SIMULATING THE EFFECTS OF NITROGEN AND PHOSPHORUS ON THE GROWTH AND YIELD OF MAIZE IN VHEMBE DISTRICT, LIMPOPO PROVINCE

BY

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ABSTRACT

Maize is the main staple food in South Africa and its production in the country constitute 50 percent of the output in Southern African Development Community (SADC) region. This study was conducted to determine the effect of nitrogen (N) and phosphorus (P) on maize growth and yield and to use the data collected in Agricultural Production Systems Simulator (APSIM) to predict the response of maize to N and P applications as observed in the field. The study was conducted over two seasons, 2005/2006 and 2006/2007. The study evaluated the biomass production, grain yield, plant tissue N and P content and soil N and P content during maize growth. The APSIM model was used to predict biomass and maize yield. Treatments consisted of N ferlilizer application at 0 and 75 Kg/ha in 2005/2006 season and 0, 37.5 and 75 Kg/ha in 2006/2007 season as Limestone Ammonium Nitrate (LAN). Phosphorus was applied at 0 and 30 Kg/ha as Single Super Phosphate (SSP) at planting in both seasons. Maize (*Zea mays L*) was the test crop and was planted at a spacing of 90 × 25 cm. Individual plot sizes measured 5m × 4.5m and were laid out in Randomized Complete Block Design with three replications. Biomass was collected at three stages of maize growth, 6-8 weeks after planting, tasseling and at harvest. At maturity, grain was harvested and the yield was determined. Analysis of the variance (ANOVA) using the General Linear Model procedure (GLM) was used to assess the variation of biomass production, grain yield and plant tissue N and P content among treatments. Chi-square test was used to assess the differences between the observed and the predicted biomass and grain yield. The predicted Pearson correlation was used to determine the relationship between soil N at different stages of maize growth and the plant tissue N content and again between soil P at different stages of plant growth and plant tissue P content. There was a significant ($P<0.05$) difference in maize biomass among plots treated with N and those without N at 6-8 weeks at Univen in both seasons. There was no significant ($P<0.05$)

biomass amongst all treatments at tasseling and at harvest at both sites and seasons. There was no significant ($P<0.05$) difference in maize grain yield amongst the treatment plots at both sites and seasons. There was no interaction between N and P in biomass and grain yield at both sites and seasons. There was no significant ($P<0.05$) difference in plant tissue N and P among the treatments. Plant tissue N was not correlated to soil N at all stages of growth. Plant tissue P was strongly correlated to soil P at different stages of maize growth. The predicted grain yield and biomass yield using APSIM were higher than the observed yield in most treatments. There was a strong relationship between the observed and the predicted biomass yield at 6-8 weeks ($r^2=0.940$) and at tasseling ($r^2=0.919$) at Univen site in 2005/6season. There was an agreement between the observed and predicted grain yield at Univen in both seasons ($r^2= 0.654$ and $r^2= 0.755$). The chi-square results showed a significant difference between the observed and the predicted biomass and grain yield. Therefore, for APSIM to estimate more acceptable results, the environmental management window should be incorporated.

DECLARATION

I..NGELETSHEDZO S. MAKHAGA..... hereby declare that this dissertation, for the partial fulfillment of Masters in Science at the University of Venda has not been submitted at any other time at this, or any other University, and that it is my own work in design and execution, and that all reference material contained therein has been duly acknowledged.

Student: N. S Makhaga

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DEDICATION

This dissertation is dedicated to my daughter Mukoni who understood when I could not be with her for my studies.

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CHAPTER 1:INTRODUCTION

1.1 Background Information

Maize (*Zea mays* L.), is the most important cereal crop in Africa when compared with rice and wheat (Heisey and Smale, 1995). Maize production is a popular practice among smallholder farmers and the crop is commonly grown around the world. Maize is high yielding if conditions are optimal, easy to process, readily digested, and costs less than other cereals. Maize is also a versatile crop, growing across a range of agro-ecological zones. Each part of the maize plant has economic value in that they are used to produce a large variety of food and non-food products. Maize is an important source of carbohydrate, protein, iron, vitamin B, and minerals (Brinton, 1985).

Maize is a major source of food to the fast growing population in developing countries such as South Africa and also supplies raw materials to several industries. Maize is utilized more indirectly in developed countries i.e. as animal feed. In South Africa, maize is the staple diet for more than half of the country's population (FAO, 1995). Maize is used as porridge, while when processed it can be used as fuel and starch. Maize is also used as popcorn instead of granules, and also as a packing material in crates (Gokmen *et al*, 2001). Green maize (fresh on the cob) is eaten baked, roasted or boiled and plays an important role in filling the hunger gap after the dry season. Failure to increase production of maize can result in food shortage. It is therefore necessary to increase the production of maize to fill the gap between supply and demand. Measures to increase maize yield need to be considered (du Toit, 1999).

Limpopo Province is the poorest and most arid province in the country and people rely heavily on agriculture for household food security. Crop production in Limpopo Province is practiced in areas with mean annual rainfall between 400 and 600 mm. Vhembe district, located in Limpopo province of South Africa has a high percentage of resource poor smallholder farmers. A Large proportion of the population in Vhembe district depends on maize as their primary staple food. The vast majority of population in this area grows maize mainly to meet their subsistence requirements. Maize in Vhembe district is mostly produced under rainfed conditions and drought is the most important its constraint to production. Drought affects production at any stage of plant growth and the maximum damage is experienced when it occurs at flowering (du Toit, 1999).

Another major factor that threatens the production of maize in Vhembe district is soil fertility. The soils, mostly Hutton and Shortlands forms (Soil Classification working group, 1991) are highly weathered and have low fertility. Phosphorus and nitrogen deficits are severe and a major constraint to smallholder maize productivity. Due to shortage of land, farmers in Vhembe also cultivate on steep slopes to meet food demand and this contributes to severe soil erosion. High percentages of the soils in Vhembe district are susceptible to erosion, and this has an effect on maize production. The availability of nutrients and uptake by the crop depend on the amount and distribution of precipitation during the growing seasons (Okalebo *et al*., 2002).

Nitrogen is a vital plant nutrient and a major yield-determining factor in maize production (Adediran and Banjoko, 1995). Nitrogen must be available in adequate quantity throughout the growing season since it is essential for optimum maize growth (Ojiem *et al*, 2000). It makes up 1 to 4 percent of the drymatter in plant (Anonymous, 2000). Nitrogen nutrition has dramatic effects on plant growth and photosynthetic characteristics of mature leaves (McCullough *et al*, 1994, Oikeh *et al*, 1997, Ojiem *et al*, 2000). Increase in nitrogen supply results in greater biomass production, shoot/root ratios, and high rates of leaf expansion during the day. Nitrogen mediates the utilization of P, K, and other nutrient elements in plants there its deficiency or excess can results in reduced yields in maize (Osanyama, 2009). Nitrogen is not only the key nutrient for obtaining maximum yield and quality, but also the one most difficult to optimize. Nitrogen encourages leaf growth and an inadequate supply means smaller leaves, reduced photosynthesis, and less total yield and protein (Onken and Wendt, 1989). If the nitrogen supply is too high, then excess leaf will be formed at the expense of grain, starch content will be reduced and yields may decline. Too much nitrogen may also delay maturity and result in lodged crops. The average maize crop yielding 40 t/ha removes 160 kg N/ha of nitrogen although peak uptake is 210 kg N/ha (Sobulo, 1980).

