UNU-INRA WORKING PAPER NO.1

UNITED NATIONS UNIVERSITY

INSTITUTE FOR NATURAL RESOURCES IN AFRICA

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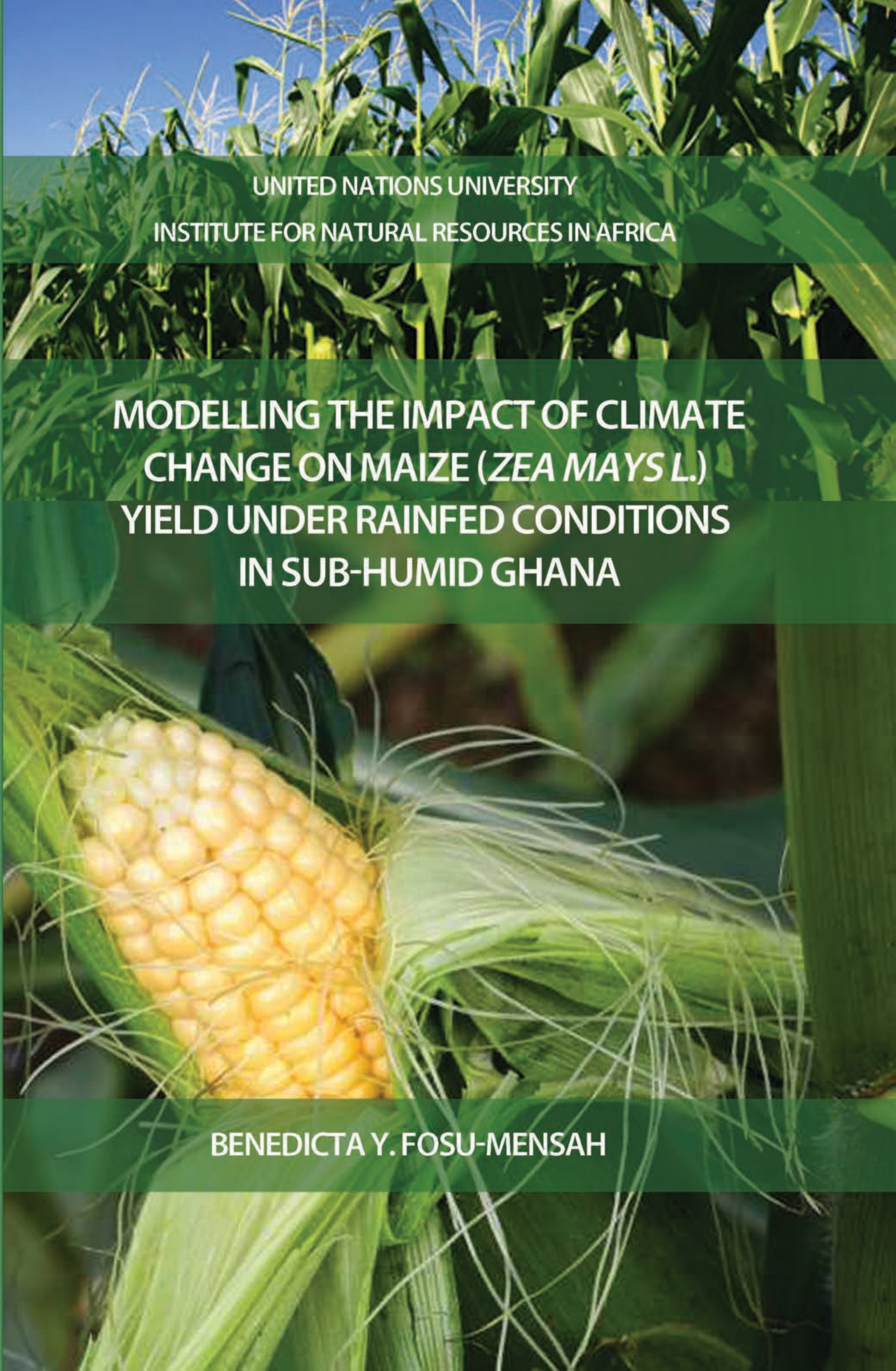
BENEDICTA Y. FOSU-MENSAH



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MODELLING THE IMPACT OF CLIMATE CHANGE ON MAIZE (*ZEA MAYS L.*) YIELD UNDER RAINFED CONDITIONS IN SUB-HUMID GHANA

BY

BENEDICTA Y. FOSU-MENSAH

March 2013

ABSTRACT

Climate change and variability pose a serious threat to food production in Sub-Saharan Africa (SSA). The projected changes in spatio-temporal patterns of rainfall and temperature are likely to affect water and nutrients availability, crop growth, and yield. This paper presents the simulated effects of climate change on maize (*Zea mays L.*) yield under rainfed conditions in Ejura, Ghana, known as one of the major food baskets of the country. Experimental data from maize grown under various nitrogen (N) and phosphorus (P) regimes in the 2008 major and minor seasons at two sites in Ejura were used to set parameters for and evaluate the cropping systems model APSIM. Daily climatic data for the period 2030-2050 under the scenarios A1B* and B1** (2030-2050) were obtained from the regional mesoscale model MM5. Assessment of the impact of climate change on the onset of the rainy season (ORS) suggested a likely six-week shift in the onset of the rainy season from week 3 of March (1980-2000) to week 2 of May for simulated data. This six-week delay in sowing resulted in a significant yield reduction and a significant increase in yield variability under both scenarios. Potential adaptation measures include early planting, introduction of fallow rotation and supplemental irrigation.

Key words: *simulation, modelling, nitrogen, phosphorus, sowing date, maize, climate change*

** A1B scenario represents an integrated future world that puts a balanced emphasis on all energy sources.*
*** B1 scenario describes a more integrated and ecologically friendly future world.*

ACRONYMS

APSIM	Agricultural Production Systems Simulator
BD	Bulk Density
BIOM	Labile, Soil Microbial Product
BMBF	German Federal Ministry for Education and Research
C	Carbon
CCCM	Canadian Climate Centre Model
DAAD	German Academic Exchange Service
DAS	Days after Sowing
DUL	Drained Upper Limit
FAOSTAT	Statistical Division of the Food & Agriculture Organisation
FOM	Fresh Crop Residue and Roots added to the Soil
GCMs	Global Climate Models/General Circulation Models
GDP	Gross Domestic Product
GFDL	Geophysical Fluid Dynamics Laboratory
HUM	Organic Soil Matter
IFPRI	International Food Production Research Institute
IPCC	Intergovernmental Panel on Climate Change
LL	Lower Level of Plant Extractable Soil Water
MdUAPE	Median Unbiased Absolute Percentage Error
MM	Mesoscale Model
N	Nitrogen
ORS	Onset of Rainy Season
P	Phosphorous
RMSE	Root Mean Square Error
SAT	Volumetric Water Content Saturation Level
SOILN2	A Type of Soil Module
SOILP	Soil Phosphorus - a Type of Soil Module
SOILWAT2	A Type of Soil Module
SRES	Special Report on Emission Scenarios
TDM	Total Dry Matter
UNU-INRA	United Nations University - Institute for Natural Resources in Africa

ACKNOWLEDGEMENTS

The author greatly appreciates financial support from the German Federal Ministry for Education and Research (BMBF) and the German Academic Exchange Service (DAAD) to conduct this research study.

Financial support from the United Nations University - Institute for Natural Resources in Africa (UNU-INRA) under the Visiting Scholars Programme is much appreciated.

I am grateful to the Director of UNU-INRA, Dr. Elias Ayuk for his support throughout my work at UNU-INRA.

