons), the planting of cowpea in the minor season is likely not only give better yields of major season-maize under both climate change scenarios (Figure 4.39), but also to reduce the variability in yield (as shown in the error bars). The rotation of maize-cowpea has a higher likelihood of improving yields (under A1B and B1 scenarios, respectively when sowing is done at 2nd -week of May, and even higher yields when sowing is done earlier). Yields under the B1 scenario were slightly higher than under A1B. From Figure 4.39, it is seen that, application of 40 kg N ha^{-1} under both historical and climate change condition gave similar yields as obtained from 80 kg N ha^{-1}. The rotation of maize and cowpea under climate change is likely to reduce average yields by 41 and 31 % under A1B and B1 scenarios respectively when averaged across sowing dates.

Introduction of fallow during the minor season is likely to reduce the adverse impact of climate change on yield with less variability in yield even compared to the maize-cowpea rotation. With the introduction of fallow into the cropping system, predicted yields ranged from 2940 to 3710 kg ha^{-1} under the A1B scenario and from 3290 to 3920 kg ha^{-1} under B1 compared to historical yields (3690 to 4690kg ha^{-1}) with application of 40 kg N ha^{-1} and 30 kg P ha^{-1}. Climate change is expected to decrease yield by 25 and 16 % across all sowing dates under A1B and B1 scenarios respectively in reference to historical yields.

Similarly, cowpea yield is predicted to also reduce as a result of climate change. A maize-cowpea rotation suggests that cowpea yield is likely to be reduced by 57 and 51 % (Figure 4.41) by 2050 under the A1B and B1 scenario, respectively.

The model runs indicate that continuous removal of crop residue even with the application of 80 and 30 kg ha^{-1} mineral N and P, respectively, would result in a decline in soil organic carbon (SOC) levels (Figure 4.42) for both A1B and B1 scenarios. With historical data, SOC levels were lower than those under climate change condition

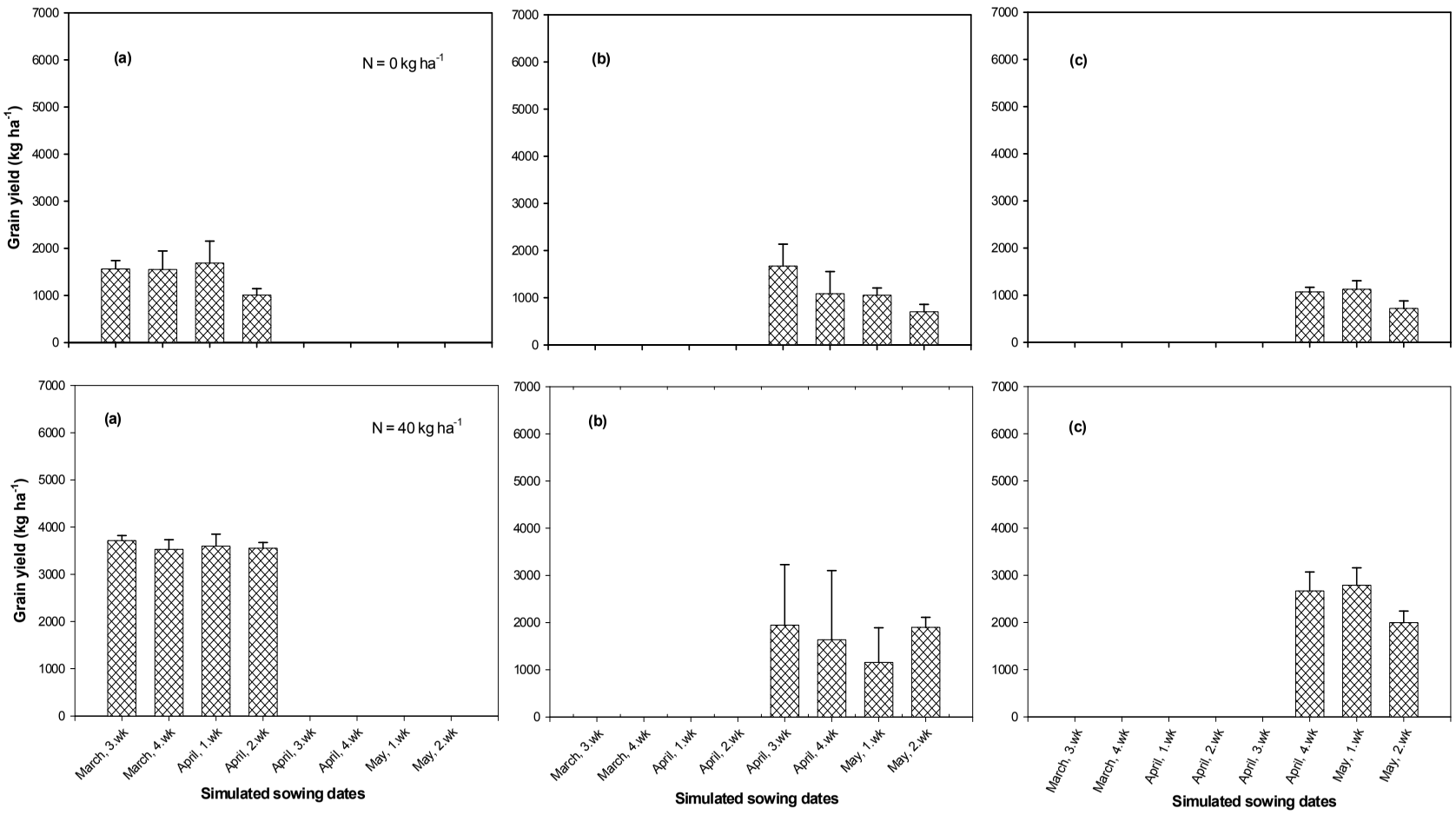


Figure 4. 37: Simulated maize (var. Obatanpa) grain yield (kg/ha) in the major season on Haplic Lixisol at Ejura, Ghana, from historical weather data (1980-2000) (a), projected climate change (2030-2050) for scenarios A1B (b) and B1 (c) with 0 and 40 kg N fertiliser ha^{-1}.

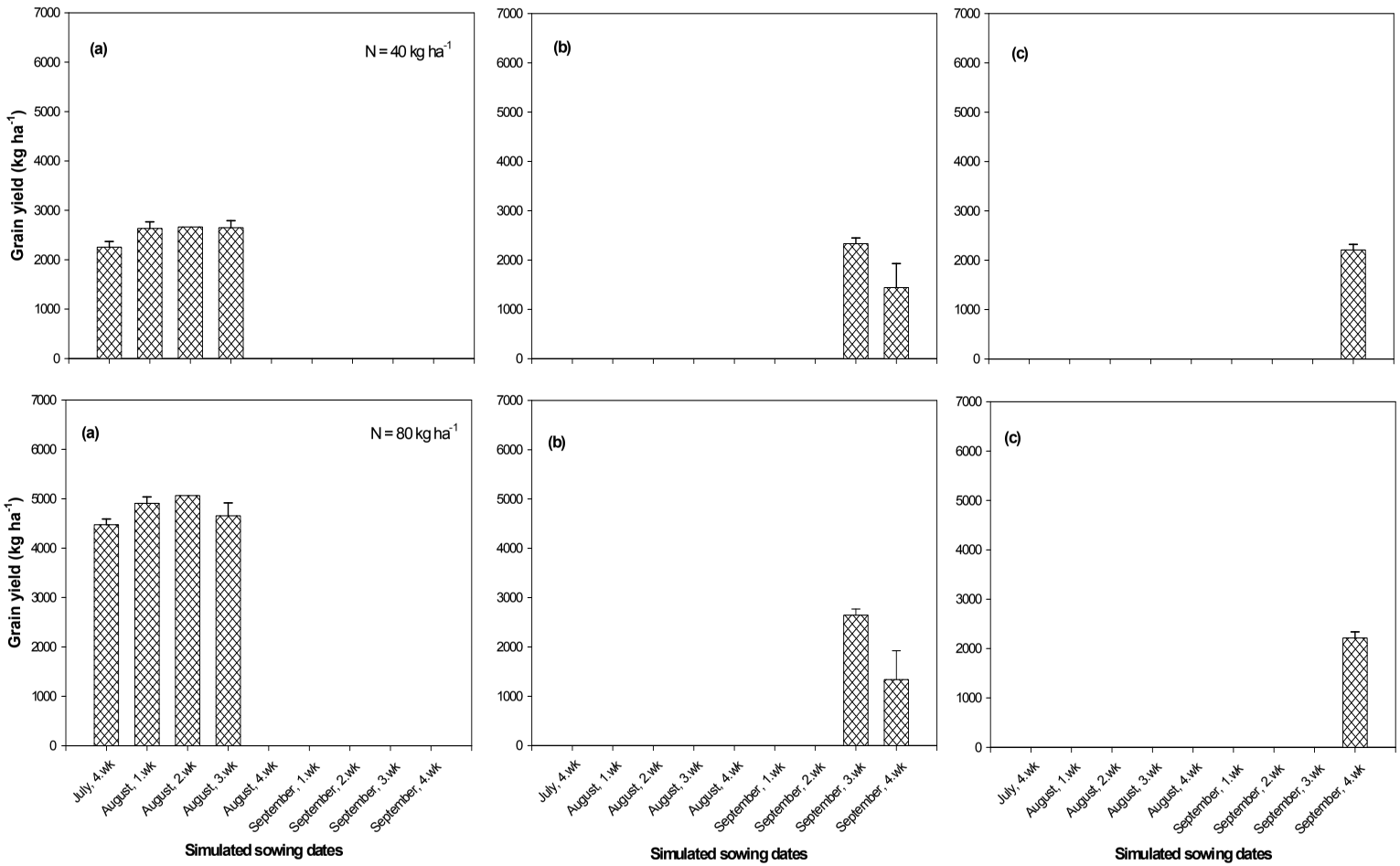


Figure 4. 38: Simulated maize (var. Obatanpa) grain yield (kg/ha) in the minor season on Haplic Lixisol at Ejura, Ghana, from historical weather data (1980-2000) (a), projected climate change (2030-2050) for scenarios A1B (b) and B1 (c) with 40 and 80 kg N ha^{-1}.