Phosphorus is required particularly by the growing tips of the plant, hence its importance for root growth. Any shortage, especially in the very early stages, reduces root growth and nutrient uptake and affects the crop for the rest of the season (Glass and Bomke, 1980). Typical phosphate removal is 0.60[illegible]g P/t fresh crop - that is 23 kg/ha P for an average 40 t/ha crop.

Simulation models are valuable tools in the analysis of farming systems for assessing impacts of climatic variability and long-term results of management strategies (Keating *et al*, 2003). They are complementary to the experimentation, which is invariably constrained by the seasonal conditions, treatment imposed and duration of the experiments. Models are means of extrapolation of knowledge from experimentation including crop sequence, tillage, residue and fertilizer management practices. Most crop and ecosystem models exclude the appropriate routines for simulating N dynamics following incorporation of organic inputs of diverse nature found in the tropical cropping system.

Agricultural Production System Simulator (APSIM) allows models of crop, soil water, nutrients and erosion to be configured to simulate (Carberry and Abrecht, 1991). Unlike other models APSIM treats the soil organic matter in soil N as a three pool instead of the two pools as used e.g. in Crop Environment Resource Synthesis (CERES).

In this experiment, APSIM was used to evaluate the performance of maize under the exact soil condition and the amount of fertilizer added. Since the model also takes into consideration the amount of moisture during planting, and all the amount of rainfall received, it could also help in understanding the best times of planting maize.

1.2 Justification

In South Africa, about 70% of the total population use maize as a staple food and a large portion of the 70% live in rural areas. Vhembe district is part of rural areas in Limpopo province where almost the whole population depends on maize. Most smallholder farmers in this area depend on natural nutrients in the soil for crop production under rain fed agriculture. The yield of maize is declining every year but the demand for maize is growing with population increase. Supplementing the natural nutrient in the soil can help to meet the nutritional demand of the maize crop and improve maize yield. Since the nutrient requirements of crops differ from crop to crop and variety-to-variety it is important to know the effect of a particular nutrient at certain levels. Fertilizer recommendations are not based on soil and climate but on the crop, whereas soils differ in the nutrient content from place to place. Hence the fertilizer recommendations for maize might not be applicable for the whole Vhembe district. Nitrogen and phosphorus are known to play an essential role in the growth, development and yield of maize. If nitrogen and phosphorus can increase yield, then both nitrogen and phosphorus fertilizer should be added in the fields where maize is produced. Increases in maize yield will contribute towards food security and better nutrition and potential for income generation by smallholder farmers in Vhembe district. Farmers in Vhembe district are resource poor smallholder farmers who cannot afford to purchase the recommended amount of fertilizers. Consequently, the use of APSIM can assist farmers to make predictions on what yield levels to expect by applying a given amount of fertilizer while taking into consideration the crop, soil, intent of weather parameters and management factors.

1.3 Objectives

The overall objective of this study was to determine the effect of nitrogen and phosphorus on maize growth and yield and to use the data collected to evaluate the ability of APSIM model to predict the response of maize to N and P applications as observed in the field experiment.

The specific objectives:

1. To determine biomass accumulation of maize crop treated with different N and P levels at different stages of maize growth.
2. To determine N and P levels in soil at different stages of maize growth.
3. To determine the N and P content in above-ground biomass at different stages of maize growth.
4. To determine maize yield at harvest.
5. To predict the response of maize to N and P application using the APSIM model.

1.4 Hypotheses

1. Maize biomass will vary with different N and P levels.
2. Nitrogen and phosphorus levels in the soil will vary at different stages of maize growth.
3. Nitrogen and phosphorus content in the above ground biomass will vary at different stages of growth.
4. Maize grain yield will be influenced by N and P application rates.
5. APSIM model can be used to predict maize biomass and grain yield at known N and P fertilizer application levels.

CHAPTER 2: LITERATURE REVIEW

2.1 The importance of maize (*Zea mays*)

White maize is consumed domestically in producing countries so that the size of international trade is limited. Yellow maize is preferred for livestock feeding because it gives poultry meat, animal fat and egg yolk the yellow colour appreciated by consumers in many countries (BFAP, 2007 and FAO,1995). In Mexico, however, large quantities of white maize is fed to animals, the colour deficiency is corrected by adding carotene as a colouring agent to the compound feed mix (Liang and MacKenzie , 1994). In contrast to yellow maize, white maize is not used for the manufacture of fuel alcohol or for high fructose sugar (Fedotkin and Kravtsov, 2001).

Human consumption of maize and maize meal constitutes a staple food in many regions of the world. Maize meal is made into a thick porridge in many cultures, known as ugali in East Africa and mealie pap in Southern Africa (Dutoit, 1999). Sweetcorn is a genetic variation that is high in sugars and low in starch that is served like a vegetable. Popcorn is kernels of certain varieties that explode when heated, forming fluffy pieces that are eaten as a snack. Maize can also be prepared as hominy, in which the kernels are bleached with lye; or grits, which are coarsely ground corn. Another common food made from maize is corn flakes used for breakfast. The floury meal of maize (cornmeal or masa) is used to make cornbread and Mexican tortillas. Teosinte is used as fodder, and can also be popped as popcorn (Liang and MacKenzie, 1994).

Some forms of the plant are occasionally grown for ornamental use in the garden. For this purpose, variegated and coloured leaf forms as well as those with colourful cobs are used. Additionally, size-superlative varieties, having reached 31 ft (9.4m) tall, or with cobs 24 inches (60cm) long, have been popular for at least a century (Rubey *et al*, 1997). Maize can be hollowed out and treated to make inexpensive smoking pipes; they are also used as a biomass fuel source. Maize is relatively cheap and home-heating furnaces have been developed which use maize kernels as a fuel. They feature a large hopper which feeds the uniformly sized corn kernels (or wood pellets or cherry pits) into the fire (Dwyer *et al*, 1993).

2.2. Maize production

Maize constitutes about 70 percent of grain production (FAO, 1995) and covers about 60 percent of the cropping area in South Africa. Maize is the main staple food in Southern Africa, and maize production in the country constitutes about 50 percent of the output within the Southern African Development Community (SADC) region (Durand, 2006). Consequently, maize is one of the key drivers of food inflation in South Africa (BFAP 2007, FAO, 1995). Although a decrease in maize production may result in increased total revenue because of its inelastic demand, it would increase food insecurity within the Southern African region (Heisey and Mwangi, 1996).

Maize is a major cereal crop produced under rainfed conditions in the tropics (Majid *et al*, 1986). Maize is widely cultivated throughout the world, and a greater amount of maize is produced each year than any other grain. While the United States produces almost half of the world's harvest, other top producing countries are as widespread as China, Brazil, France, Indonesia, and South Africa (Weber *et al*., 1992; Heisey and Mwangi, 1996). The Republic of South Africa is the world's largest supplier of white maize to the international market (FAO, 1994a, and Rubey *et al*, 1997). Worldwide production was over 600 million metric tons in 2003 (Benhin, 2006; Du Toit *et al*, 2002), slightly more than rice or wheat. Close to 33 million hectares of maize were planted worldwide, with a production value of more than $23 billion in 2004. Developing countries have become the principal importers of white maize. Their share is reported to have increased from an annual average of 50 percent during 1981-85 to about 80 percent in the early 1990s (Jayne *et al*., 1997 and Rubey *et al*, 1997).