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1. INTRODUCTION

Climate change is a threat to food security and the livelihoods of the rural poor. Reported projections indicate that with the trend in climate change and variability the impact on people's livelihoods will be greatest in Africa, where many poor smallholders largely or totally rely on rainfed 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 Sub-Saharan Africa, the agriculture sector is one of the most important sectors providing employment for about 70 per cent of the population and accounts for about 35 per cent of GDP (World Bank, 2000). Rainfed agriculture takes about 95 per cent of cropped land (FAOSTAT 2005, *http://faostat.fao.org*), making it very important in this part of the world. The spatial and temporal variability (erraticness) of rainfall which is reflected in drought spells and floods are the most important phenomena that affect crop productivity in this region (Laux *et al.,* 2010). Mishra *et al.,* 2008 and Usman *et al.,* 2005 reported that inter - and intra-seasonal rainfall variability are the major causes of crop failure. Thus the amount and distribution of rainfall within the season is very important for crop growth, development and ultimate yield.

In the semi-arid regions of Africa, it is evident that for 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 phenomenon is gradually shifting to the sub-humid regions, where increasing variability in seasonal rainfall totals and distribution are occurring (Cooper *et al.,* 2006). While seasonal rainfall totals and their season-to-season variability are themselves important, the nature of within-season variability can also have a major effect on crop productivity, especially at certain critical stages (flowering and grain filling stage) of crop growth. The onset and duration of the season are also important variables that affect crop production (Ingram *et al.,* 2002; Ziervogel and Calder, 2003), and available water for plants depends on the onset and length of the season.

Climate change and variability, coupled with low soil nutrient content, are likely to have a significant impact on crop growth and developmental processes. The photosynthetic rate of plants can be affected by an increase in carbon dioxide (CO_2) which will, in some cases, lead to higher yields (Kimball, 1983). Similarly, changes in temperature and precipitation will affect crop photosynthesis, crop development rates, as well as water and nutrient availability (Long, 1991).

The effects of climate change will however differ depending on local conditions. For example, in temperate regions where temperatures affect the length of the growing season, crops may benefit from warmer conditions, resulting in higher yields. On the other hand, increases in temperature in tropical regions which already have a warmer climate (like West Africa) are likely to lead to yield reduction and or crop failure, as increases in temperature, evapotranspiration and reduction in precipitation worsen existing water stress conditions (Challinor *et al.,* 2007). Crop productivity will be significantly affected by climate change, as crop growth and development respond dynamically to daily weather conditions (Rosenzweig and Hillel, 1998).

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 the rainfed farming systems being practised. These systems already have the problems of low soil fertility resulting in low crop yields, insufficient domestic production, national food insecurity and poverty, all of which pose challenges for development.

The sub-humid region in Ghana is one of the high food producing areas in the country, with maize being one of the most cultivated cereal crops. Over the years there has been a decreasing trend of yield due to the decline in soil fertility, especially of nitrogen and phosphorus. As farmers battle to increase productivity under low soil fertility conditions, climate change and variability present other challenges that farmers will have to deal with. Chances are that climate change and variability will greatly affect maize yields and hence the livelihoods of the rural poor.

This paper seeks to investigate the impact of climate change on maize yields and nutrient use efficiency under rainfed conditions in sub-humid Ghana. The results will be used to inform policy and to enable government develop and implement climate change policies and programmes.

The use of robust and well-tested crop growth models can be an effective way of analysing the complex relationship between climate, management options, and crop productivity. The capability for simulating crop growth in response to soil P makes the Agriculture System Simulator Model (APSIM) particularly suitable for analysing crop production in Africa, where crop yield and efficient use of applied mineral fertilisers N are greatly affected by low soil P.

Young maize plants in a farmer's field

2. MATERIALS AND METHODS

2.1 Study area

The study was conducted 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 sub-humid or 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 at the year 2000, which is projected to increase to 34,612 by the year 2009 (Ghana Statistical Service, 2002).

2.2 Climate

The sub-humid zone of Ghana, also known as the transition zone, lies between the Guinea savanna ecological zone to the north characterised by a monomodal rainfall pattern, and the forest ecological zone to the south characterised by a bimodal rainfall pattern. Mean annual rainfall in this zone is about 1400 mm. Rainfall follows a pseudo bimodal pattern, meaning that in August there is a slight decrease in rainfall (marking the end of the major season and the beginning of the minor season); the peak of the season is in September and/or October. The wet season lasts for roughly seven months from April till October. The onset of the season is highly variable. The period from April through October has 80 per cent 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 per cent at its peak in June and 55 per cent in February. Figure 2.1 depicts cumulative rainfall for the major and minor seasons of the year of experimentation.

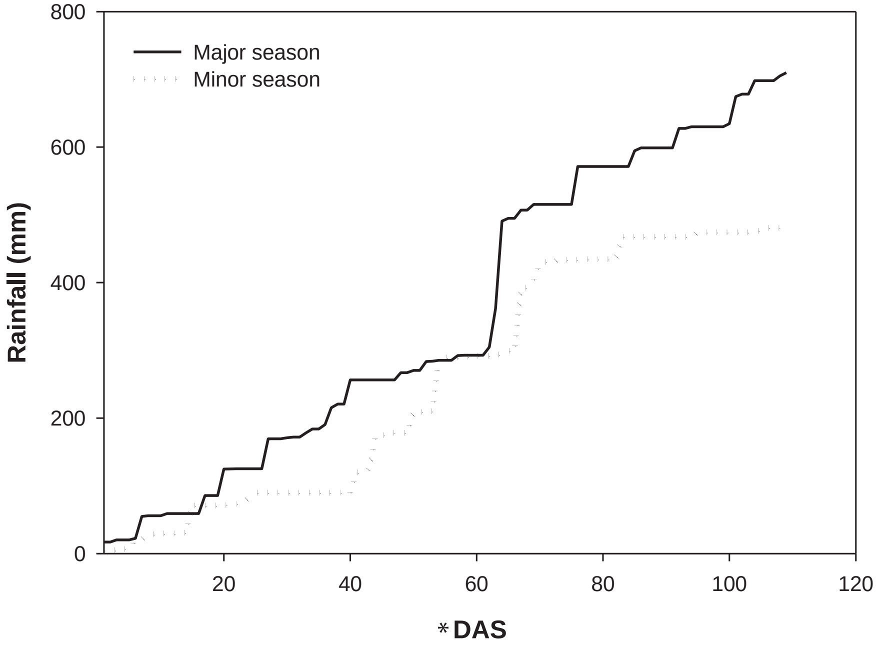

Figure 2.1: Cumulative rainfall during major and minor seasons in Ejura, Ghana, (2008).
****DAS depicts days after sowing***

2.2.1 Vegetation

The vegetation in the study area is typical for the transitional zone. The southern part of the zone is covered with moist semi-deciduous forests. The northern part is generally typical of the Guinea savannah zone and the vegetation 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 study area is largely attributable to the increase in the rate of shifting cultivation and the consequent decrease in the length of bush fallowing in the district. The climatic conditions together with the topographical layout are favourable for the cultivation of food crops such as *Discorea species* (yam), *Manihot esculenta* (cassava), *Zea mays* (maize) among others in the transition zone.

2.3 APSIM model description

The Agricultural Production Systems sIMulator (APSIM) is a modular modelling framework that can be used to simulate complex climate-soil-crop systems (Keating *et al.,* 2003). The APSIM-Maize, SOILN2, SOILWAT2 (Probert *et al.* 1998), and SOILP (soil phosphorus) modules were linked within APSIM version 7.3 to simulate the yield response of maize to inorganic fertiliser, nutrient dynamics and climate change.