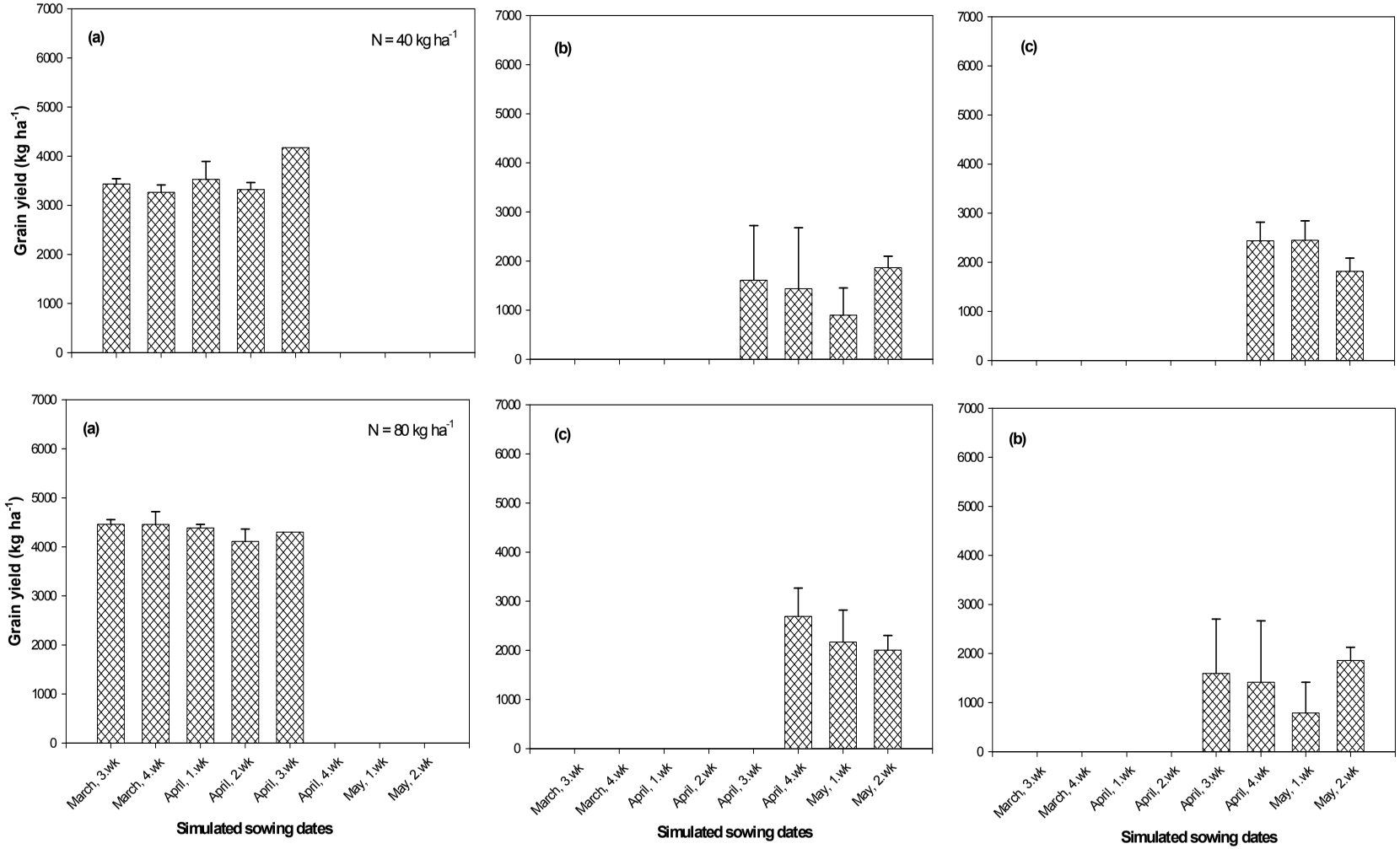


Figure 4.38: Simulated maize (var. Dorke) grain yield (kg/ha) in the major season on Haplic Lixisol at Ejura, Ghana, from historical weather data (1980-2000) **(a)**, projected climate change (2030-2050) for scenarios A1B **(b)** and B1 **(c)** with 40 and 80 kg N fertiliser ha^{-1}.

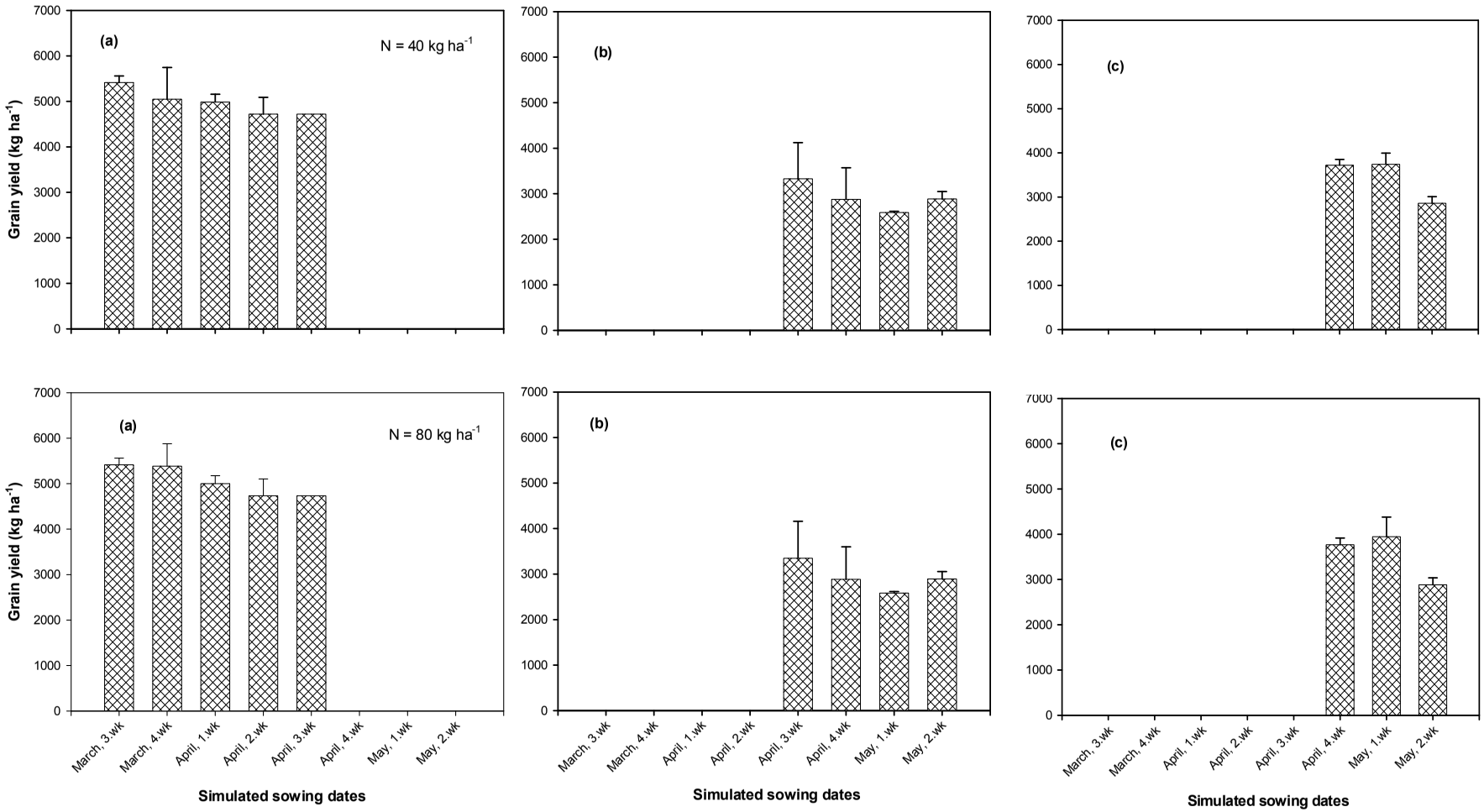


Figure 4. 39: Simulated maize (var.Obatanpa) – cowpea (Malam yaya) grain yield (kg/ha) rotation on Haplic Lixisol at Ejura, Ghana, from historical weather data (1980-2000) (a), projected climate change (2030-2050) for scenarios A1B (b) and B1(c) with 40 and 80 kg N fertilizer ha^{-1}.

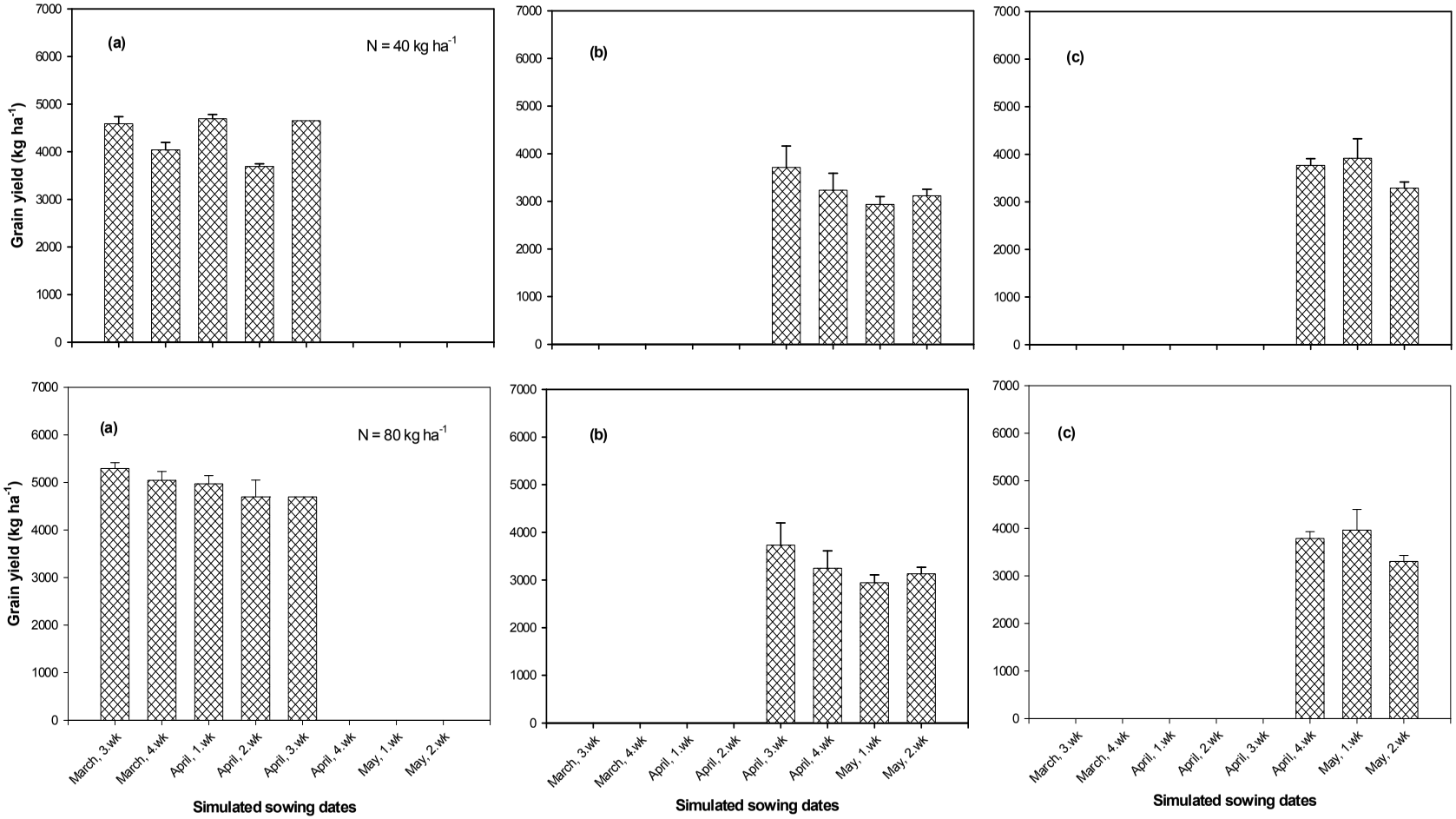


Figure 4. 40: Simulated maize (var. Obatanpa) grain (kg/ha) – fallow rotation on Haplic Lixisol at Ejura, Ghana, from historical weather data (980-2000) (a), projected climate change (2030-2050) for scenario A1B (b) and B1 (c) with 40 and 80 kg N fertilizer ha^{-1}.