In developing countries, imports into sub-Saharan Africa are estimated to account for about half of world trade (Durand, 2005; Gbetibouo and Hassan, 2005; Kurukulasuriya and Mendelson, 2006)). Over 20 countries have been identified as importers of white maize of which, however, only three (Lesotho, Mozambique and Democratic Republic of Congo) appear to regularly import over 50,000 tons per annum (FAO, 1994b). Approximately 60 percent of the total maize area is planted to improved varieties in most developing countries and the rest to local varieties except for Argentina, Brazil and China (Weber *et al*, 1992). The required increase in maize production in the foreseeable future is likely to come from yield growth rather than area expansion. This means that further deployment of improved maize hybrids and varieties is crucial (Heisey and Mwangi, 1996, Fedotkin and Kravtsov, 2001).

Maize is cold-intolerant, and therefore in the temperate zones, maize must be planted in the spring. Its root system is generally shallow, so the plant is dependent on soil moisture. It is a considerably more water-efficient crop than small grains such as alfalfa and soybeans (Ticconi and Abel, 2004). The yield of maize however, varies from variety to variety, location to location and also depends on the availability of essential factors such as soil nutrient status and application of fertilizers (Brar *et al*, 1989, Ojiem *et al*, 2000). Moisture stress is one of the crop management problems in developing countries for maize production. The importance of sufficient soil moisture is shown in many parts of Africa, where periodic drought regularly causes famine by causing maize crop failure (Dwyer *et a*l, 1993).

However, moisture stress is less easily addressed by input management, and water control strategies should be applied, since most maize in the developing world is non-irrigated and large-scale expansion of irrigated maize area is unlikely (Jayne *et al*, 1997). Moisture availability over the season is subject to considerable uncertainty when the growing period begins. Maize is most sensitive to drought at the time of silk emergence, when the flowers are ready for pollination. Another most important management problem in developing country maize production is weed control, followed by plant density management (Jayne *et al*, 1997, Ojiem *et al*, 2000). Complicating the development of management options is the possibility that all factors mentioned, soil fertility, moisture availability, weeds and plant density, are likely to interact with one another.

2.3. Importance of Nitrogen in maize

Maize is a fast growing crop producing a large biomass, and hence adequate macro-nutrient fertilization is essential for optimum yield and quality. Varieties that are being released require different rates of fertilizer so there is a need to determine their nutrient requirements. Maize production can be limited by the deficit of nitrogen in the soil (Adiku *et al*, 1993). Studies with conventional maize hybrids (Chevalier and Schrader, 1977) have shown that maize genotypes vary in their response to N availability reflecting variations in their relative abilities to absorb native or fertilizer N from the soil (N uptake efficiency). They also vary in their relative efficiencies in using acquired N to produce yield components (N use efficiency) (Moll *et al.*, 1982).

Nitrogen recommendations have been based on the maize field trials of which many developing countries are limited in the ability to conduct. Due to the complex nature and the behavior of nitrogen, models were developed that utilize specific crop, soil, and climate and management information to make site-specific nitrogen fertilizer recommendations (Adiku *et al.,* 1993). Nitrogen requirement by maize is large as compared to other nutrients for optimum plant growth. Many physiological processes associated with maize growth are enhanced by nitrogen supply. Nitrogen has dramatic effects on maize growth, development and grain yield on soils that are limiting in nitrogen supply. Some studies have shown that reduced nitrogen can affect leaf area index, plant height, shoot weight and plant N uptake (Brar *et al*, 1989). McCullough *et al* (1994) found that increasing rate of nitrogen supply resulted in greater leaf area index and leaf nitrogen.

Leaf area duration, crop photosynthesis rate, radiation interception and radiation use efficiency are increased by nitrogen supply (Brar *et al*., 1989). Reduced nitrogen supply decreases crop growth but nitrogen response is also modified by water supply under field conditions. If the nitrogen supply is too high, then excess leaf will be formed at the expense of grain, starch content will be reduced and yield may decline (Okalebo *et al*, 2002). Too much nitrogen may also delay maturity and result in lodged crops. The average maize crop yielding 40 t/ha removes 160 kg N/ha of nitrogen although peak uptake is 210 kg N/ha (du Toit, 1999).

2.3.1. Nitrogen effect on maize biomass and grain yield

Nitrogen is a vital plant nutrient and a major yield-determining factor required for maize production (Adediran and Banjoko, 1995; Shanti *et al*., 1997). Its availability in sufficient quantity throughout the growing season is essential for optimum maize growth. Maize yield response to soil available N is a function of both N uptake from the soil and utilization of N within the plant to produce grain. Nitrogen is also important for carbon (C) flow and protein synthesis of higher plants (Yamazaki *et al*, 1986; Sugiharto *et al*, 1990). Deficiency of N interfers with protein synthesis and growth (Epstein, 1972).

Nitrogen fertilizer is important for increasing maize grain yields (Olson and Sander, 1999). Nunes *et al*. (1996) reported that biomass and grain yields of maize increase with increasing N rates. Similarly, Sanjeev *et al. (*1997), and Fedotkin and Kravtsov (2001) reported a significant increase in grain and stover yields with up to 240 Kg N/ha. Studies by Shivay and Singh (2000), and Mahmood *et al*, (2001) showed that the highest plant height and grain weight, LAI and dry matter accumulation were recorded with 120 Kg N/ha. Other researchers (Dahiya *et al*, 1991; Arain *et al*, 1989) reported an increase in dry matter with an increase in N application. Onisie *et al*, (1993) reported that grain yield ranged from 5.5 t/ha without N and P and 8.4 t/ha with 30 kg/ha of N and P fertilizer.

Nitrogen stress during grain-filling shortens the duration of this phase which is opposite to the effect of stress during pre-silking. The combined effect of N stress on the duration of sowing to maturity may be small. Under N limiting conditions, both the effect on growth and the shortened duration of the grain-filling stage contribute to lower grain yield (Brar *et al*, 1989). Onken and Wendt (1989) reported that under rainfed condition, application of N fertilizer increased water use efficiency and grain yield of sorghum; however, they stated that under severe moisture stress, application of N did not increase water use efficiency and yield. Negrila and Negrila (1994) in their study concluded that the best fertilizer dose for maize biomass yield was 100 kg/ha N and 34 kg/ha P.