The APSIM-Maize module simulates crop phenology, biomass accumulation, LAI, grain yield, and water, N and P uptake on a daily time-step. The Maize module has 11 crop stages and nine 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 to light if the cultivar is photoperiod sensitive (further details are available in APSIM documentation at *http://www.apsim.info/Wiki/Maize.ashx).*

The SOILN2 module accounts for the dynamics of both carbon (C) and N in each soil layer. There are three pools of soil organic matter (FOM, BIOM and HUM). The FOM is the fresh crop residue and roots added to the soil and when these decompose, the product is partitioned into the BIOM and HUM pools. The BIOM is the more labile, soil microbial product and has a high turnover, whilst the HUM forms more stable soil organic matter. The decomposition rate of soil organic matter depends on soil water content, soil temperature, and C:N ratio. The SOILP module in APSIM simulates the mineralisation of organic P sources in each soil layer, which is linked to decomposition of carbon from the HUM, BIOM and FOM pools. SoilP assumes constant C:P ratios in BIOM and HUM but tracks C:P ratios of FOM and surface residues as crops add residues of varying P concentrations. In addition to mineralisation, the P dynamics in soil depend on the addition of P from fertiliser and crop residues, dissolution of rock P, loss of availability with time, and removal of P by crop uptake (for detailed description of SOILP see *http://www.apsim.info/Wiki/SoilP.ashx*. The SOILWAT2 module is a cascading layer and works on a daily basis to simulate soil water balance. Soil water characteristics are described in terms of volumetric water content at saturation (SAT), drained upper limit (DUL), and lower limit (LL15) of plant extractable soil water.

2.4 Experiments for APSIM evaluation

The APSIM-maize model was evaluated by using experimental data from four experiments conducted in Ejura during the major and minor seasons of 2008 at two different sites. Four levels of N (0, 40, 80, and 120 kg ha^{-1}) in the form of ammonium sulphate and three levels of P (0, 30, 60 kg ha^{-1}) in the form of triple-super-phosphate were laid out in a randomised complete block design.

Obatanpa and Dorke maize cultivars were sown on April 21 and 24 in Experiments 2 and 1, respectively, in the major season. In the minor season, sowing was done on August 8 and 9 in Experiments 3 and 4, respectively. Experiments 1 and 3 were located at the Ejura farm site and Experiments 2 and 4 at the Agricultural College. Experiments 1, 2 and 3 were established on Haplic Lixisol, whereas the soil type for Experiment 4 was Plinthosol. Plant density was 6.7 m^{-2}. Treatments were replicated three times in each experiment. Soil characteristics required for the APSIM model were obtained from all experimental sites.

Flowering maize plants

2.5 Scenarios for assessing the impact of climate change on maize yields

The daily climatic data for the period 2030-2050 under the scenarios A1B and B1 (IPCC synthesis report 2007) were obtained from the regional mesoscale model MM5 (Jung 2006). The A1B scenario represents an integrated future world that puts a balanced emphasis on all energy sources. The B1 describes a more integrated and ecologically friendly future world (clean and resource-efficient technologies). Both A1B and B1 scenarios showed an increase in mean temperature of 1.6°C and 1.3°C, respectively, compared to the 1980-2000 period (used as a baseline). Precipitation is projected to decrease by about 20 per cent and 21 per cent under the A1B and B1 scenarios, respectively.

The assessment of the impact of climate change on maize yields was done by considering two main rotations, (i) Maize-cowpea bimodal simulation (simulation of maize during major seasons and cowpea during minor seasons) for 21 years; (ii) Maize-fallow rotation (maize during major season and fallow during minor season). The sowing window used was 15 March to 10 May and sowing was at a soil depth of 50 mm. Sowing was done when there was 20mm rainfall within five days. Apart from the maize-cowpea simulation where both Obatanpa and Dorke cultivars were simulated, the maize-fallow scenario considered only Obatanpa and major season yields with the application of 40kg and 80kg N ha^{-1} with 30kg P ha^{-1}.

2.6 Statistical analysis

The performance of the model in predicting the grain yield, total biomass, N and P uptake of maize was evaluated using the square of the correlation coefficient (R^2), root mean square error (RMSE), modified coefficient of efficiency (E_1) and the median unbiased absolute percentage error (MdUAPE). The calculations were as follows:

i. Root mean square error (RMSE)

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

Where n is the number of replication, sim and meas denote simulation and measured total biomass or total dry matter, yield, or any parameter compared for each replicate.

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

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

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

iii. The median unbiased absolute percentage error (MdUAPE) was calculated as

$$\text{MdUAPE} = 100 * \text{Median} \left[\frac{|Simulated_i - Observed_i|}{0.5\ (Observed_i + Simulated_i} \right]$$

3. RESULTS

The APSIM-maize model was parameterised and evaluated with data collected during field experiments in 2008. The soil properties used in model evaluation simulations are presented in Tables 3.1, 3.2 and 3.3. The soil's pH was acidic for all plots and depths. Plant available P was low for both soil types and decreased with depth. Similarly, the percentage of organic carbon was rated very low, according to Landon (1996).

Table 3.1: Soil properties of Haplic Lixisol used for APSIM model evaluation in Experiments 1 and 3 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})	1.50	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}]	0.310	0.318	0.311	0.308	0.344	0.359	0.407	0.407	0.407
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

Table 3.2: Soil properties of Haplic Lixisol used for APSIM model parameter setting and 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}]	0.310	0.318	0.311	0.308	0.344	0.359	0.407	0.407	0.407
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 sorptionc (mg kg^{-1})	50	150	200	200	200	200	200	200	200

Table 3.3 : Soil properties of Plinthosol used for APSIM model evaluation in Experiment 4 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})	1.57	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}]	0.310	0.318	0.311	0.308	0.344	0.359	0.407	0.407	0.407
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 sorptionc (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, Finert[a] defines the proportion of soil organic matter that is not susceptible to decomposition; Fbiom[b] is the proportion of 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}

3.1 Simulated days to tasselling and days to physiological maturity

APSIM simulated the days to tasselling of both cultivars with an overall RMSE of 1.5 and 1.4 days for Obatanpa and Dorke, respectively. In general, the model simulated crop durations were RMSE values of 4.7 and 2.9 days for Obatanpa and Dorke, respectively (Table 3.4). Statistical analysis revealed that there was no significant ($p > 0.05$) difference between the simulated and observed number of days taken to reach physiological maturity, which confirms the APSIM-Maize model's ability to simulate the duration from sowing to physiological maturity.

3.2 Total biomass

The APSIM-Maize model simulated time-series crop biomass accumulation that agreed well with observed biomass data. However, due to the enormous quantity of data, only the comparison of simulated and observed total dry matter (TDM) at final harvest is presented. There was good agreement between the observed and simulated TDM, with overall correlation coefficient (R^2) values of 0.89 and 0.91 for Obatanpa and Dorke, respectively (Figure 3.1). The RMSE values for TDM were 78.0 g m^{-2} and 66.1 g m^{-2}, and model coefficients of efficiency (E_1) were 0.68 and 0.70 for Obatanpa and Dorke respectively.