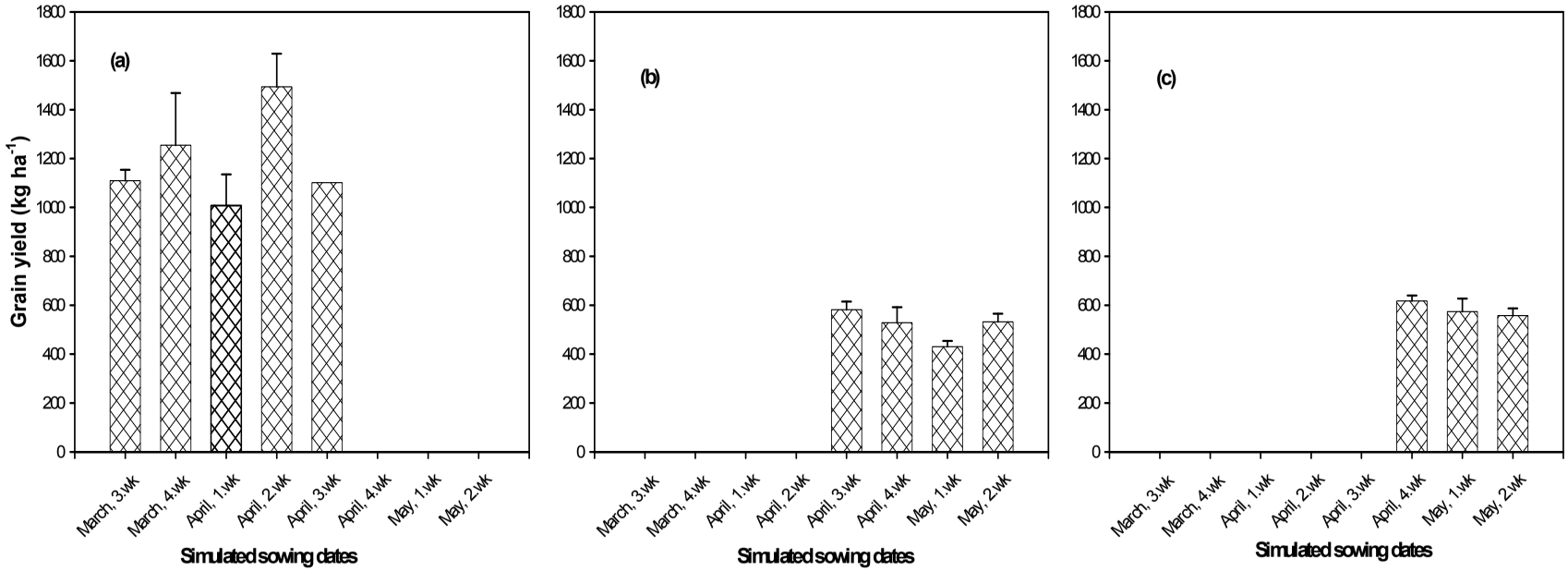


Figure 4. 41: Simulated cowpea (var. Malam yaya) grain yield (kg ha^{-1}) on Haplic Lixisol at Ejura, Ghana, from historical weather data (980-2000) (a), projected climate change (2030-2050) for scenario A1B (b) and B1 (c).

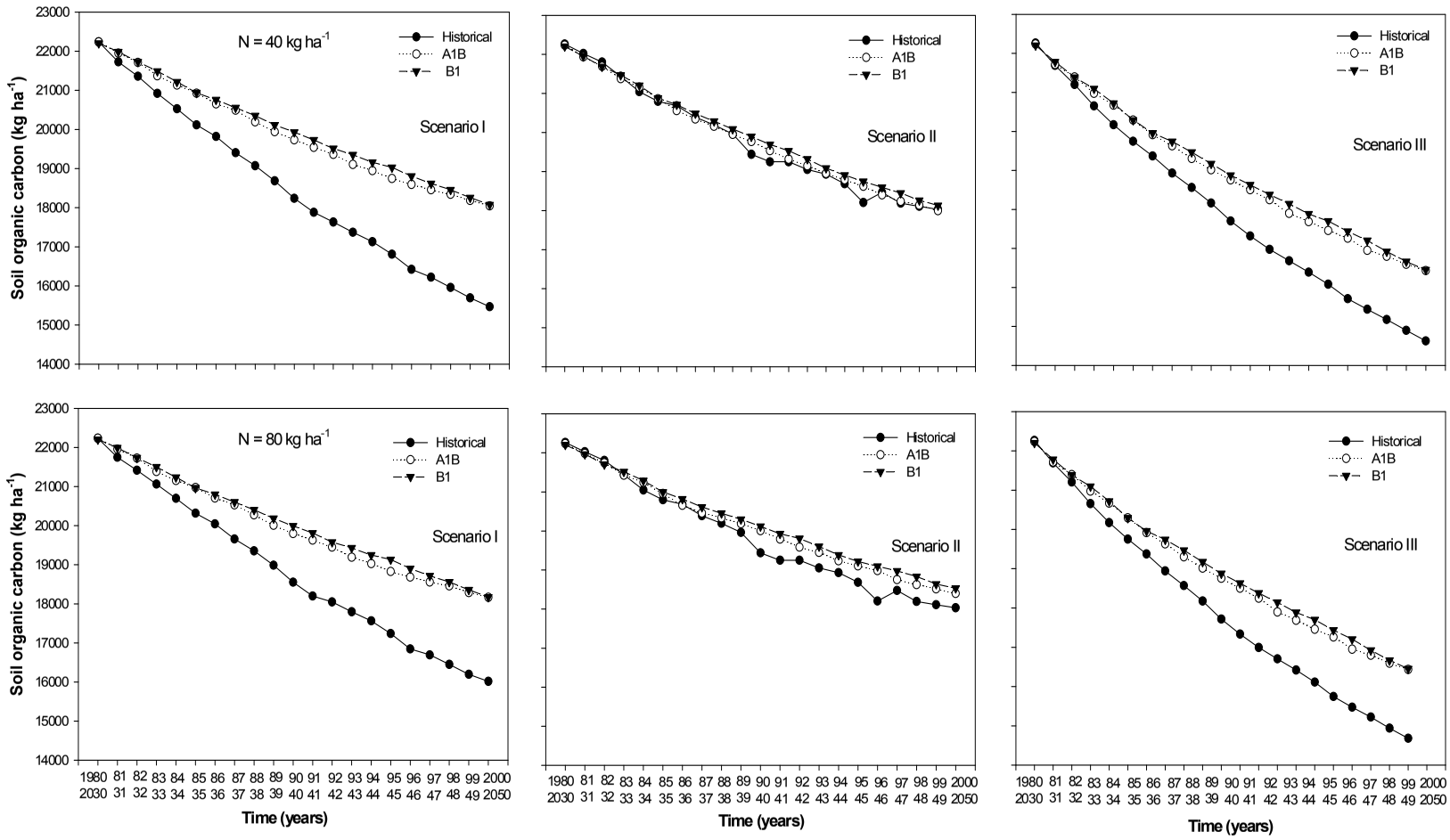


Figure 4. 42: Simulated organic carbon (kg ha^{-1}) on Haplic Lixisol at Ejura, Ghana, under maize-maize simulation (I), maize-cowpea rotation (II) and maize-fallow (III) from historical weather data (1980-2000), projected climate change (2030-2050) for scenario A1B and B1.

4.23 Perception of farmers regarding changes in temperature

Figure 4.43 shows that of the farmers interviewed, 91.1 % perceived a long-term change in temperature. Almost 88 % perceived an increase in temperature, while only 3.3 % were of a different opinion. A total of 8.9 % gave other answers. As to the causes of the perceived rise in temperature, 63.3 % of the farmers attributed it to deforestation, 18.9 % to bush burning, 3.3 % to increased population, and 8.9% to other factors. Only 5.6 % of the respondents could not give any reason for the perceived change in temperature.

Historical mean annual temperature data at Ejura from 1972 to 2008 (36 years), with omission of 2003, confirmed a slightly increasing trend in temperature especially from 2001 to 2008 (Figure 4.44).