2.4. The role of Phosphorus (P) in maize production

Phosphorus (P) is one of the macro-nutrients which is important for cell division, energy transfer, nucleic acid formation, protein synthesis and carbohydrate metabolism. It is also important for crop establishment, root development and early crop growth (Kavanová *et al*, 2006; Chiera *et al*, 2002; Rosolem *et al*, 1994). Phosphorus is a limiting nutrient in maize production, and its availability to the crop is determined by various factors. These include the form of native soil P, the type of P applied to the soil, and soil reaction (Glass and Bomke, 1980). When the available P is less than the crop requirement, P is applied to the soil in the form of both inorganic and organic fertilizer (Adepetu, 1970; Adepetu and Corey, 1975). Inorganic fertilizers are readily available, but they are slowly converted to unavailable forms due to precipitation. During early growth stages, plants may utilize the readily available form, while they compete for the slowly available forms in the later stages of growth (Brar *et al*, 1989).

In maize (*Zea mays*), Assuero *et al*. (2004) attributed the reduction in leaf growth to a decreased cell production rate. Phosphorus is essential for plant growth and development, but inorganic phosphorus is one of the least available nutrients in soils of many terrestrial ecosystems (Vance *et al*., 2003). Plants are profoundly affected by phosphorus deficiency because phosphorus is an indispensable constituent of nucleic acids and membrane phospholipids (Negrila and Negrila, 1994). Moreover, phosphorus plays a pivotal role in energy transfer, as a regulator of enzyme activity, and in signal transduction. Low phosphorus availability activates a series of morphological and physiological responses that maximize phosphorus acquisition (Raghothama, 1999; Ticconi and Abel, 2004). Leaf growth depression under phosphorus deficiency is well documented (Radin and Eidenbock, 1984; Chiera *et al*., 2002; Assuero *et al*., 2004; Kavanova´ *et al*., 2006). The growth reduction must be due to an alteration of cell division or cell elongation parameters.

Phosphorus availability has been shown to affect root growth, notably on maize. Authors agree that P deficiency leads to a higher root-to-shoot ratio (Khamis *et al*., 1990; Rosolem *et al*., 1994). The experiment by Plénet *et al*. (2000) showed that P deficiency severely reduced the leaf area index of maize. The reduced LAI was the consequence of the delayed appearance of leaves on P-deficient plants and of a reduction of their final surface area. Phosphorus is a structural component of nucleic acids and responsible for energy transfer (Ali *et al*, 2002). The transfer of energy is accomplished by phosphate ester and energy rich phosphate (Glass *et al*, 1985). The availability of P in the solution phase is usually variable and unpredictable due to the formation of insoluble compounds through soil chemical reactions. Zhang and Baber (1992) explained that the formation of insoluble compounds limits the plant available P making phosphate fertilization use efficiency very low by crops.

Management of phosphate fertilizers is a major concern and is stimulated by economic as well as environmental concerns. Mallarino and Rueber (2001) found that the banded P increased early crop growth more than the broadcast placement because of increased plant uptake, Glass *et al* (1985); Zhang and Barber, (1992); and Rehm and Wiese, 1975) also reported similar results. Agricultural crops have different response to P fertilization. Amon (1965) found that maize responded positively to low rates of phosphorus fertilizer application. Application of high rate was reported to cause nutrient imbalance and yield depression of western yellow maize (Sobulo, 1980).

2.5. APSIM Model

Agricultural Production Systems Simulator (APSIM) was developed to simulate the biophysical processes in farming systems where there is climatic risk. Models are important tools in the analysis of farming systems for assessing impacts of climatic variability and long-term results of management strategies. They are corresponding to the experimentation, which is invariably constrained by the seasonal conditions, treatment imposed and duration of the experiment. Models are means of extrapolation of knowledge from experimentation including crop sequence, tillage, residue and fertilizer management practices. APSIM system allows models of crop, soil water, nutrients and erosion to be configured to simulate (Carberry and Abrecht, 1991).

Simulation models can increase the benefits of using inorganic fertilizer in maize in different soils and climates. Models have been tested in maize systems for their ability to simulate the impacts of fertilizer nitrogen. Shamudzarira and Robertson (2002) tested the ability of APSIM to predict maize yield response to nitrogen fertilizer and they reported the results to be satisfactory. The work by Robertson *et al,* (2001) confirmed the ability of APSIM to simulate the response of maize to fertilizer nitrogen. Crop and ecosystem models exclude the appropriate routines for simulating N dynamics following incorporation of organic inputs of diverse nature found in the tropical cropping systems.

The development and application of crop simulation models has focused on water and nitrogen as the main constraints to crop growth. The models were useful for evaluating alternative management strategies and effects of climatic conditions (Robertson *et al,* 2001). Their use assumes that other factors such as nutrients other than N, pests and diseases are not limiting (McCown *et al*, 1996, Probert *et al*, 1998). The phosphorus management is another major gap in the tropics. Most crop and ecosystem models could not adequately capture the P dynamics for estimating crop production. The P-aware crop module is a newly developed APSIM model that evaluates the plant P uptake process and estimates P stress in the crop (Robertson *et al*, 2001, Whitebread *et al*, 2004). It also takes into account the resulting restrictions to the key plant growth processes such as photosynthesis, leaf expansion, phenology and grain filling. It is used in association with a new module (APSIM SoilP) that simulates the dynamics of P in soil and is linked to the modules simulating the dynamics of carbon and nitrogen in soil organic matter and crop residues. Accurate modeling of crop duration and growth is necessary for reasonable yield prediction (Keating *et al*, 2003).

The stimulus for APSIM development was based on the need for modeling tools that provide accurate prediction of crop production in relation to crop, farming systems and environmental aspects. APSIM was developed to address the long-term resource management issues in farming systems. Since some models have limited ability in addressing crop management issues, APSIM was designed as a farming system simulator. APSIM combines the accurate yield estimation in response to management with prediction of long-term consequences of farming practice systems on the soil resource (McCown *et al,* 1996).

2.5.1. APSIM Structure

APSIM modeling system consists of biophysical modules, management modules and the simulator engine. The modules are responsible for simulation and they allow the user to specify the management rule. The engine drives the simulation process and controls all messages passing between modules. APSIM can be applied in situations where the appropriate biophysical modules are available. The majority of modules available in APSIM are grain crop modules in the tropical areas (Jones *et al*, 2001). The modules include soil water, solute movement, soil nitrogen, soil phosphorus, soil pH and erosion. It includes the soil surface residue dynamics module that is linked to the water nutrient process. The first version was restricted to a single point simulation but version 5.3 has multi point capability simulation infrastructure (Steiner *et al*, 1994).

CHAPTER 3: MATERIALS AND METHODS

3.1. Experimental Sites

The experiments were conducted at two sites namely Dzwerani village (30 25 582'E and 23 03 081'S) and University of Venda (Univen) experimental farm (30 26 441' E and 22 58 081'S) both located in Vhembe district, Limpopo province. The experiments were conducted during the period January to June in the 2005/6 season and December to April 2006/7. The soils at Univen and Dzwerani are classified as Hutton and Bainsvlei soil forms, respectively (Soil classification Work Group, 1991).