Table 3.4: 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	

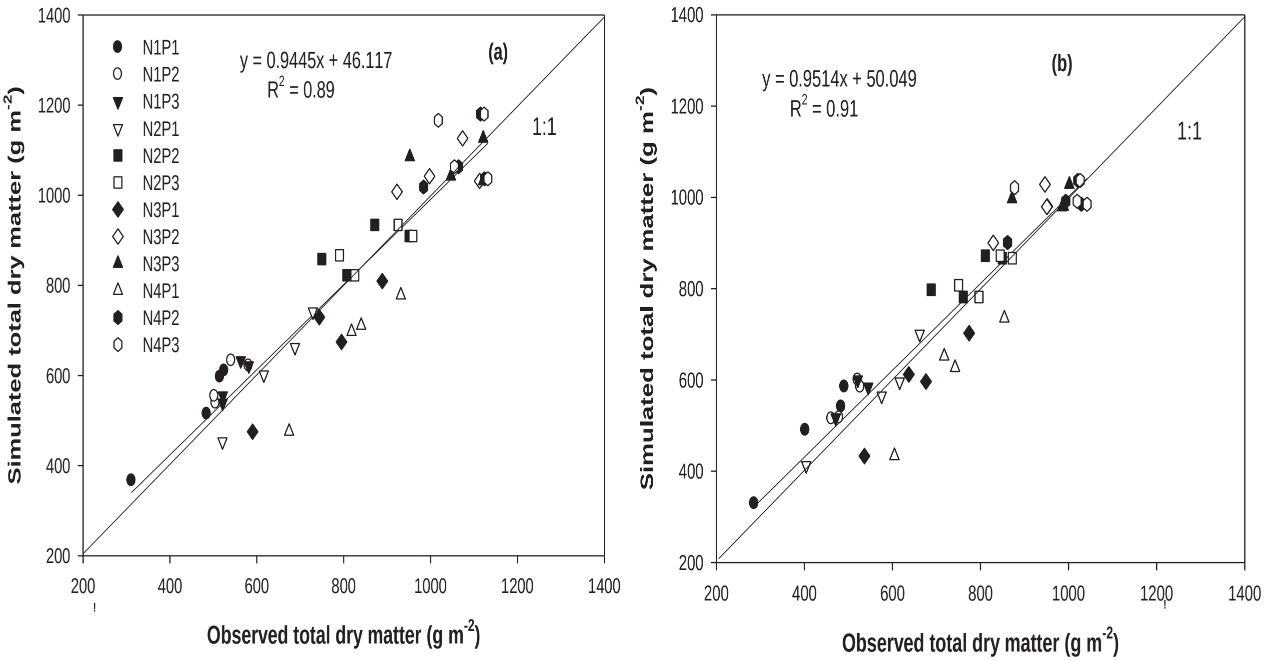

Figure 3.1: ***Comparison of observed and simulated total dry matter of Obatanpa (a) and Dorke (b) maize for different treatments at Ejura, Ghana, 2008. N1, N2, N3 and N4 indicate 0, 40, 80 and 120 kg N ha^{-1}; P1, P2 and P3 are for 0, 30 and 60kg P ha^{-1}***

3.3 Grain yield

The model predicted well the response of grain yield to different levels of inorganic N and P fertiliser application when compared with observed data (Figure 3.2). The RMSE values for grain yield ranged from 26.1 g m^{-2} to 67.1 g m^{-2} and the modified coefficients of efficiency (E_1) were 0.63 and 0.62 for Obatanpa and Dorke, respectively (Table 3.5). Grain yield was generally better simulated in the major season than in the minor season with an overestimation of grain yield particularly at the higher level of N by the model in the minor season. The overestimation is attributed to the difficulty in simulating water stress properly and also the presence of other stress factors like diseases and pests not included in the model.

Diseased maize plants in the field

Maize plants showing signs of pest attack

During the minor season, both experimental sites were infested with stem borer disease, which led to the death of some plants and might also have affected the weight of the grain, and hence the yield. However, this was not reflected in the model. Generally yields obtained during the major season were higher compared to yields in the minor season. This is however expected, as higher rainfall was recorded during the major season compared to the minor season (Figure 2.1).

Table 3.5: Performance of APSIM-Maize to predict maize grain yield response to inorganic N and P fertiliser

Experiments	Number of observations	RMSE (gm^{-2})	MdUAPE (%)	E_1	R^2
Obatanpa					
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

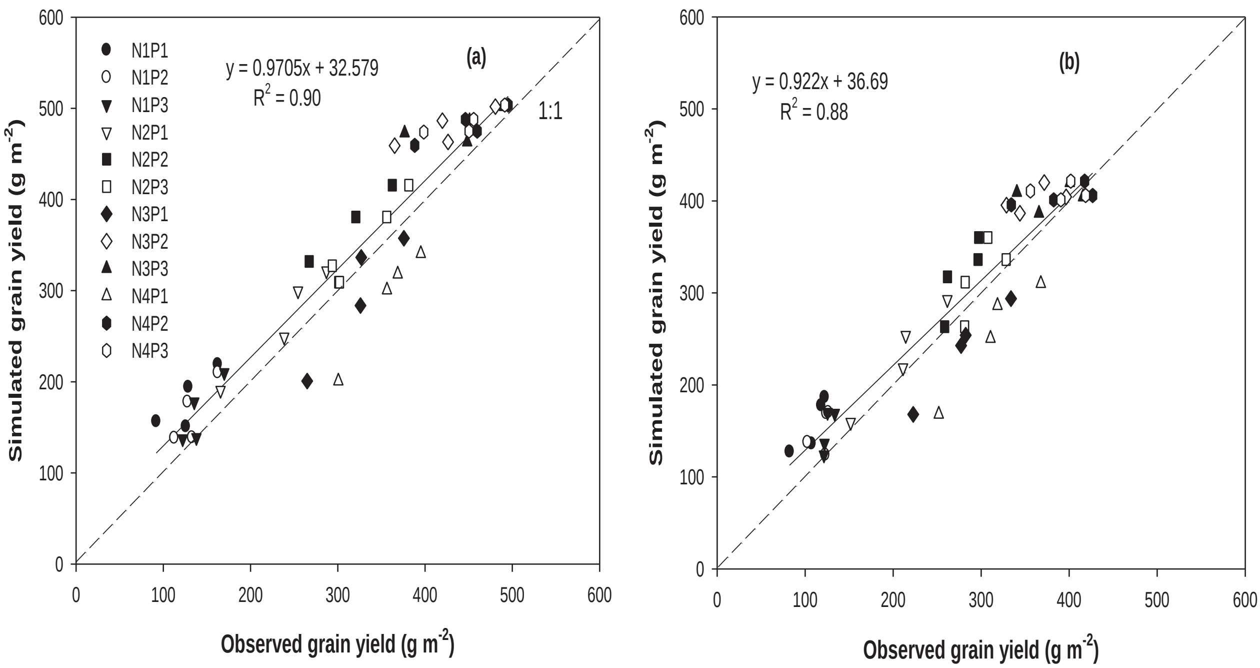

Figure 3.2: ***Comparison of observed and simulated grain yield of Obatanpa (a) and Dorke (b) maize cultivars for different levels of N and P at Ejura, Ghana, 2008. (for legend see Figure 3.1)***

3.4 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 3.4) 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 correlation coefficient (R^2) of 0.86 and 0.82 was obtained for Obatanpa and Dorke respectively. There was a good MdUAPE of 16 per cent and 20 per cent for Obatanpa and Dorke, respectively. The model, however, overestimated grain N uptake at higher N levels (80kg ha^{-1} and 120 kg ha^{-1}) during the minor season.