The response of farmers to changes in precipitation was very similar to that of temperature, with the majority of respondent (87.2 %) indicating a decreasing trend (Figure 4.45). Deforestation was perceived as the key cause of declining rainfall

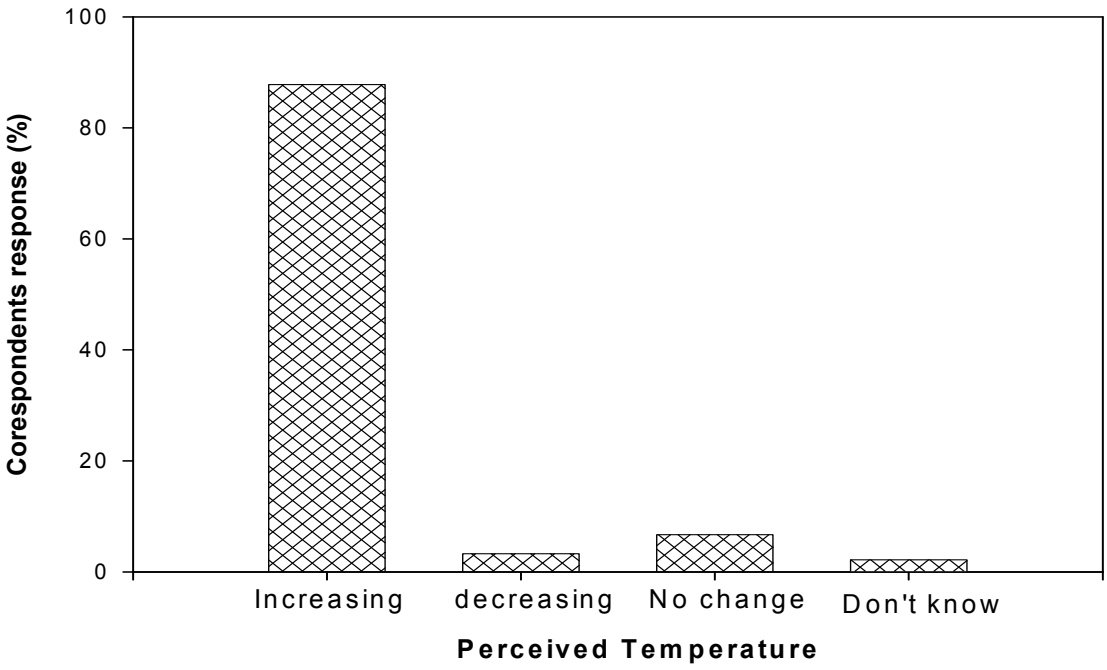


Figure 4. 43: Farmers perception of change in temperature (%) 1972-2007 in the Ashanti region of Ghana.

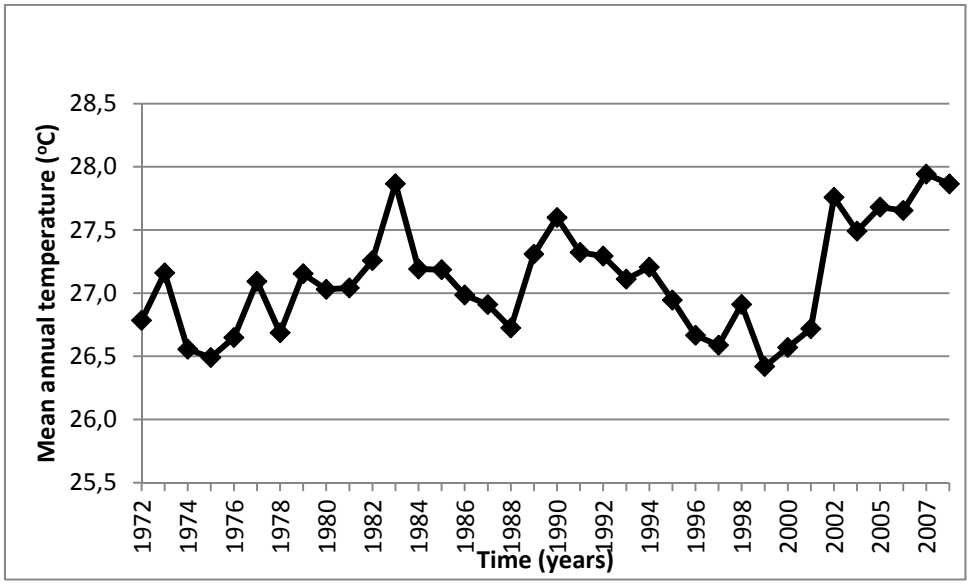


Figure 4. 44: Historical mean annual temperature in Sekyedumase district in Ghana. (Source: Ghana Meteorological Agency, 2007)

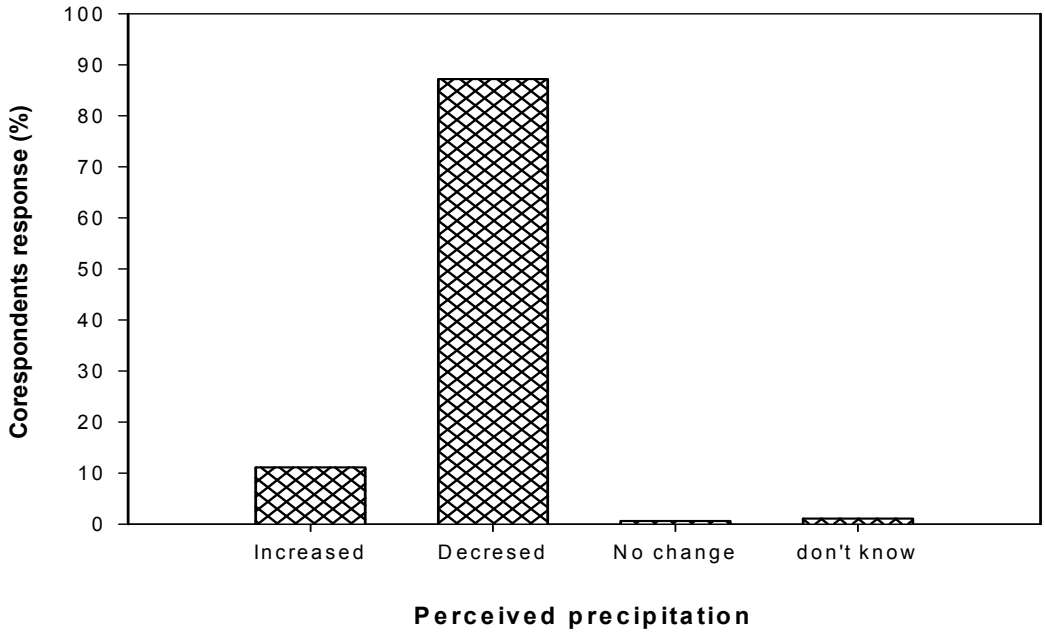


Figure 4. 45: Farmers' perception of changes in precipitation (%) in the Sekyeredumase district in Ghana.

4.24 Adaptation strategies by farmers

In spite of the perceived increase in temperature by the majority of farmers, only 44.4 % indicated the adoption of some adaptation measures (Table 4.29). Crop diversification

and changing crop planting dates were identified as the main adaptation strategies to a warmer climate. Similarly, about 41 % of the farmers appeared to have changed their management in response to declining precipitation, with crop diversification and shifting the planting date being the most important adaptation measures (Table 4.29). Land tenure, soil fertility level, access to extension services, access to credit and community are the significant determinants of adaptation to climate change (Table 4.30).

Table 4. 29: Adaptation strategies in response to change in temperature and precipitation (%) in Sekyeredumase district in Ghana.

Adaptation strategy	Increasing temperature (%)	Decreasing precipitation (%)
Crop diversification	16.7	7.8
Change crops	7.2	3.9
Reduce farm size	1.1	0
Change planting date	14.4	18.9
Find off-farm jobs	1.1	0
Plant short-season variety	1.1	7.2
No adaptation	55.6	58.9
Others	2.8	3.3
Total	100	100

Table 4. 30: Results of logistic regression of adaptation to increasing temperature in Sekyeredumase district in Ghana.

Adaptation	Coefficients	Std Err	z	P>z	[95 % confidence intervals]	
Age	0.273	0.265	1.03	0.303	-0.246	0.791
Gender	0.340	0.404	0.84	0.401	-0.453	1.132
Edu. Level	0.169	0.116	1.47	0.143	-0.057	0.396
Farm size	-0.085	0.169	-0.50	0.616	-0.417	0.247
Land tenure	0.263*	0.114	2.30	0.022	0.039	0.247
Soil fertility	-1.169**	0.475	-2.46	0.014	-2.101	0.487
Access to extension	1.405**	0.379	3.71	0.000	0.663	-0.238
Access to credit	1.091*	0.482	2.26	0.024	0.144	2.147
Farming experience	-0.084	0.231	-0.36	0.716	-0.540	2.037
Ejura	0.795	0.429	1.85	0.064	-0.046	1.637
constant	-3.275**	1.133	-2.89	0.004	-5.496	-1.054

*Note: ** significant at 0.01, * significant at 0.05*
Log Pseudo likelihood = -102.98. Number of observations = 180

Table 4. 31: Logistic regression of determinants of adaptation to decreasing precipitation in Sekyeredumase district in Ghana.

Adaptation	Coefficients	Std Err	z	P>z	[95 % confidence intervals]	
Age	-0.218	0.278	-0.79	0.432	-0.763	0.326
Gender	0.815	0.441	1.85	0.064	-0.049	1.678
Education level	0.040	0.118	0.34	0.734	-0.192	0.272
Farm size	-0.225	0.181	-1.24	0.213	-0.579	0.129
Land tenure	0.235*	0.119	1.99	0.047	0.003	0.468
Soil fertility	1.020**	0.588	-3.44	0.001	-3.180	-0.874
Access to extension	1.020*	0.397	2.57	0.010	0.242	1.800
Access to credit	2.076**	0.543	3.82	0.000	1.012	3.140
Farming experience	0.137	0.260	0.53	0.599	-3.73	0.646
Ejura	0.907*	0.459	1.98	0.048	0.008	1.807
constant	-1.692	1.098	-1.54	0.123	-3.845	0.461

*Note: ** significant at 0.01, * significant at 0.05*
Number of observations = 180

5 DISCUSSION

5.1 Initial soil properties

The low pH value recorded at the experimental sites could be attributed to the amount of acidic cations present due to the leaching of basic cations. A similar low value was reported by Arthur (2009) for a soil in Kwadaso, Kumasi, Ghana. Nitrogen is one of the most essential components of organic matter. The decomposition of organic matter leads to the release of some nutrients including N. The low amount of total soil N was a result of the low soil organic matter (SOC), which is due to the lack of applied crop residues to field. Crop residues and farmyard manure are reported to increase SOC (Kpongor, 2007). Low extractable P values indicate deficiencies (Landon, 1996).

5.2 Days to 50% tasseling

Days to tasseling were delayed with increasing N stress in both cultivars. This indicates that maize development and phenology are influenced by N levels in the soil. The earlier tasseling of the maize crop in Expt.1 than the other experiments is attributed to the soil at the location of Experiment 1 being relatively more fertile. Similar observations were reported for silking in maize in the semi-arid region of Nigeria by Gungula *et al.* (2003), for tasseling of maize in the transition zone in Ghana by Adiku *et al.* (2009), flowering in sorghum in semi-arid region of Ghana by Kpongor (2007), and for tasseling in maize across arid to semi-arid regions of Pakistan by Khaliq (2008). The differences in tasseling dates between the cultivars at a particular N rate suggest that the effect of N stress on phenology differs among cultivars even when they are adapted to the ecological zone Gungula *et al.* (2003).