3.2. Soil Properties

Prior to the establishment of the experiment, soil samples were collected from both experimental sites to a depth of 20 cm. The soils were collected from several spots within each experimental area separately and bulked together to form a composite sample. The composite sample was then analyzed to determine some soil physical and chemical properties. [pH determined by using 1:1(Soil: Water) ratio, Particle size distribution determined by Hydrometer method. Organic Carbon was determined using the Walkley Black method (Walkey and Black, 1934) whereas the total nitrogen was determined by the Kjeidahl method. Bray 1 method was used to determine the amount of phosphorus in the soil (Bouyoucos, 1962). Soil samples were prepared and analyzed using the standard analytical methods (Non-Affiliates Soil Analysis Work Committee, 1990). The exchangeable cations and CEC were determined using 1N Ammonium Acetate solution at pH 7 (Schollenberger, and Simon, 1945). The method used in the determination of electrical conductivity is the soil water extract (1:1 soil water extract). Table 3.1 shows some of the soil physical and chemical properties of the two experimental sites prior to planting maize.

Table 3. 1: Some physical and chemical properties of soils (0-20cm) at the experimental sites before cropping in 2005/2006.

Parameter determined	Experimental Site	
	Dzwerani	Univen
pH (Water)	6.5	5.7
EC (Ms/m)	13	22
Particle size distribution		
Sand (%)	75	17.9
Silt (%)	11	32.1
Clay (%)	14	50
Organic C (%)	1.23	1.72
N (%)	4	6.8
P(ppm)	0.29	16.08
Exchangeable Cations		
Na(mg/kg)	0.17	140
K (mg/kg)	0.16	67
Ca (mg/kg)	6.44	798
Mg (mg/kg)	2.33	265
CEC(cmol$_c$/kg)	17.95	18.80

3.3. Field Experimental Set-up

The experiments were conducted in two seasons, 2005/2006 and 2006/2007. In the 2005/2006 season, maize seeds (ZM 521) were planted at Dzwerani and at Univen experimental sites on 20/01/2006 and 24/01/2006, respectively. The experiment was a 2×2 factorial arrangement laid out as a completely randomized block design replicated three times. The seeds were hand sown at the depth of approximately 2 cm. The plant spacing was 0.9 m between rows and 0.25 m within rows. Fertilizer treatments consisted of two levels of nitrogen (N0 = 0 kg/ha and N1 = 75 kg/ha) applied as Limestone Ammonium Nitrate (LAN) and two P levels (P0 = 0 kg/ha and P1 = 30 kg/ha) applied as Single Super Phosphate (10.5%P) giving a total of four treatments NOPO, NOP1, N1PO and N1P1. Fertilizer N was split applied with 50% applied at planting, 25% at 6-8 weeks and 25% at tasselling. Phosphorus was band applied at 30 kg/ha at sowing. The experiment was a 2×3 factorial arrangement laid out as a completely randomized block design and replicated three times. Individual plot size measured 5 m by 4.5 m. In the 2006/2007 season, the same procedure was repeated at both sites with additional N level of 37.5 kg/ha giving a total of six treatments (N0P0, N1P0, N1P1, N0P1, N2P0, and N2P1). The planting dates were 19/12/06 and 14/12/06 for both Dzwerani and Univen, respectively.

3.4. Dry matter and grain yield sampling procedure

Dry matter was collected from each treatment by sampling four plants per plot at the stages 6-8weeks after emergence, at tasselling and at harvest. The samples were dried for several days in a forced-air oven at 65^{0}C, until a constant weight was obtained. The samples were then labelled and sent to the Institute for Soil, Climate and Water (ISCW) for analysis of nitrogen and phosphorus content. Grain yield was determined by sampling ten plants in two middle rows in each plot. Table 2 provides a summary of the management activities undertaken during the study.

Table 3. 2: Summary of management activities.

Data	**2005/2006 Dzwerani**	**2005/2006 Univen 06**	**2006/2007 Univen**	**2006/2007 Dzwerani**
Planting	20-Jan-06	24-Jan-06	19-Dec-06	20-Dec-06
Emergence	27-Jan-06	30-Jan-06	26-Dec-06	27-Dec-06
Topdressing	07-Mar-06	02-March-06	01-Feb-07	ND
	16-Mar-06	16-Mar-06	27-Feb-07	
Dry matter sampling	27-Mar-06	27-Mar-06	05-Feb-07	ND
	07-April-06	07-Mar-06	20-Feb-07	
		15-June-06	23-April-07	
Grain Harvest	Animal damage	15-June-06	23-April-07	ND

ND= not done

3.5. Soil Sampling

Soil samples were collected at two stages of biomass collection i.e. at 6-8 weeks and at tasselling. The samples were collected at depth 0-20, 20-50, and 50-100 cm for the determination of available N and P. The soil was randomly sampled in between the rows of the plants using an auger. Three samples were collected per plot and they were then mixed to make a composite sample. The samples were kept in plastic bags and transported to the laboratory for analysis.

3.6. Determination of parameters used in APSIM modeling

The depth of sowing was recorded. Some other soil parameters that were determined for use in APSIM modeling include bulk density (BD), Drained Upper Limit (DUL), Crop Lower Limit (CLL) and the initial water content. The initial water content was determined using the gravimetric method. For bulk density determination, soil samples were collected at different depth of the profile with soil cores of known volume. The weight of the wet samples was recorded. The samples were then oven dried for 48 hours at 105 ^{0}C. After cooling the weight of the dry sample was recorded, and then the bulk density was determined by dividing the weight of the dry soil by the total volume of the soil, i.e. dry soil weight/ total volume of soil. The gravimetric water content was determined when the moisture is high and when the crop is stressed by the following formula: (Weight of wet soil - Weight of dry soil) / (Weight of dry soil) × 100. The DUL was calculated using the following equation; DUL = Gravimetric Water content (%) ×BD (g/cm^3). Crop Lower Limit was determined by the same equation as the one for DUL but the gravimetric content was the one calculated when the crop is stressed. The weather data were downloaded from the two weather stations based at Dzwerani and Univen. The weather parameters were temperature, evaporation and rainfall.

3.7. Simulation set-up

APSIM requires some field management data and the climate of the experimental area. The weather data (daily temperatures and rainfall) were obtained from the weather station in Dzwerani for the whole experimental period in Dzwerani for all the seasons. The Univen data were obtained from the ARC-ISCW weather station installed at the University of Venda. The calculated bulk density, DUL and CLL were entered in the APSIM soil window. The management data such as the sowing date, sowing depth, fertilizer application rates and dates and fertilizer application methods were all entered in the manager window in APSIM. The initial water content and initial N (as NO_3 and NH_4) were set into the APSIM data base. The cultivar that was used in APSIM for all the seasons in both sites was PAN 6671 since it has the same characteristics as ZM 521. The summary of some soil characteristics used is shown in table 3.3.

Table 3. 3: Soil Characteristics used for modeling

Property determined	**Univen**	**Dzwerani**
Bulk density (g/cm^3)	1.1	1.4
Saturation (%)	49	40
Drain Upper Limit (mm/mm)	29	33
Depth (cm)	0-90	0-90
Crop Lower Limit (mm/mm)	12	17

3.8. Data analysis

Analysis of variance using the General Linear Model procedure of SPSS (SPSS, 2006) was used to assess the treatment effect and their interaction at 5% level of testing. Treatment means were separated according to Duncan multiple range procedure ($p \leq 0.05$). The Pearson correlation coefficients were estimated for all possible pair combinations of the response variables to generate a correlation coefficient matrix between soil N and P and plant tissue N and P. In order to assess the goodness of fit of biomass and grain yield, Chi-square test was used to determine whether a set of observed and predicted data were significant or non-significant. The correlation coefficient was estimated between observed and predicted data (SPSS, 2006).