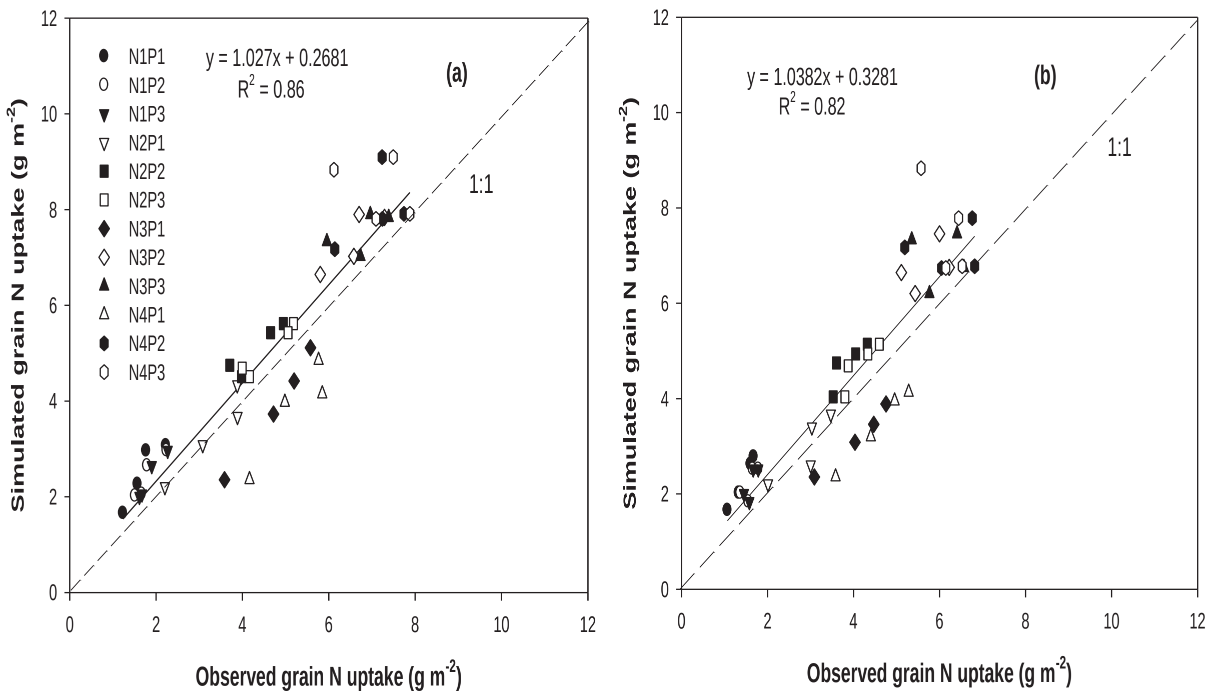

Figure 3.3: ***Comparison of observed and simulated grain N uptake of Obatanpa (a) and Dorke (b) maize for different N and P fertiliser rates at Ejura, Ghana, 2008. (for legend see Figure 3.1).***

3.5 Total N uptake

The trend in total N uptake was successfully simulated by the model for both varieties for the different treatments (Figure 3.4). 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 Experiment 4 (Table 3.6). The model effectively simulated the interactive effect of N and P. In general, the model performed well with an overall correlation coefficient (R^2) of 0.96 and a modified coefficient of model efficiency (E_1) of 0.71 and 0.72 for Obatanpa and Dorke, respectively (Table 3.6).

Table 3.6: Performance of APSIM to predict maize total N uptake in response to inorganic N and P fertiliser

Experiments	Number of observations	RMSE (g m^{-2})	MdUAPE (%)	E1	R^2
Obatanpa					
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

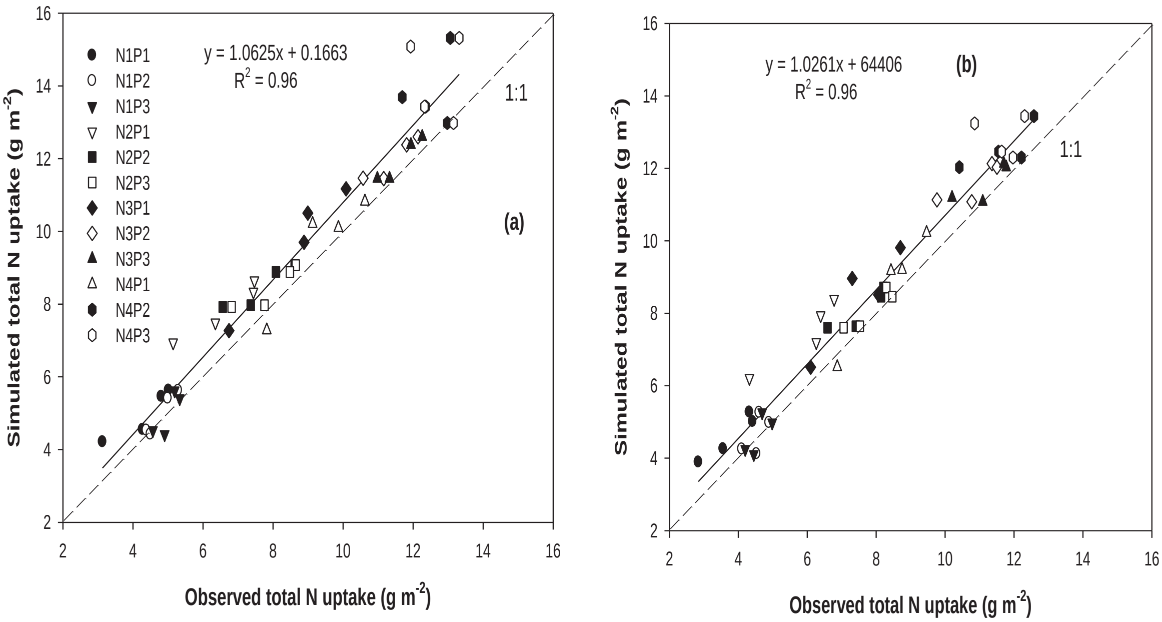

Figure 3.4: ***Comparison of observed and simulated total N uptake of Obatanpa (a) and Dorke (b) maize for different N and P fertiliser rates at Ejura, Ghana, 2008 (for legend see Figure 3.1)***

3.6 Total P uptake

Similarly, total P uptake was well simulated by the model (Figure 3.5), 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 3.7).

Table 3.7: Performance of APSIM to predict maize total P uptake in response to N and P inorganic fertiliser

Experiments	Number of observations	RMSE (g m^{-2})	MdUAPE (%)	E1	R^2
Obatanpa					
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

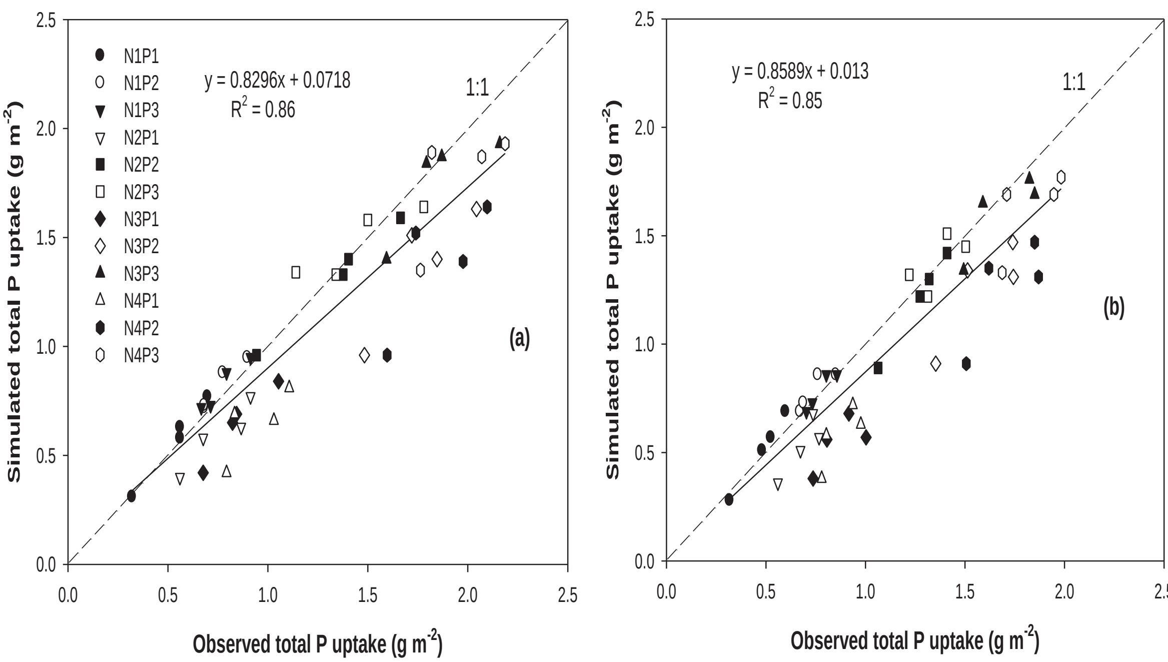

Figure 3.5: Comparison of observed and simulatedtotal P uptake of Obatanpa (a) and Dorke (b) maize for different N and P fertiliser rates at Ejura, Ghana, 2008. (for legend see Figure 3.1)

Table 3.8: Genetic parameters for the maize cultivars Obatanpa and Dorke used in APSIM

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

3.7 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 (version 7.3) using weather series representing both historical (1980-2000) and future (2030-2050) climate assuming the use of the A1B and B1 scenarios (IPCC SRES).