5.3 Dry matter accumulation at 55 days after sowing

The seasonal difference in dry matter (DM) accumulation at 55 DAS is attributed to the different amount and distribution of rainfall between the two seasons. The major season had higher and better distribution of rainfall compared to the minor season. The difference in DM accumulation between the two cultivars at 55 DAS is attributed to the differences in time to complete the life cycle. Dorke has a shorter life cycle and will normally grow faster than Obatanpa. The significant difference in DM accumulation

between 30 and 60 kg P ha^{-1} application in Expt. 4 is attributed to very low plant-available P in this highly acidic soil resulting in higher P sorption capacity.

5.4 Nitrogen uptake at 55 days after sowing

The difference in N uptake at the different sites is attributed to difference in soil organic matter (SOM) and soil structure. The Ejura farm site had relatively higher SOM, and the soil was able to retain moisture for a longer period than the soil in at the Agricultural College. Differences in the amount and distribution of rainfall between the two seasons led to the differences in N uptake. There was a higher amount of rainfall during the major season than during the minor season, which led to higher biomass production during the major season.

5.5 Grain yield

The interactive effect of N and P on grain yield signifies the additional benefit of eliminating both constraints to plant growth. The application of 30 kg P ha^{-1} increased grain yield by an average of 21 % in Obatanpa and 23 % in Dorke, which is significant for the farmer. Although the Ejura farm site recorded relatively high SOM (1.14%) and a total N of 0.13 mg g^{-1} in the top 15 cm soil depth (Expts. 1 and 3) this was still below the optimum amount for soil productivity. Low SOM can reduce the effective use of mineral fertilizer (Kpongor, 2007), especially in areas where crop production relies heavily on rainfall. Yields on the Ejura farm site were generally higher than those at the Agricultural College. This difference was more pronounced during the minor season, which was probably due to the difference in SOM and soil water retention which was relatively higher at the Ejura farm than at Agricultural College.

The soil type in Expt. 3 (Ejura farms during minor season) was a Lixisol, which is moderately fertile compared to the Plinthosol in Expt. 4 (Agric College during minor season), which is poorer in nutrients and SOM. As a result, the water holding capacity at the Ejura farm site was higher than that of the Agricultural College site. Thus, for sustainable crop production, a way must be found to increase the SOM levels in the soil. In all experiments with the exception of Expt. 4 (Plinthosol), there was no significant grain yield response beyond 30 kg P ha^{-1}. This signifies that beyond 30 kg P ha^{-1}, there are other factors (other soil nutrients, environment) limiting crop yield. The

lack of significant increase in grain yield in plots that received 30 kg P ha^{-1} and 0 kg N ha^{-1} indicate that under such condition, N was a limiting factor.

The difference in grain yield for the two cultivars is attributed to the difference in days to completion of the life cycle and the genetic makeup of these cultivars. This is in line with the findings of Khaliq (2008), who compared maize hybrids and found a difference of one ton per ha between the highest and lowest yielding hybrid in the Punjab province of Pakistan.

Difference in grain yields for the different seasons is attributed to the amount and distribution of rainfall between and within the seasons. Total rainfall during the major season (from planting to harvesting) was 709.8 mm whereas only 476 mm was recorded during the minor season. Similar observations have been reported by Tetteh (2004), Tanimu *et al.* (2007) and Arthur (2009). The control plots in all experiments had the lowest yield because of limited nutrient supply by the soil without any external input.

5.6 Total dry matter production

The trend in aboveground TDM production is similar to that of grain yield. Nitrogen and P and their combined effect significantly influenced total biomass production. All treatments in all experiments produced higher TDM than the control. Similar findings have been reported by Arthur (2009), Adiku *et al.* (2009), and Kpongor (2007). The differences in TDM between the seasons are attributed to the amount and distribution of rainfall between and within the seasons. Pest attacks (stem borers) on some plants were observed during the minor season, which farmers said was usual during that season. Nitrogen uptake correlated well with total biomass production, which signifies the important role of N in the final biomass yield of the crop.

5.7 Harvest index

Grain filling is an important stage in the phenology of maize crops. Any stress due to insufficient moisture or nutrients at this time will adversely affect this process. The harvest index (HI), defined as the ratio of economic yield to biological yield is used to describe the accumulation and redistribution of assimilates to achieve final yield (Bange et al., 1998). The vital determinants of crop yield are the harvest index value and its

stability (Echarte and Andrade, 2003). In general, in this study, the treatments that promoted better growth of the maize crop had a positive influence on HI, presumably due to faster growth and partitioning of more carbohydrates into the grain. All treatments had higher HI compared to the control, reflecting poor plant growth in the control.

The results suggest that an optimum N supply is essential for optimized partitioning of DM between grain and other parts of the maize plant. Similar results were reported by Fosu (1999) and Khaliq (2008). The HI of maize has been reported to be 0.5 for most tropical maize crops (Hay and Gilbert 2001). However, in all treatments, the HI value was below those reported by Hay and Gilbert (2001). Low HI values can be attributable to late sowing, low plant population, diseases and unavailability of water at the critical growth stage of the crop (Ahmad *et al.,* 2007).

5.8 Grain N uptake

Studies on N uptake further support the importance of N and P fertilizer for N uptake and use efficiency. In this study, P and N uptake significantly increased with N and P fertilization (Figures 4.9- 4.16) indicating increased availability or accessibility of these nutrients in the soil. Nitrogen uptake by maize crop is governed by its concentration in the plant. The high interactive effect of N and P on grain N uptake is an indication of the effect of P on grain N uptake. With the application of 30 kg P ha^{-1}, grain N uptake was increased by more than 20 %. This translated into higher yields and makes it attractive to apply P fertilizer. The combination of 30 kg P ha^{-1} and 40 kg N ha^{-1} produced more grain than 80 kg N ha^{-1} without P application. This result is in line with the findings of Akinnifesi *et al.* (2007).

5.9 Grain P uptake

An average of 65% of the total P uptake is found in the grain. This has great implications for P export and soil P depletion, as the grain is removed for consumption, thus removing a large fraction of the P taken up by the crop. A similar observation was reported for maize and cover-crop intercropping in the semi-arid region of Ghana by Fosu (1999). The higher P uptake is also reflected in the grain yield, which is very important to the farmer. The high interactive effect of N and P on P uptake is an

indication of the relatively poor accessibility of soil P which improved with greater soils exploitation due to better root growth. The lower grain P uptake observed in Expt. 4 is due to the extremely low availability of soil P due to high sorption P by the soil at the site. Thus, a large quantity of the applied P could have been fixed by the soil there. The low P uptake in the treatments without P fertilizer application, which led to low grain yields, is attributed to soil P below the critical value.

5.10 Crop growth simulation

The APSIM-Maize model was not sensitive to N and P stress in terms of differentiating days to tasseling or maturity observed in this study. Similar results were reported by Gungula *et al.* (2003) in Nigeria and by Khaliq (2008) in the Punjab province of Pakistan.

5.11 Grain yield and total dry matter production

The model performed well in predicting grain yield and TDM, with an average RMSE of 44.2 for Obatanpa and 39.4 g m^{-2} for Dorke, which is within an acceptable range. The overestimation of grain yield by the model is likely due to the fact that other stress factors like diseases and pests are not included in the model. During the minor season, both sites were infested with stem borers, which led to the death of some plants and might have also affected the weight of the grain and hence yield. However, this was not reflected in the model. Thus, the model assumed a pest- and disease-free environment.

5.12 Grain N uptake

The model also predicted grain N uptake during the major season very well for both sites with an overall R^2 of 0.96 for Obatanpa and Dorke. A good estimation of grain N uptake by APSIM-Wheat under rainfed conditions in The Netherlands has been reported by Asseng *et al.* (2000). However, there was an overestimation of grain N uptake during the minor season (Expts. 3 and 4). This is attributed to the stress factors caused by the stem borer during that season, which was not incorporated into the model. This is a limitation of the current model.

5.13 Total N and P uptake

The model simulated N and P uptake satisfactorily with overall coefficients R^2 of 0.96 and 0.86, respectively. The overestimation of total N uptake by the model is attributed to the overestimation of the grain yield.

5.14 Soil moisture

The simulation results indicate a satisfactory soil moisture balance parameterization of the model for various soil parameters such as DUL, Sat and LL.

5.15 Impact of climate change on the onset of the rainy season

The predicted delay in the season as a result of climate change delays the sowing period or narrows it and hence planting long season cultivars will cause interference with planting in the minor season by the harvesting operations for the major season crops. Similar findings on the impacts of climate variability on rice were reported by Lansigan *et al.* (2000) in the Philippines, where sowing in normal years is commonly done on the 173 day of the year (DOY), but in El Niño years sowing may have to be delayed until 229 DOY.

5.16 Impact of climate change on maize yield

The dynamic trends of maize yield indicate that the existing practice of farming (application of 0 – 9 kg N ha^{-1} fertilizer) will not sustain crop productivity and hence an increase dependence on fertilizer use under climate change.

There are clear differences between the impact of Special Report on Emission Scenario (SRES) A1B and B1. The greater impact of A1B can be attributed to a stronger increase in temperature (1.6 °C) projected with this scenario as compared to the 1.3 °C for the B1 scenario. The study region already suffers high temperatures. Moderately cool temperatures favor high yields, as they allow the crop to progress slowly through the season so as to maximize the time for light capturing and carbon assimilating as well for partitioning assimilates to reproductive structures (Boote and Sinclair, 2006). However under warmer conditions, yields are expected to be lower. This finding is in line with many reports on the impact of climate change on maize yield. For example, Bancy (2000) using two GCMs (GFDL and CCCM model)

projected temperature increases of 2.9 and 2.3 °C, respectively. He further stated that the planting date has a profound influence on maize yields. Higher yields were obtained for crops planted earlier compared to those planted late due to higher moisture levels in the soil during the grain filling stage of the crop. Results of a simulation by Travasso *et al.* (2008) using HadCM3 climatic projections for the year 2080 under A2 scenario showed that increases in temperatures reduced the growing season of maize crops in southeastern South America by 27 days and consequently reduced yields. Under non-limiting water supply and considering CO_2 fertilization, maize crops could still experience reduced grain yields with temperature increases greater than 1°C (Magrin and Travasso, 2002). Meza *et al.* (2008) reported that under climate change, a high yielding maize cultivar DK 647 in Chile showed a reduction between 15 and 28%. They attributed the reduction in yield to the shortening of the growth period of maize of as much as 40 and 28 days for the A1F1 and B2B scenario, respectively. Early sowing and the reduction of fertilizer use were recommended as an adaptation measure under the B2B scenario.