CHAPTER 4: RESULTS AND DISCUSSIONS

4.1. Rainfall Data

In 2005/ 2006 season, the rainfall received during the growing period of maize varied from 256.5mm (January) to 19.3 mm (May) (Figure 4.1). Maize seeds were planted at the end of January. From the planting month (Jan) to tasseling, a high amount of rainfall was received in February (297.2 mm) and March (183.9 mm). The rainfall at both sites during the maize growth window in 2006/7 season ranged from 207.26 mm (November) to 25.4 (April) (Figure 4.2). The planting of maize in this season was done by mid December 2006, and an amount of 68.83 mm of rainfall was received in the same month. The December rainfall supplied enough moisture for germination. In January, February and March when the maize was four weeks old to tasseling, the amount of rainfall received was 162, 62.06 and 113.03 mm respectively (Figure 4.2).

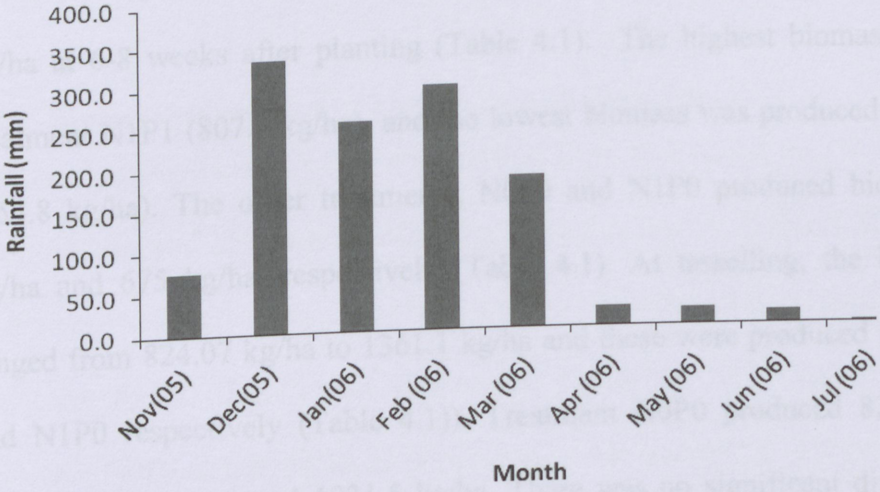


Figure 4 1: Rainfall at Univen and Dzwerani experimental sites 2005/2006 Season

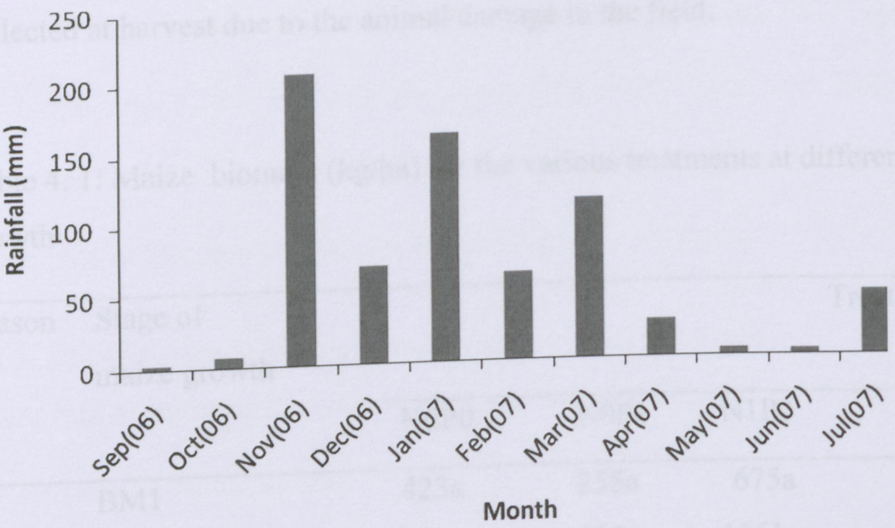


Figure 4 2: Rainfall at Univen and Dzwerani experimental sites in 2006/2007 season

4.2. Maize Biomass production

4.2.1. Biomass production at Dzwerani 2005/2006

The biomass production at Dzwerani in the first season ranged from 254.8 kg/ha to 807.3 kg/ha at 6-8 weeks after planting (Table 4.1). The highest biomass was produced by treatment N1P1 (807.3 kg/ha), and the lowest biomass was produced by treatment N0P1 (254.8 kg/ha). The other treatments, N0P0 and N1P0 produced biomass yield of 423 kg/ha and 675 kg/ha, respectively (Table 4.1). At tasselling, the biomass production ranged from 824.07 kg/ha to 1361.1 kg/ha and these were produced by treatments N0P1 and N1P0 respectively (Table 4.1)). Treatment N0P0 produced 824.1 kg/ha biomass whereas N1P1 produced 1231.5 kg/ha. There was no significant difference in biomass production in all treatments at 6-8 weeks and at tasselling. There was no biomass collected at harvest due to the animal damage in the field.

Table 4.1: Maize biomass (kg/ha) for the various treatments at different stages of maize growth

Season	Stage of maize growth	Treatment			
		N0P0	N0P1	N1P0	N1P1
2005/6	BM1	423a	255a	675a	807a
	BM2	824a	824a	1361a	1232a
	BM3	Nd	Nd	Nd	Nd
2006/7	BM1	Nd	Nd	Nd	Nd
	BM2	Nd	Nd	Nd	Nd
	BM3	Nd	Nd	Nd	Nd

Values with the same letter in a row are not significantly different, P≤0.05. Nd= no data. BM1= Biomass at 6 t0 8 weeks, BM2= Biomass at tasseling and BM3= Biomass at harvest. N0P0= 0kg/ha N and 0 kg/ha P, N0P1= 0kg/ha N and 30 kg/ha P, N1P0= 75 kg/ha N and 0 kg/ha P and N1P1= 75 kg/ha N and 30 kg/ha P.

4.2.2. Biomass production at Univen in 2005/2006 Season

Biomass production at Univen site ranged from 145 Kg/ha to 710 Kg/ha at 6-8 weeks after planting and 1519 Kg/ha to 2380 Kg /ha at tasselling (Table 4.2). At both two stages (6-8 weeks and Tasselling), the high yields were produced by treatment N1P1 (710 kg/ha and 2380 kg/ha). The lowest yields (145 Kg/ha and 1519 kg/ha) were produced by treatment N0P0 at 6-8 weeks after planting and at tasselling. Treatment N1P0 produced biomass yield of 406 kg/ha and 1768.5 kg/ha at 6-8 weeks and at tasselling, respectively, while N0P1 produced 181 kg/ha and 2287.2 kg/ha at 6-8 weeks and at tasselling, respectively. There was a significant difference between treatment N0P0 and N1P1 at 6-8 weeks after planting. Biomass yield at harvest ranged from 1337 Kg/ha to 2459 Kg/ha for N0P0 and N1P1, respectively. Treatment N0P1 produced 2024 kg/ha and while treatment N1P0 produced 2329 Kg/ha. There were no significant differences among the treatments in biomass production at tasselling and at harvest.