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

Simulation results indicate that climate change and variability will likely result in a shift in the onset of the rainy season. Under both scenarios, about 60 per cent of the years under simulation will receive the minimum amount of rainfall for sowing in the 2nd week of May (Figure 3.6) as compared to simulations with historical data, which predict a high likelihood of sowing in the 3rd week of March. This represents a six-week delay in sowing due to climate change by the year 2050. The predicted delay in the onset of the rainy season, as a result of climate change, delays the sowing period, or narrows it, and hence planting long season cultivars will cause interference from harvesting operations for major season crops when planting in the minor season.

Impact of climate change and variable soil conditions on maize cultivation

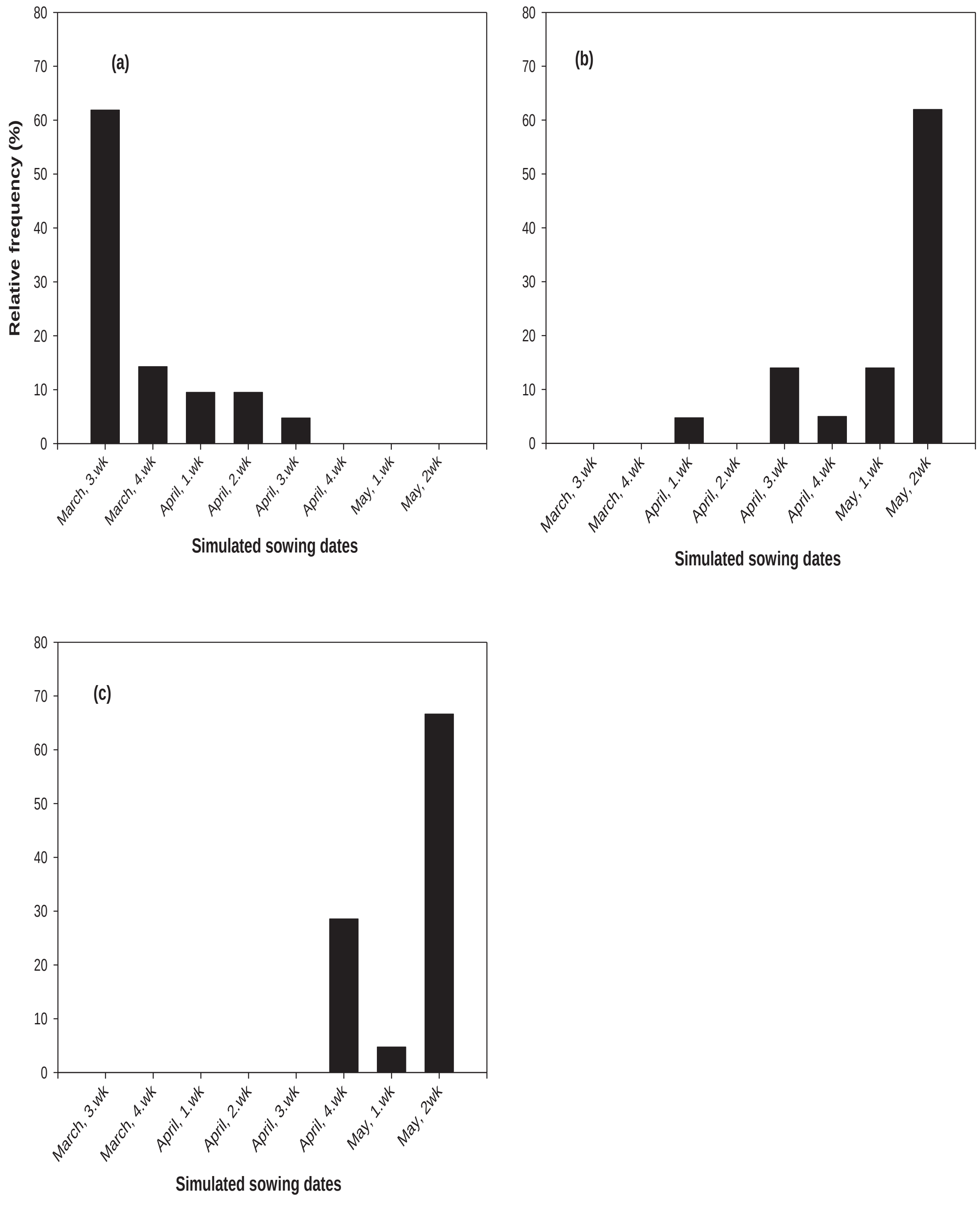

Figure 3.6: ***Relative frequency (%) of simulated maize sowing dates during the major season in Ejura, Ghana, from historical weather data (1980-2000) (a), projected climate change (2030-2050) for scenarios A1B (b) and B1(c)***

3.9 Impact of climate change on maize grain yields

As shown in Figure 3.7, climate change will have a significant impact on maize yields. Climate change will result in a significant increase in variability of rainfall which will be reflected in the yield. There were however higher variability in yields (error bars) for earlier sowing under climate change, representing a higher risk of crop loss compared to late sowing (2nd week of May) for Obatanpa. The same observation was made for the Dorke cultivar.

Historical yields in the region range between 4091 kg ha^{-1} and 4884 kg ha^{-1} with the application of 40 kg N ha^{-1} and 30 kg P ha^{-1} (Figure 3.7) for Obatanpa. As a result of the shift of the onset of the rainy season due to climate change, yields will be negatively affected with grain yields likely to reduce by an average of 35 per cent and 31 per cent under the A1B and B1 scenarios respectively with a high variability in yield (error bar) during the major season for Obatanpa maize cultivars (Figure 3.7). The mean grain yield under the A1B scenario varies from 3164kg ha^{-1} to 4087 kg ha^{-1}, while yields under B1 vary from 3368kg ha^{-1} to 3810 kg ha^{-1}. From these results (Figure 3.7) it is revealed that under climate change, early sowing will give a higher yield but with a high variability in yield, compared to late sowing, where yields are less, but more stable. A similar trend in yield reduction (31 per cent and 29 per cent for A1B and B1, respectively) was observed for the Dorke maize cultivar in the major season when a shift of the sowing dates is considered (graph not shown). The impact of climate change is likely to reduce Dorke maize yields, ranging between 3126 kg ha^{-1} to 3922 kg ha^{-1} and 3399 kg ha^{-1} to 3615 kg ha^{-1} in A1B and B1, respectively under the maize-cowpea cropping system, compared with historical yields ranging from 4041 kg ha^{-1} to 4785 kg ha^{-1}.

Climate change is likely to also reduce the efficiency of nutrient utilisation by crops. From Figures 3.7 and 3.8, the application of 40 kg N ha^{-1} gave the same yield as that of 80 kg N ha^{-1} under both scenarios. A substantial increase in historical yields was, however, obtained with an increase in N level from 40kg ha^{-1} to 80 kg ha^{-1}. This is attributed to water stress conditions, as plant nutrients are transported through soil moisture. Moisture stress will result directly in nitrogen stress as water is needed for nutrient uptake. Thus water stress means less nutrient uptake by the plant.

Compared to the maize-cowpea rotation (cultivation of maize during the major season and cowpea during the minor season), the introduction of fallowing during the minor season is likely to reduce the variability in yields (as shown in the error bars) as well as reduce the adverse impact of climate change, with less variability in yields. With the introduction of fallowing into the cropping system, predicted yields ranged from 3166 kg ha^{-1} to 4069 kg ha^{-1} under the A1B scenario and from 3370 kg ha^{-1} to 3812 kg ha^{-1} under B1 compared to historical yields (3627 kg ha^{-1} to 4669 kg ha^{-1}) with the application of 40 kg N ha^{-1} and 30 kg P ha^{-1}. Climate change is expected to decrease yields by 32 per cent and 28 per cent under the A1B and B1 scenarios respectively with reference to historical yields. There was however, a higher variability in yield in early sowing compared to late sowing. This variability represents the risk and uncertainty of the weather. Thus with higher variability, farmers are at a higher risk of crop failure and loss.