Increased variability of rainfall, which is reflected in the high variability in grain yield, is another factor leading to the reduction of yields. It has a significant effect on crop yield comparable to those of climate change. Soil moisture stress at an important development stage (grain filling) of the plant development can have a serious effect on grain size and weight and hence on yields.

5.17 Impact of climate on soil organic carbon

The presumed continuous removal of crop residues from the field results in a decrease in soil organic carbon (SOC). Inputs of root biomass contributes little to the SOC, as carbon derived from root biomass is highly labile (Balesdent and Balabane, 1992), and hence has a high decomposition rate with most of it entering the active pool of SOC. Similar trends of SOC decline were reported by Kpongor (2007) using APSIM-Sorghum to simulate SOC in semi-arid Ghana and by Zingore *et al.* (2006) using the FARMSIM model to simulate SOC content in sandy virgin soils with woodlands.

The slower loss of SOC in the A1B and B1 scenarios than predicted using historical data is likely due to lower availability of soil moisture, an important factor in

the decomposing process since temperature is not a limiting factor in this part of the world.

5.18 Farmers' perception and adaptation to climate change

Access to credit/loan facilitates adaptation to climate change, as access to cash allows farmers to purchase inputs like seeds of improved cultivars and fertilizer. The positive correlation between adaptation to climate change and the availability of credit observed in this study is in line with such findings by Gbetibouo (2009) and Deressa *et al.* (2009). Similarly, farmers who perceive to have more fertile soil on their farms are more likely to adapt to climate change, while those who perceive to have less fertile soil are less likely to adapt as low soil fertility negatively influenced adaptation to decreasing precipitation and increasing temperature. This indicates that farmers are more likely to abandon their farms or will not invest in external inputs (e.g. fertilizer for crop production) if soils are less fertile and marginal income obtained by an additional unit of input (e.g. nitrogen fertilizer) is smaller than the unit cost of that particular input (fertilizer) under climate change.

6 SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

6.1 Summary

Increasing N rates significantly increased grain and TDM production irrespective of application of P fertilizer. The application of P fertilizer increased N use efficiency with grain yield ranging from 92 (control) to 495 g m^{-2} (N4P2) and 82 (control) to 427 g m^{-2} (N4P2) for Obatanpa and Dorke, respectively. The two cultivars were significantly different from each other with higher grain yield produced by Obatanpa.

The APSIM-Maize model (version 6.1) was used to simulate growth, development and yield of maize at different locations. The model predicted the phonological development of the crop rather well for both cultivars with 4 and 3 days difference between the observed and simulated days to maturity for Obatanpa and Dorke, respectively. The grain yield was well simulated with a 4.5 and 4.1 % difference between the observed and simulated for Obatanpa and Dorke respectively. A 1.1 (Obatanpa) and -2 % (Dorke) difference were obtained for total biomass during model parameterization.

APSIM-Maize model was evaluated for grain yield, total biomass, N and P uptake using data collected from field experiments during major and minor seasons, 2008 with different N and P rates. The model effectively captured the influence of N and P and their interactive effect on yield, total biomass, total N and P uptake. Grain yield was closely simulated by the model when compared with observed data. The average coefficient of determination (R^2) between simulated and observed grain yield were 0.90 and 0.88 for Obatanpa and Dorke respectively. The overall RMSE for total biomass were 78 and 66.1 g m^{-2} for Obatanpa and Dorke respectively.

The APSIM-Maize model, parameterized for both cultivars, was used to simulate impact of climate change on maize yields under A1B and B1 (2030-2050) scenarios with historical data (1980-2000) as bench mark. The model predicted a 6-week delay in the on-set of the season. The predicted delay in the season as a result of climate change delays the sowing period and hence, planting of long season cultivars will cause interference with planting in the minor season by the harvesting operation for the major season crops. This delay is likely to reduce yield by 55 and 34 % under A1B and B1 scenarios for continuous Obatanpa maize cropping and 59 and 37 % reduction

for Dorke maize cultivar. Farmers in the study area are well aware of climate change but only 44 and 41 % have taken steps to adapt to climate change conditions.

6.2 Conclusions

Based on the results, the following conclusions are drawn:

Inorganic fertilizer use in the study area was agronomically efficient though generally more efficient at the Ejura farm site than the site at Agricultural College. The application of inorganic P fertilizer increased the efficient utilization of inorganic N fertilizer by the plants in grain yield and total biomass production; hence P nutrition of soils is critical for the efficient use of inorganic N fertilizer in the area.

Grain yield among various treatments was related to their photosynthetic activity and the soil conditions. Though plants were more responsive to N fertilizer applications, deficiency in soil P limited the efficient use of applied N by the plants. Owing to the spatial variability in soil nutrients in the area, site-specific recommendation of fertilizer application is suggested for efficient fertilizer use.

Though the cultivars were different, they reacted similarly to N and P inorganic fertilizer application. The Obatanpa maize cultivar however, was more responsive to inorganic fertilizer by producing higher grain yield than Dorke.

The APSIM-Maize model was successfully parameterized and evaluated for the sub-humid region of Ghana. The evaluation of the APSIM-Maize model in this study affirms that the model is ready to be used as a research tool in a variable agro-environment in Ghana. The model successfully captured the effects of inorganic N and P fertilizer applications on grain and biomass yield, N and P uptake of maize in the area. Both cultivars can be adequately modeled with parameters that are readily available.

The results suggest that APSIM can be used to predict alternate ways of improving maize production in Ejura and possibly in the whole of Ghana. However, some model inputs for Ghana need to be determined, including the genetic coefficients of various maize varieties and the minimum data set for soils and weather for the whole country.

The study shows that climate change has a significant impact on maize productivity in the sub-humid zone of Ghana.

The model predicts a 6-week delay in the season as a result of climate change over the next 30 years. The delay in sowing or narrowing of the sowing period will cause interference with planting in the minor season if long season cultivars are planted during the major season. The model predicts a 49 and 46 % decrease in Obatanpa grain yield (comparing sowing on 3rd - week March for historical data and 2nd - week May under climate change) or 55 and 34 % reduction when averaged across sowing dates under A1B and B1, respectively. The model also predicts a 59 and 37 % reduction in grain yield for Dorke cultivar under A1B and B1 scenarios, respectively. This reduction has serious implications for food security if adaptation measures are not taken. The model also illustrates a sharp decline in SOC even with application of inorganic fertilizer due to the practice of removal of crop residues at the end of each cropping season. This practice makes attaining food sufficiency impossible. Land-use practices that contribute to SOC are very vital to the future productivity of maize crop, even with fertilizer applications.

The APSIM model demonstrates that farmers can reduce temporal variability (representing crop loss) in grain yield by adopting a maize-cowpea cropping system and or maize-fallow rotation. Also, factors that limit or reduce stress (nutrient and soil moisture) during crop growth and development in turn reduce temporal variability in grain yield. Under both scenarios, the most effective adaptation measure would be early planting as soon as the season has started or conditions are favorable combined with the introduction of legume and or fallow rotation into the cropping system. Reduction of fertilizer application to a maximum of 40 kg N ha^{-1} is another effective adaptation measure as lower yields no longer justify increase mineral fertilizer use. The marginal income obtained by an additional unit of nitrogen application over 40 kg ha^{-1} is smaller than the unit cost of fertilizer under both climate change scenarios.

The majority of farmers in the study area perceive changes in climate. However, only 44 and 41 % have adopted management technologies to counteract the adverse effects of increasing temperature and decreasing precipitation. Farmers who have access to credit, extension services, use fertile land or farm on their own land are more likely to adapt to climate change particularly with regard to decreasing precipitation. The major barriers to climate change adaptation are poverty, lack of or high cost of improved seed, and lack of information on adaptation strategies. Access to

credit/loan facilitates adaptation to climate change, as access to cash allows farmers to purchase inputs like seeds of improved cultivars and fertilizer. The positive correlation between adaptation to climate change and the availability of credit observed in this study indicates the need to make cash available to farmers. Similarly, farmers who perceive to have more fertile soil on their farms are more likely to adopt management technologies that help in improving or maintaining soil productivity such as application of inorganic fertilizer, application of manure, incorporation of crops residue, etc. when precipitation is decreasing.

6.3 Recommendations

Based on the findings of this study, it is recommended that in developing fertilizer recommendation for a cropping system, site specific nutrient stock should be considered

The application of inorganic fertilizer increased grain yield considerable; to improve the rate of fertilizer adoption, the government could subsidize the cost of fertilizer in order to make it affordable for farmers to purchase. Government policies should ensure that terms for bank credits are flexible to enhance farmers' access to affordable credits, which will increase their ability to boost crop production and productivity, enhance flexibility to change crop and soil management strategies in response to climate change.

The APSIM-Maize model was able to simulate the impact of climate change on maize yield and assess some adaptation measures to take. It is therefore recommended that in developing an adaptation strategy to mitigate the impact of climate change on crops, the model be used to arrive at site and season-specific adaptation measures. Combined with better prediction of the onset of the rainy season, farmers could select the right cultivar and crop in order to avoid significant yield losses and also capitalize on good seasons. This would require seed availability of crops and cultivars with different maturity periods. It is also recommended that the government should consider ways of establishing irrigation systems in the region for supplementary irrigation. There is no knowledge of the economics of fertilizer use in the region under climate change. It is therefore recommended that further study be done on the economics of fertilizer use under climate change. In addition, further research should be carried out on the impact of climate change on land use and nutrient dynamics. Finally,

further studies on the impact of climate change on maize and other crop production in the region and beyond should be carried out with the retention and incorporation of crop residues.

Farmers' dialogue is crucial to the adaptation process. Given the inadequacy of the extension services in the region, improving the knowledge and skills of extension service personnel about climate change and adapted management strategies should be of high priority. Increasing the extension-farmer ratio, and making the extension services more accessible to farmers appear to be the key components of a successful adaptation program.

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8 APPENDICES

Appendix 1: Socio-economic survey

Kwame Nkrumah University
of Science and Technology

CENTER FOR DEVELOPMENT RESEARCH (ZEF) AND KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY

DEPARTMENT OF ECOLOGY AND NATURAL RESOURCE / CROP AND SOIL SCIENCES

QUESTIONNAIRE ON FARMERS PERCEPTION OF CLIMATE CHANGE SURVEY
(FEBUARY, 2009)

3. **Location/Town ……**
6. **House Number…….**
7. **Name of Interviewer……**
8. **Date of Interview…….**
9. **Time Interview Started……...**
10. **Time Interview Ended…….**

Section 1: Personal Data

1. Name of respondent ……..
a. Age ……
b. Sex: Male Female (Tick answers like 'X')

c. Marital status: married separated widowed single divorced

2. How many are you in the household? .....

Educational Background

1. What is your level of education?
(a) Primary (b) JSS/Meddle school (c) Secondary (d) Tertiary (e) Non

(ii) Number of years attained (a)1-6 years (b) 7-10 (c) 12-15 years (d) 16-25 years

Section 2: Crop production

1. What crop do you cultivate in the;

a) Major season?