4.2.3. Biomass production at Dzwerani in 2006/2007 Season

There was no biomass harvested at 6-8 weeks, tasselling and at harvest due to crop failure due to the high temperatures.

4.2.4. Biomass production at Univen in 2006/2007 Season

Biomass production at 6-8 weeks ranged from 872 Kg/ha to 2257 Kg/ha, whereby the lowest yield was produced by treatment N0P0 and the highest yield produced by N2P1. N2P0 yielded 1972 Kg/ha and N1P1 produced 1606 Kg/ha. The biomass accumulations for all treatments were not significantly different. At tasselling, the biomass production for all the treatments ranged from 2655 Kg/ha (N0P0) to 3604 Kg/ha (N2P0). The amount of biomass produced by treatments N2P0 (3604 kg/ha) and N2P1 (3574 Kg/ha) were higher than the biomass produced by the N1P1, N1P0, N0P1 and N0P0. There were no significant differences in biomass production at harvest among all the treatments. The biomass production ranged from 4767 Kg/ha (N0P0) to 10231Kg/ha (N2P0). Treatment N2P1 and N1P1 produced 10165 Kg/ha and 7998 Kg/ha, respectively (Table 4.2).

Table 4. 2: Maize biomass (kg/ha) for the various treatments at different stages of maize growth

Season	Stage of maize growth	Treatment					
		N0P0	N0P1	N1P0	N1P1	N2P0	N2P1
2005/6	BM1	145a	406a	181a	710b	NI	NI
	BM2	1519a	1769a	2287a	2380a	NI	NI
	BM3	1337a	2024a	2329a	2459a	NI	NI
2006/7	BM1	872a	1344a	1372a	1606a	1972	2257
	BM2	2655a	2094a	2111a	2250a	3604	3574
	BM3	4767	8779a	5164a	5071a	10231	10165

Values with the same letter in a row are not significantly different, $P \leq 0.05$. nd= no data. BM1= Biomass at 6 t0 8 weeks, BM2= Biomass at tasseling and BM3= Biomass at harvest. N0P0= 0kg/ha N and 0 kg/ha P, N0P1= 0kg/ha N and 30 kg/ha P, N1P0= 37.5 kg/ha N and 0 kg/ha P and N1P1= 37.5 kg/ha N and 30 kg/ha P, N2P0= 75 kg/ha N and 0 kg/ha P and N2P1= 75 kg/ha N and 30 kg/ha P. NI= Not included in the experiment.

4.3. Grain yield

4.3.1. Dzwerani 2005/2006

There was no grain yield harvested at Dzwerani in the 2005/2006 season due to the damage caused by the animals in the field. The field was not properly fenced, and this led to animals destroying the maize before harvest.

4.3.2. Univen Grain Yield 2005/2006

The grain yield at Univen site varied from 880.55 Kg/ha (N0P0) to 3003.5 kg/ha (N1P1). The other two treatments N1P0 and N0P1 produced 1430 Kg/ha and 1352 kg/ha, respectively (Figure 4.3.). There was no significant difference between the treatments.

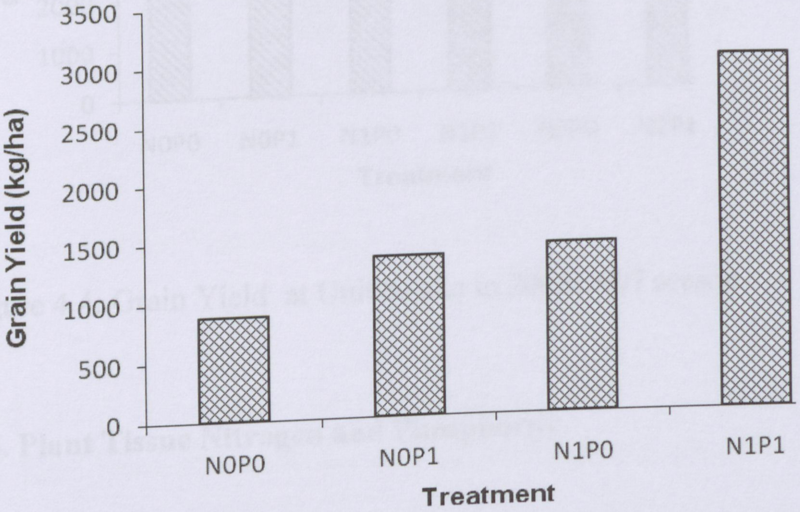


Figure 4 3: Grain yield at Univen site in 2005/2006 season.

4.3.3. Dzwerani Grain Yield (GY) in 2006/2007 Season

There was no grain yield harvested in Dzwerani due to crop failure.

4.3.4. Univen Grain Yield (GY) 2006/2007

The grain yield ranged from 6099 Kg/ha (N0P0) to 7871 Kg/ha (N2P0). There was no significant difference in grain yield among treatments. Treatment N2P1 produced grain yield lower than that of N2P0 by 15% (Figure 4.4).

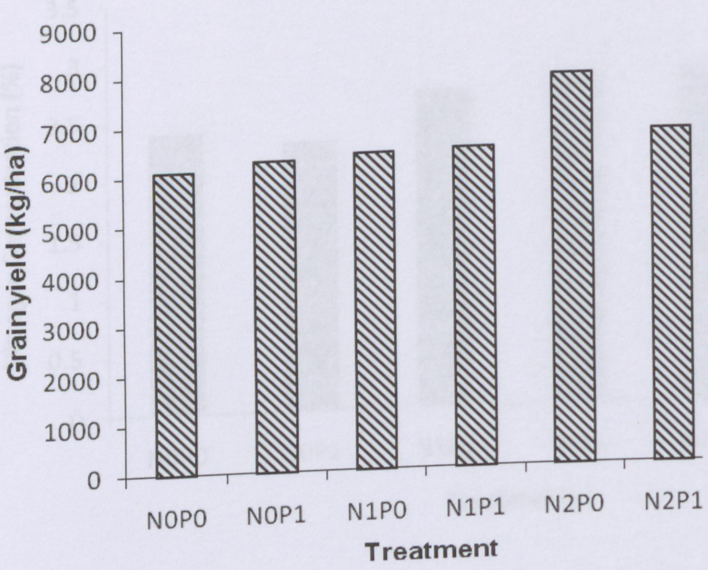


Figure 4 4: Grain Yield at Univen site in 2006/2007 season

4.4. Plant Tissue Nitrogen and Phosphorus

4.4.1. Plant Tissue Nitrogen (N) Concentration

The observed results showed that the N in plant ranged from 2.4 % to 3.2 %, where treatment N2P1 had high N concentration (3.2 %) in the plant tissue and N0P0 had 2.4 %. The difference in plant tissue concentration were not significant among the treatments. All treatments with nitrogen had the plant tissue N content that is slightly higher than the no nitrogen treatments (e.g. 2.3 % and 2.7 % for N0P1 and N1P0 respectively) (Figure 4.5).