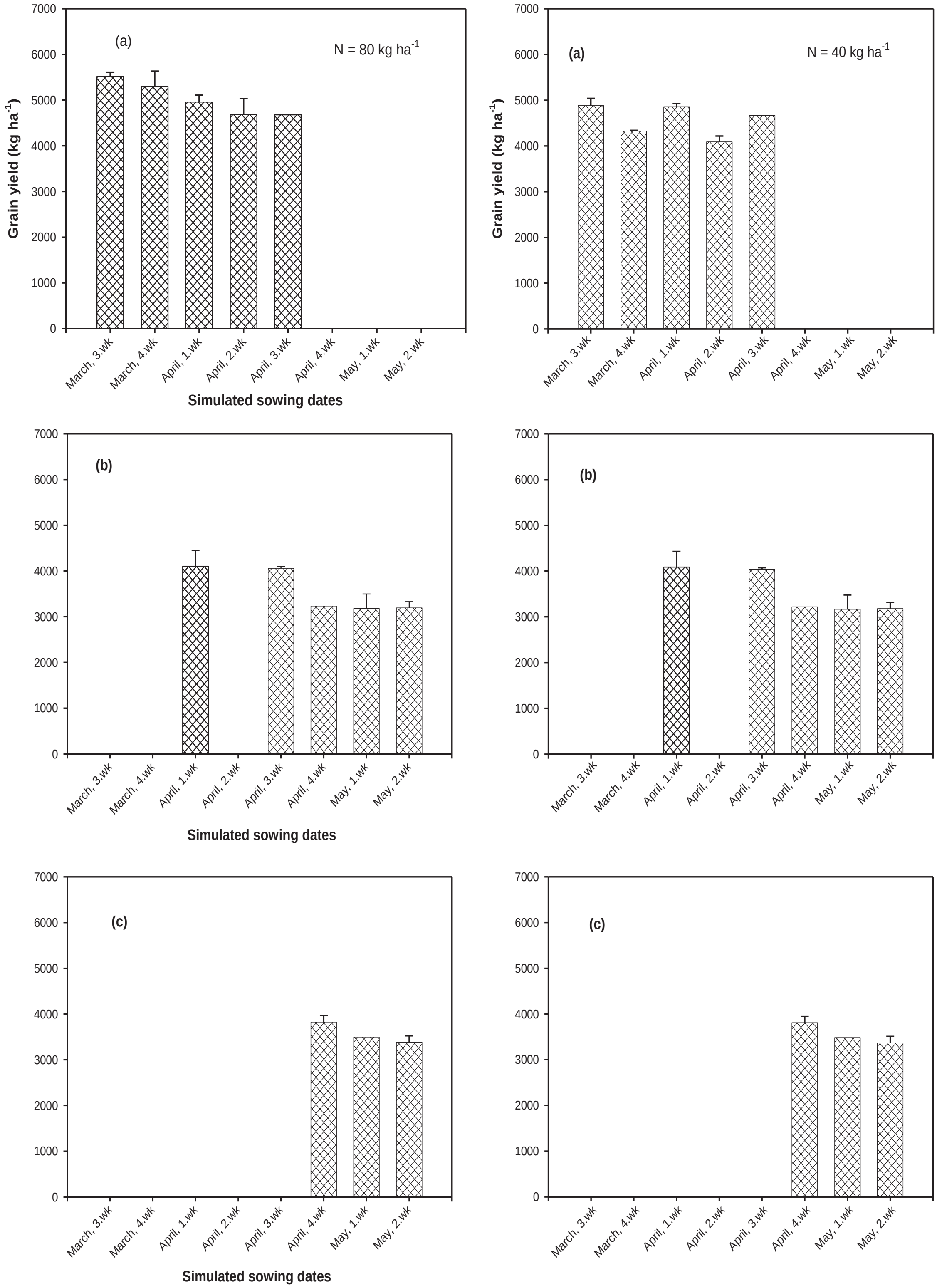

Figure 3.7: ***Simulated maize (var Obatanpa) – cowpea (Malam yaya) grain yield (kg/ha^{-1}) rotation on Haplic Lixisol at Ejura, Ghana, from historical weather data (1980-2000) (a), projected climate change (2030-2050) for scenarios A1B (b) and B1(c) with 40 and 80 kg N ha^{-1} and 30 kg P ha^{-1}***

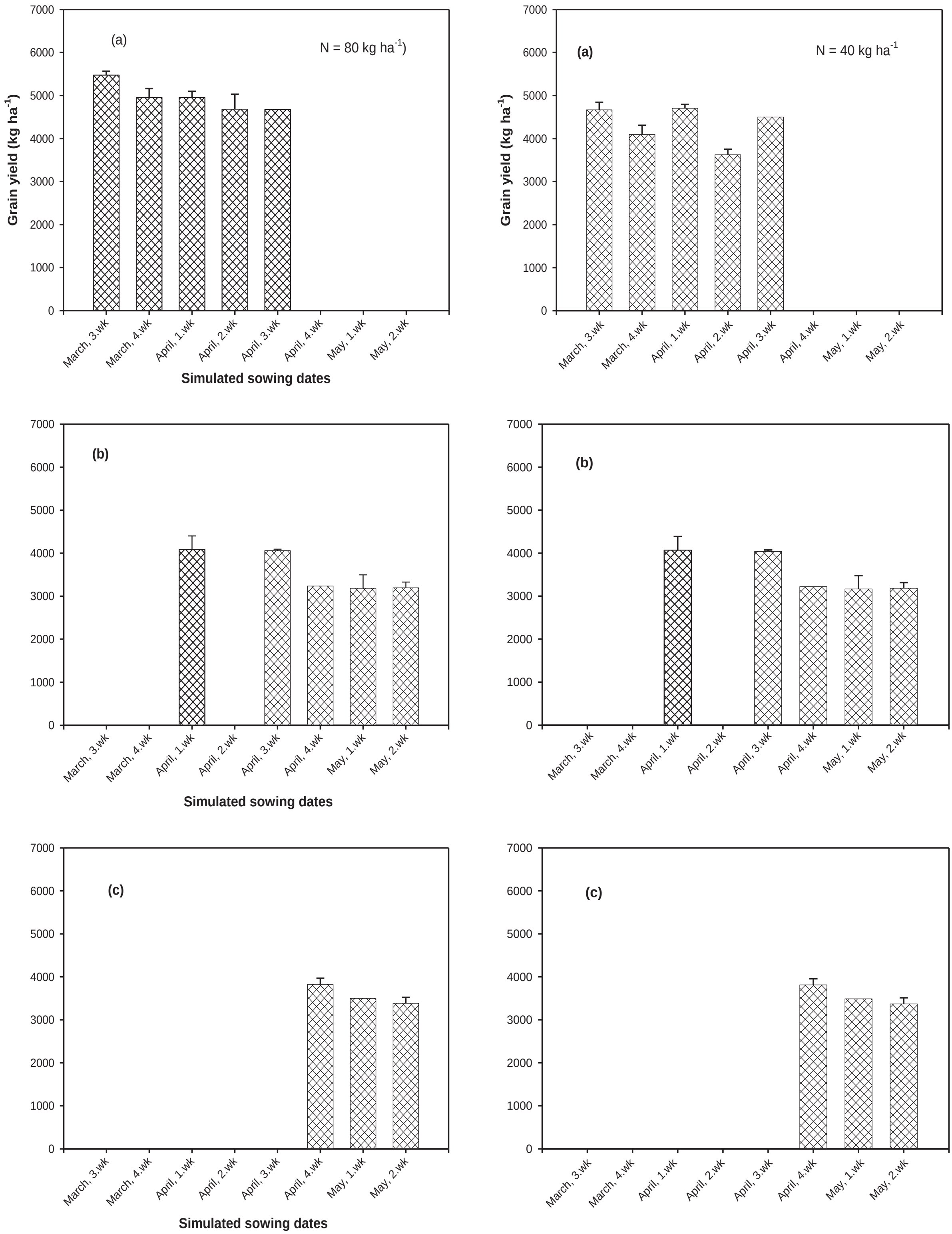

Figure 3.8: ***Simulated maize (var Obatanpa) grain yield (kg/ha^{-1}) – fallow rotation on Haplic Lixisol at Ejura, Ghana, from historical weather data (1980-2000) (a), projected climate change (2030-2050) for scenarios A1B (b) and B1(c) with 40 and 80 kg N ha^{-1} and 30 kg P ha^{-1}***