(i) Maize (ii) Beans (iii) Yam (iv) Groundnut (v) Cassava
(vii) All the above (vi) Others
(specify)……..

(b) Minor season?

Maize Beans Yam Groundnut Cassava
Others (specify)
……

2. What is your farm size (in acres/hectares)?.....

3. How did you get the land?

(a) My own land (b) Family land (c)Lease land (d) Rented
(e) Community land (f) Chief
Others (specify)…….

3b. Is your land fertile>

3c. Do you use fertilizer? Yes No

(i)What type of fertilizer do you use?

(a) NPK (a) Ammonia (c) NPK and Ammonia

(d) Others (specify)……

(ii) How many bags do you apply per acre of the following fertilizer?

a) NPK…….. b) Ammonia……c) Others (Specify)……..

(iii) Do you sell some of your produce? (a) Yes (b) No

(iv)How many bags do you get from your farm per season?

4. Do you have access to market?

(a) Yes (b) No

5. In which market do you sell your produce?

(a) Ejura market , (b) Mampong market

(d) Others (specify)……

(v) How much do you make from the sales of produce per year? In GHC.....

6. Do you have access to extension services?

(a) Yes (b) No

(i) If yes, how many times per year?.....

(ii) If no why……...

7. Do you have access to credit facilities?

(a) Yes (b) No

(i) If yes Where (Source of credit)? (a) Commercial bank (b) Rural Bank (c)Relatives (d) Friends (f) My children (g) Others (specify)…….

(ii) If no why…….

8. How long have you been farming?

(a) 1-5 years (b)6 – 10 year (c) 10- 20 years

(d) More then 20 years

Section 3: Climate change Questions

1. Have you notice any change in the weather pattern?

(a) Yes □ (b) No □

2. What changes have you observed?

a)……..

b) ……..

c)…….

3. Have you heard about climate change? If too difficult to answer, have you heard some one talk about long term change in weather? (a) No (b) Yes

ii). If yes, where did you hear it from?

(a)Radio (b) Television (c) From a friend (d) Extension Officer

(e) Others (Specify)……

iii). When did you hear it?

(a) This year (b) Last year (c) 2 - 4 years ago (d) 5-8 years ago

(e) More than 10 years ago

4. Has there been a change in rainfall pattern in the last 20 years?

(a) Yes , (b) No (c) I don't know I

(b) If yes, has the rainfall period;

i) Increased? (ii) Decreased? (iii) I don't know

(c) Has the intensity of rainfall increased over the years?

(i) Yes □ (ii) No □ (iii) I don't know □

(d) Has length of dry spells during the rainy season increased?

(i) Yes □ (ii) No □ (iii) I don't know □

5. Has there been a change in temperature in the last 20 years?

(a) Yes (b) No (c) I don't know

6. Is the temperature for the past 10 years, (a) Increasing? (b) Decreasing?

(c) I don't know

7. What Month (date) do you plant during the Major season?.....

8. Has the timing (date) of planting for the major season changed?

(a) Yes (b) No (c) I don't know

9. What Month (date) do you plant during the Minor season?.....

10. Has the timing (date/period) of planting for the minor season changed?

(a) Yes (b) No (c) I don't know

(ii) If yes, why? …….

11. Has there been a change in the duration/length of major season over the past 20 year?

(a) Yes (b) No (c) I don't know

12. Has the duration /length of minor season changed over the past 20 year?

(a) Yes (b) No (c) I don't know

13. Have you seen a change in grain yield or produce over the past 20 years?

(a) Yes (b) No (c) I don't know

(ii)What change is it in yield?

(a) Increased in crop yield (b) Decreased in crop yield

(c) I don't know

14. If there is a decrease in yield, what could be the reason?

(a) Less rainfall (b) High temperature

(c)Low soil fertility (d) all the above (e) a, and b (f) I don't know

What caused the Observed changes? (rate them from 1-5) (1=very high….5=very low)

Observed changes in climate	**Causes**
1. Increasing in temperature	a) Burning bushes
	b)Felling of trees/Deforestation
	c) Use of too many cars
	d) Increase in population
	e)
2. Decrease in rainfall	a) Cutting down of trees/Deforestation
	b)Burning
	c) Less tree planting
	d)Increase in population
	e)
3. Shortening of season duration/ length	a) reduction of rainfall duration
	b) increase in temperature
	c)
4. Increase in draught spells	a) Increase in temperature
	b)Decrease in rainfall
5. Increases in weeds and past out breaks	a) Increase temperature
	b)
	c)

Section 4: Adaptation Strategies

1. What have you done or will you do to reduce the impact of (1) **increase temperature** (2) **decrease rainfall** on your farm or crop yield/livelihood?

Let the farmer give his option

Check and tick the answers below for **1** and then ask for the ones not yet listed there: What additional measures would you consider in the future? **(rate them from 1-5) (1=very high….5=very low).**

Increase in average Temperature	Decrease in rainfall
(a) Apply less fertilizer □	(a) Plant short season varieties
(b) Crop diversification □	(b) Change from crops to livestock
(c) Change in crops □	(c)Change in planting date
(d) Reduce farm size □	(d) Apply less fertilizer □
(e) Change in planting date □	(e) Migrate to a big city □
(f) Lease your land □	(g) Plant different crops □
(g)Change from crops to live stock □	(h) Reduce farm size □
(h) Plant different crops □	(i) No Adoption □
(i) Find off-farm job □	(j) Others
(j) No Adoption	
(k)Others □	

19. Will you buy weather insurance to cover your crops?

(a) Yes (b) No (c) I don't know

20. What are the possible barriers to adapt to climate change or long term change in weather?

(a) Lack of funds or credit facilities / Poverty

(b) Lack of technology (c) Increase in population

(d) Lack of access to water

(e)Lack of access to market

(f) Lack of appropriate seed

(g) Lack of knowledge about adaptations

(h) Lack of information about weather

(i) Others (Specify)……

1. What material is the roof of the main building made of? 1. Mud 2. Thatch 3. Wood 4. Metal Sheets 5.Cement/ Concrete 6.Roofing tiles 7.Asbestos 8. Others… ……	2. Main material of the floor 1. Earth/mud/mud bricks 2. cement/ concrete stone 3. Burnt bricks 4. wood 5. Ceramic /marble tiles 6. Carpet 7. Terrazzo 9. Others..	3. What is the material of the walls of the house? 1. Mud/mud bricks 2. stone 3. burnt bricks 4. cement/sandcrete 5. wood/bamboo 6.Iron Sheets 7. Cardboard 8. Others….	4. How many separate rooms do members of your household occupy? *(Count living rooms, dining rooms but not bathrooms, toilets, garage and kitchens)*	5. What is the main source of drinking water for members of your household? 1. Piped into dwelling or compound 2. Public outdoor tap 3. Borehole 4. Protected well 5. Unprotected well, rain water 6. River, lake ,pond 7. Vendor or truck 8. Others…	6. How long does it take you to go to the nearest hospital/ clinic? Km Min.		7. What kind of toilet facility does your household have? (a) Flush toilet (b) Covered Pit Latrine (c) Uncovered Pit Latrine (d) KVIP (e) Bucket /Pan (f) No facility/Bush/Field/Beach (g) Others… …… …. (Specify)	8. Do your (household) share these facilities with other households? 1= Yes 2= No	9. How many households do you share these facilities with? *(tick)* 1-2 [ ] 3-4 [ ] 5-9 [ ] 10+) [ ]	10. What type of fuel does your household mainly use for cooking? 1. Electricity 2. LPG/Natural Gas 3. Kerosene/Oil 4. Charcoal/firewood 5.Crop residue/sawdust 6. Animal waste 7. others (specify)	11. Does any member of your household own (any means of transport?) 1. A bicycle 2. A motor cycle or motor scooter 3. A car or track 4. A tractor 5. A horse/cart?	12. How long (average) does it take to reach other nearest facilities by kilometres and minutes? 1.Public Transportation 2. Telecommunication facility 3. Supply of drinking water 4. Distance to food market 5. Distance to Vaccination center/hospital (U5C) Km Min			13. Does house hold have electricity? 1 = Yes 2 = No
												1			
												2			

Assets

Do you currently own any of the following assets?	1. Yes 2. No	Qty owned	Current Resale value
1. Motor car			
2. Motorbike			
3. Bicycle			
4. Truck			
5. Tractor			
6. Furniture/Sofa			
7. Sewing machine			
8. Refrigerator/Freezer			
9. Radio			
10. Radio cassette			
11. Video deck			
12. Television			
13. Video camera/camera			
14. Mobile phone			
15. Electric/Gas stove			
16. Electric iron			
17. Electric Fan			
18. Air conditioner			
22. House made of blocks			
23. Land (Hectares)			
24. Generator			
26. Cattle			
27. Sheep/Goats			
28. Poultry			
29. Other…			

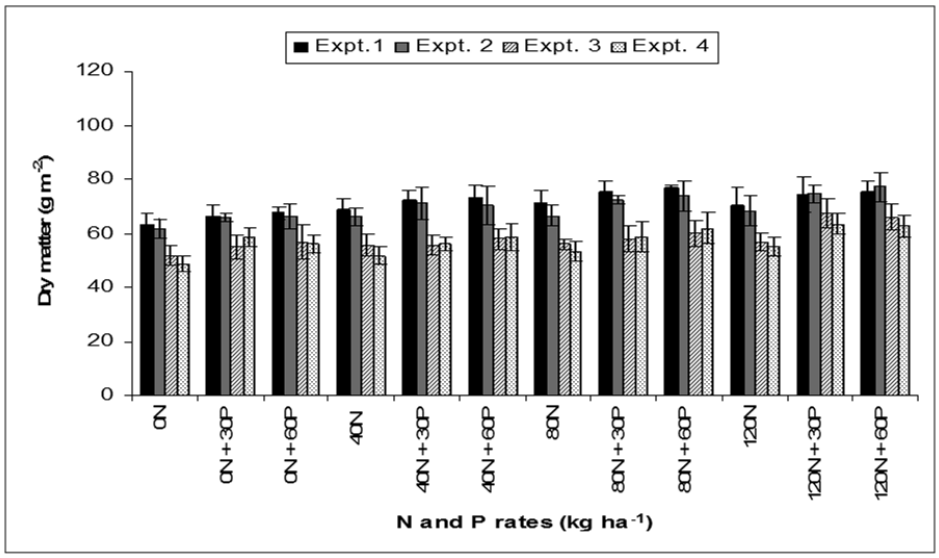
Appendix 2: Duration of Maize (Obatanpa) growth from sowing to maturity expressed in calendar and growing degree days (^{o}C days).

				Calendar days				Thermal time (°C days)			
				Experiment number							
Stage	Treatment combination	N applied (kg ha^{-1})	P applied	1	2	3	4	1	2	3	4
	N1P1	0	0	57	57	58	59	1148	1152	1096	1114
	N1P2	0	30	57	57	58	59	1148	1152	1096	1114
	N1P3	0	60	56	57	58	58	1129	1152	1096	1095
	N2P1	40	0	56	57	57	57	1129	1152	1077	1076
Tasseling	N2P2	40	30	56	56	57	57	1129	1132	1077	1076
	N2P3	40	60	56	56	56	56	1129	1132	1058	1057
	N3P1	80	0	55	56	57	57	1110	1132	1077	1076
	N3P2	80	30	55	55	56	56	1110	1112	1058	1057
	N3P3	80	60	54	55	55	56	1090	1112	1039	1057
	N4P1	120	0	55	56	56	56	1110	1132	1058	1057
	N4P2	120	30	54	55	55	55	1090	1112	1039	1038
	N4P3	120	60	54	54	55	55	1090	1094	1039	1038
	N1P1	0	0	105	106	107	107	2051	2074	2073	2069
	N1P2	0	30	105	106	106	107	2051	2074	2052	2069
	N1P3	0	60	105	106	106	106	2051	2074	2052	2049
	N2P1	40	0	105	105	105	106	2051	2055	2032	2049
	N2P2	40	30	105	105	105	106	2051	2055	2032	2049
	N2P3	40	60	105	105	105	106	2051	2055	2032	2049
	N3P1	80	0	105	105	105	106	2051	2055	2032	2049
	N3P2	80	30	104	105	105	105	2031	2055	2032	2029
	N3P3	80	60	104	104	104	105	2031	2037	2012	2029
	N4P1	120	0	105	105	105	106	2051	2055	2032	2049
	N4P2	120	30	104	104	104	105	2031	2037	2012	2029
	N4P3	120	60	104	104	104	105	2031	2037	2012	2029

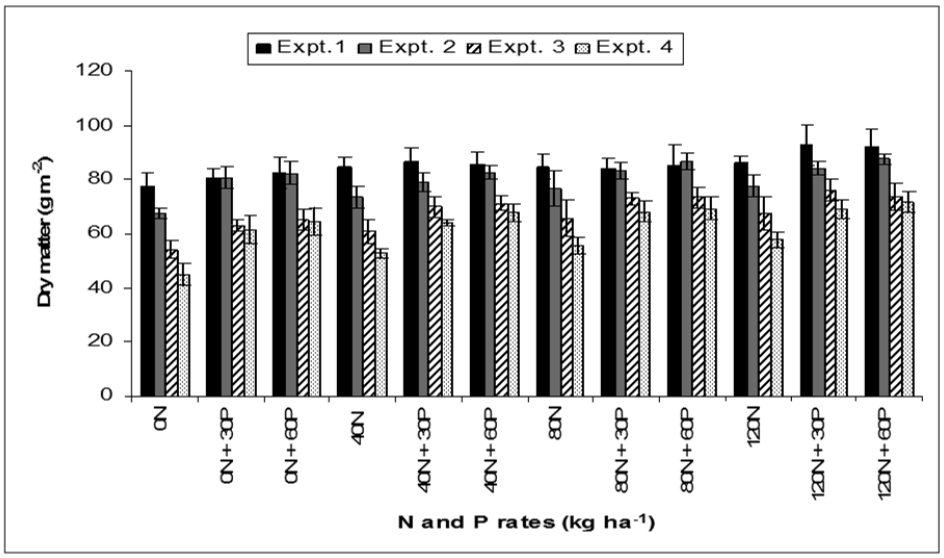
Appendix 3: Duration of Maize (Dorke) growth from sowing to maturity expressed in calendar and growing degree days (^{o}C days).

				Calendar days				Thermal time (^{o}C days)			
				Experimental Number							
Stage	Treatment combination	N applied (kg ha^{-1})	P applied (kg ha^{-1})	1	2	3	4	1	2	3	4
Tasseling	N1P1	0	0	54	54	56	56	1090	1094	1058	1057
	N1P2	0	30	54	54	56	56	1090	1094	1058	1057
	N1P3	0	60	53	54	55	56	1071	1094	1039	1057
	N2P1	40	0	53	54	54	55	1071	1094	1019	1038
	N2P2	40	30	53	53	54	55	1071	1074	1019	1038
	N2P3	40	60	52	53	54	55	1050	1074	1019	1038
	N3P1	80	0	52	53	53	54	1050	1074	1001	1020
	N3P2	80	30	51	52	53	54	1032	1055	1001	1020
	N3P3	80	60	51	52	52	53	1032	1055	983	1001
	N4P1	120	0	52	53	53	54	1050	1074	1001	1020
	N4P2	120	30	51	52	52	53	1032	1055	983	1001
	N4P3	120	60	51	52	52	53	1032	1055	983	1001
Maturity	N1P1	0	0	93	94	95	96	1827	1851	1832	1849
	N1P2	0	30	93	94	95	95	1827	1851	1832	1828
	N1P3	0	60	93	94	95	95	1827	1851	1832	1828
	N2P1	40	0	93	94	94	95	1827	1851	1812	1828
	N2P2	40	30	92	93	93	94	1809	1833	1791	1808
	N2P3	40	60	92	93	93	94	1809	1833	1791	1808
	N3P1	80	0	92	93	93	94	1809	1833	1791	1808
	N3P2	80	30	92	92	93	93	1809	1815	1791	1788
	N3P3	80	60	91	92	92	93	1790	1815	1771	1788
	N4P1	120	0	92	92	93	94	1809	1815	1791	1808
	N4P2	120	30	91	92	92	93	1790	1815	1771	1788
	N4P3	120	60	91	92	92	93	1790	1815	1771	1788

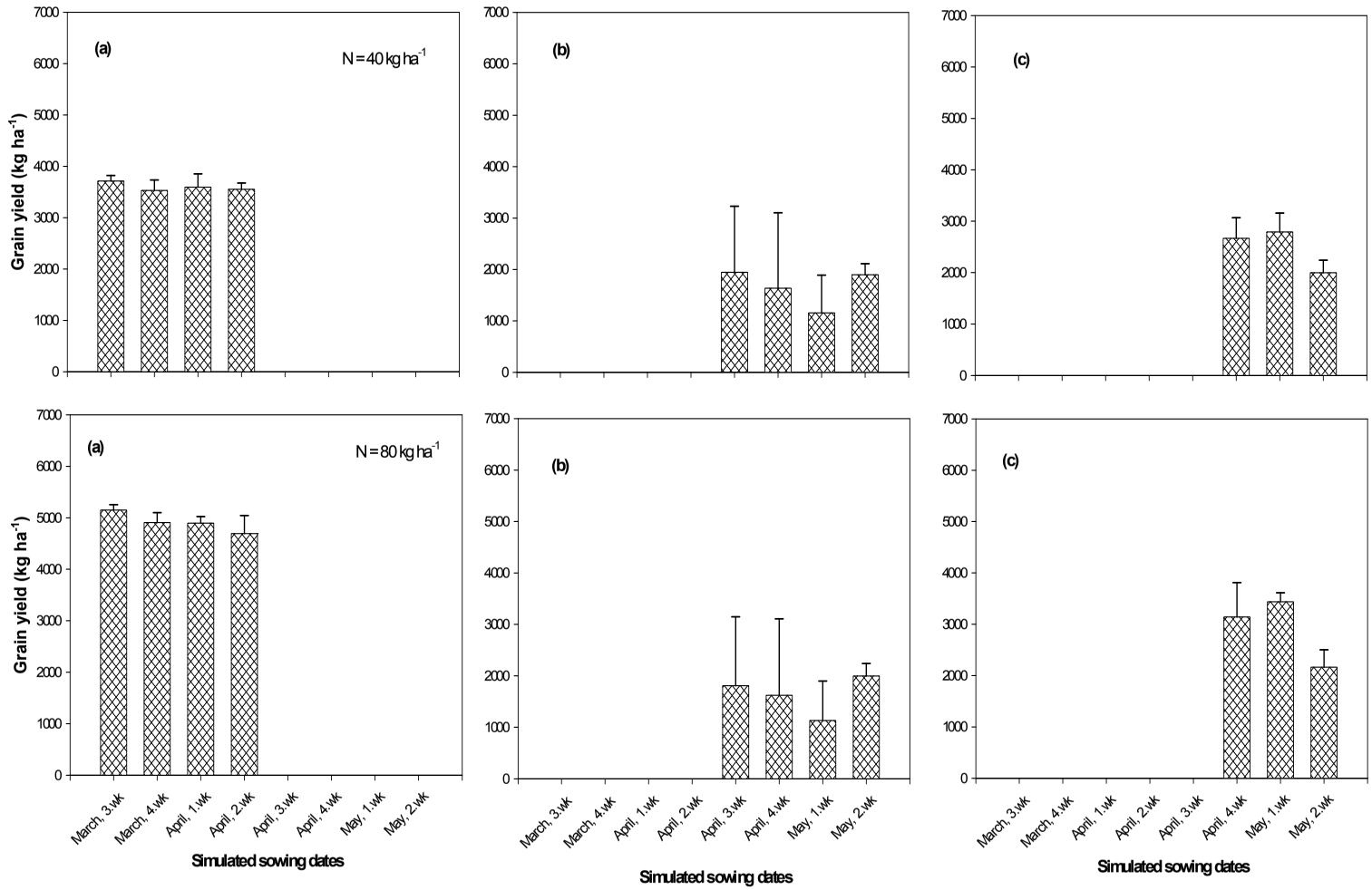
Appendix 4: Dry matter accumulation of Obatanpa maize at 34 days after sowing in Ejura, Ghana, 2008.



Appendix 5: Dry matter accumulation of Dorke maize cultivar 34 days after sowing in Ejura, Ghana, 2008



Appendix.6: Simulated maize (var. Obatanpa) grain yield (kg/ha) in the major season at Ejura, Ghana, from historical weather data (1980-2000) (a), projected climate change (2030-2050) for scenarios A1B (b) and B1 (c) with 40 and 80 kg N ha^{1} fertilizer



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