4. DISCUSSION

4.1 Physiological days to maturity

The decrease in days to physiological maturity with increased N rates indicates the importance of N and P in determining days to maturity, as a high percentage for the variation in days to maturity was accounted for by N and P rates. However, this was not reflected in the model simulation results, which means the model was not very sensitive to the effect of N and P stress on days to maturity. A similar result was reported by Gungula *et al.*, (2003) in a study on predictions of maize phenology under nitrogen-stressed conditions in Nigeria.

The delay in maturity in the minor season (Experiments. 3 and 4) is attributed to the effects of water and pest stress on crop growth and photosynthesis. Rainfall during the major season was higher than during the minor season (Figure 2.1). Moisture stress is known to result indirectly in nitrogen stress, as water is the medium through which nutrients are taken up by plants.

4.2 Grain yield and total dry matter production

The model performed well in predicting grain yield and TDM, with an average RMSE of 44.2 g m^{-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 which might have also affected the weight of the grain and hence the yield. However, this was not reflected in the model. Thus, the model assumed a pest-free and disease-free environment.

4.3 Grain N uptake

The model predicted grain N uptake during the major season very well for both sites with an overall R^2 of 0.96 for both 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 (Experiments. 3 and 4). The overestimation of grain N uptake during the minor season 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.

4.4 Total N and P uptake

The model simulated N and P uptake satisfactorily with overall coefficients of efficiency (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.

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

The predicted delay in the onset of the rainy 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 activities for major season crops. Similar findings on the impact 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 173rd day of the year (DOY); but in El Niño years sowing may have to be delayed until the 229th day of the year. The onset of the rainy season is said to be the most important variable for agricultural management practices (Ingram *et al*., 2002; and Ziervogel and Calder, 2003 cited in Laux *et al*., 2010) especially for sowing, which in turn affects crop growth, development and hence yields (Kumar, 1998).

4.6 Impact of climate change on maize yield

There are clear differences between the impact of the Special Report on Emission Scenarios (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. This result is in line with the findings of Sagoe, (2006) who carried out research in the six ecological zones and reported that by the year 2050, the mean temperature in the country will increase by 2.0 °C. The study region already suffers from high temperatures. Moderately cool temperatures favour high yields, as they allow the crop to progress slowly through the season so as to maximise the time for light capturing and carbon assimilating as well as for partitioning assimilates to reproductive structures (Boote and Sinclair, 2006). However under warmer conditions, yields are expected to be lower. The result obtained is in line with many reports on the impact of climate change on maize yields. For example, Bancy (2000) using two GCMs (GFDL and CCCM model) projected temperature increases of 2.9 °C and 2.3 °C, respectively in semi-humid and semi-arid areas of Kenya. He further stated that the planting date has a profound influence on maize yields and hence concluded that early maturing cultivars and early planting practices are necessary to counter the adverse effects of climate change on maize production in the area.

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 the A2 scenario showed that increases in temperatures reduced the growing season of maize crops in south-eastern South America by 27 days and consequently reduced yields. Under non-limiting water supply and considering CO_2 fertilisation, 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 per cent and 28 per cent. 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 fertiliser use were recommended as adaptation measures under the B2B scenario.

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

This finding is in line with reports by Usman *et al*., 2005; and Mishra *et al.,* 2008 who stated that the within- and between-season variability of rainfall is one of the major causes of yield reduction and or crop failure in Sub-Saharan Africa.

4.7 The uncertainties with modelling

There are a number of uncertainties and assumptions in crop modelling, and climate change impact assessments which are challenges in modelling. Some of these assumptions are that the model assumes a pest- and disease-free environment, and no effect of weeds or flooding on crop productivity. In addition, the model assumes that farmers will continue to use the same cultivar by 2050, which may not be the case, as breeders are likely to research into new cultivars which will be higher yielding under climate change. The deficiencies in predicting future climate, particularly in Africa (downscaling of general circulation models) where the level of confidence is still questioned is a challenge facing modellers, although there has been an improvement in future climate projections in recent times.

CONCLUSION

The APSIM-Maize model was successfully evaluated for the sub-humid region of Ghana. The evaluation of the APSIM-Maize model in this study confirms that this model can be used as a research tool in a variable agro-environment in Ghana. The results suggest that it can be used to explore alternative ways of improving maize production in Ejura. It explicitly captured the effects of inorganic N and P fertiliser application on total dry matter, grain yield, and N as well as P uptake of Obatanpa and Dorke maize cultivars. Simulation results of the climate change scenarios indicated a six-week delay in sowing as a result of the delay in the onset of the rains. This will result in late planting and hence reduced maize yields. The increase in temperatures in the region by 1.6 °C and 1.3 °C by 2050 under scenario A1B and B1, respectively, will have an effect on soil moisture and hence crop water availability.

Using historical yield data as a baseline, the average yield of maize by 2050 is likely to decrease by 35 per cent to 31 per cent in a continuous maize-cowpea cropping system under the A1B and B1 scenarios respectively. Furthermore, the inter-seasonal variability in maize yields is likely to increase significantly. With the introduction of some adaptive measures, such as the maize-fallow rotation, the expected reduction in maize grain yield will be 32 per cent and 28 per cent under the A1B and B1 scenarios, respectively. Early sowing will however reduce the advance effect of climate change on yields. Site specific adaptation measures will be required under climate change and variability. For instance, depending on the onset of the rainy season, farmers would need to have access to suitable maize cultivars in order to avoid significant yield losses in case of delayed sowing, and capitalise on favourable conditions in good seasons. This will require the development and availability of locally-adapted maize varieties with different maturity periods. Under both scenarios, the most effective adaptation measure would be early planting, as soon as the season starts, or conditions that are favourable. This requires climate or weather information at the onset of the season.

There is a need for supplementary irrigation in the future. The government needs to do feasibility studies on irrigation systems as well as establish irrigation systems to provide water to crops in conditions of dry soil moisture to boost crop productivity. The application of 40 kg N ha^{-1} seems to be sufficient under both scenarios, as increasing the fertilisation rate to 80 kg ha^{-1} did not improve maize yields. Thus the reduction of fertiliser application to a maximum of 40 kg N ha^{-1} is another effective adaptation measure as lower yields no longer justify increased mineral fertiliser use. The marginal income obtained by an additional unit of nitrogen application over 40 kg ha^{-1} is smaller than the unit cost of fertiliser, under both climate change scenarios.

There is a need for the government to facilitate the widespread dissemination of information and education on climate change and available adaptation measures, and also build the infrastructure necessary to adapt to climate change.

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MATE MASIE
"What I hear, I keep" - symbol of wisdom, knowledge and understanding

NEA ONNIM NO SUA A, OHU
"He who does not know can know from learning" symbol of life-long educationand continued quest for knowledge

NYANSAPO
"wisdom knot" - symbol of wisdom, ingenuity, intelligence and patience

ISBN: 978-9988-633-72-1
9 789988 633721