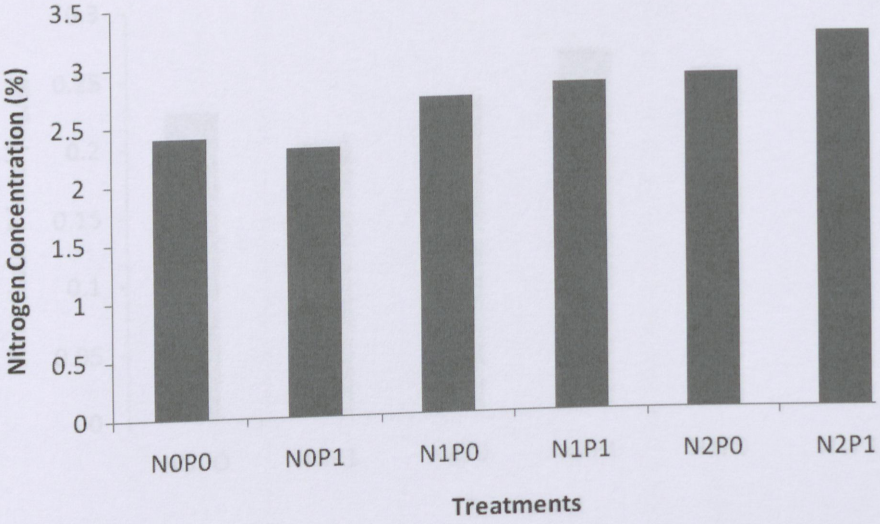


Figure 4 5: Plant Tissue Nitrogen Concentration at Univen site

4.4.2. Plant Tissue Phosphorus Concentration

The plant tissue P content varied from 0.178 mg/kg to 0.262 mg/kg, the highest amount being for treatment N2P1 and the lowest attained by treatment N0P0. There were no significant differences among the treatments in plant tissue P concentration. In this regard, treatments with P had higher amount of plant tissue P than the treatments without P (Figure 4.6).

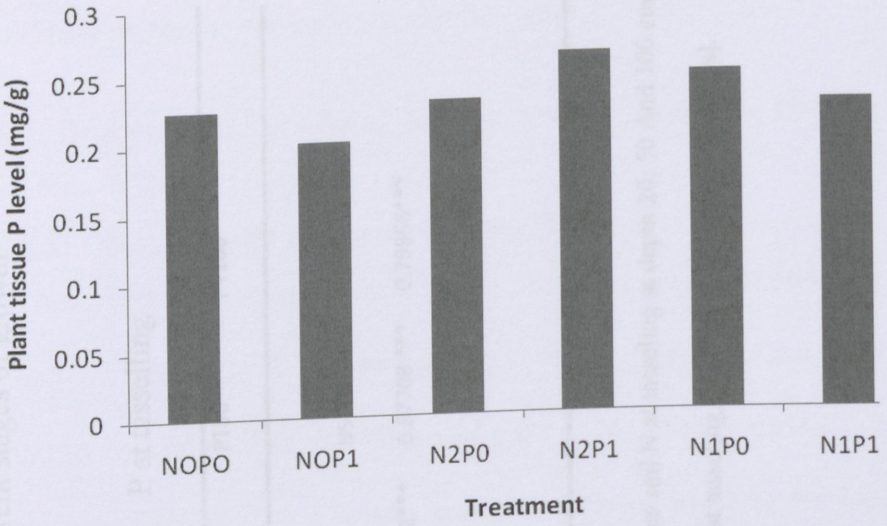


Figure 4 6: Plant Tissue Phosphorus (PP) Concentration

4.5. Soil Nitrogen and Phosphorus levels during Maize growth

4.5.1. Soil N and P levels

The correlation between the soil N at all depths and plant tissue N at different stages of growth was not significant (Table 4.3). There was a strong relationship between soil P at 6-8 weeks at 50 cm depth (P50) and plant P (PP) (Table 4.3). Soil P at tasselling (PT) at different depths (PT20, PT50 and PT100) was strongly related to plant P (PP) i.e. PT20 and PP, PT50 and PP, and between PT100 and PP ($p<0.001$, $r = 0.79$), ($p<0.001$, $r= 0.99$), ($p<0.001$, $r = 0.88$) and ($p< 0.01$, $r = 0.67$), respectively (Table 4.3).

Table 4. 3: The relationship between soil N and P at different depths and Plant N and P at different stages of growth

	N at 6-8 Weeks			N at tasselling			P at 6-8 Weeks			P at tasselling		
	N20	**N50**	**N100**	**NT20**	**NT50**	**NT100**	**P20**	**P50**	**P100**	**PT20**	**PT50**	**PT100**
NP	NS	NS	NS	NS	NS	NS	0.53408*	NS	NS	NS	NS	NS
PP	NS	NS	NS	NS	NS	NS	NS	0.66905**	NS	0.99882***	0.87708 ***	0.79866***

NS= Not significant, * Significant at $p < 0.05$), **Significant at $p < 0.01$ and *** Significant at $p<0.001$

[N20, N50, N100 represent soil N at 20cm, 50cm and 100 cm depth respectively. NT20, NT50, NT100 represents soil N at tasseling at depth 20, 50 And 100 cm. P20, P50 and P100 represents soil P at depths 20, 50 and 100 cm. PT20, PT50 and PT100, PT stands for soil P at tasseling, 20, 50 and 100 represent depths].

4.6. Simulation for biomass and grain yield.

4.6.1. Observed and predicted biomass and grain yield in 2005/6 season at Dzwerani

4.6.1.1. Observed and predicted biomass yield

The observed data ranged from 254.8 kg/ha to 807.26 kg/ha and the predicted data varied from 536 kg/ha to 3551.3 kg/ha at 6-8 weeks The predicted data in all the treatments were found to be higher than the observed yield. The APSIM model over-predicted biomass yield by ≈ 32% at 6 to 8 weeks and two folds at tasseling for treatment to N1P1 The difference in observed and predicted yield for treatment N0P0, N0P1 and N1P0 at tasselling varied from 259.9 Kg/ha to 811.9 Kg/ha with the predicted yield being the highest There was a significant difference between the observed and the predicted yield for all the treatments at 6-8 weeks and at tasseling (Table 4.4).

Table 4. 4: The relationship between observed and predicted biomass for Dzwerani in 2005/6 season.

	Biomass at 6-8 weeks			Biomass at Tasseling		
Treat	Obs	Pred	X^2	Obs	Pred	X^2
N0P0	423	535	23*	824.1	1084	62*
N0P1	255	523	138*	824.07	1365	214*
N1P0	675.	990	100*	1361.1	2173	303*
N1P1	807.3	1064	62*	1231.47	3551	1515*

*Significant at $p<0.05$. OBS= Observed, PRED= Predicted, BM1= Biomass at 6-8 weeks, BM2= Biomass at tasseling.

4.6.1.2. Observed and predicted grain yield.

The predicted grain production for Dzwerani showed treatment N0P1 with the least grain yield as compared to the other treatments (Figure 4.7). Treatments N0P0 and N1P0 produced almost the same grain yield (517 kg/ha and 516 Kg/ha). The predicted grain yield for treatment N1P1 was five times the predicted grain yield produced by N0P0 and N1P0 (Figure 4.7).

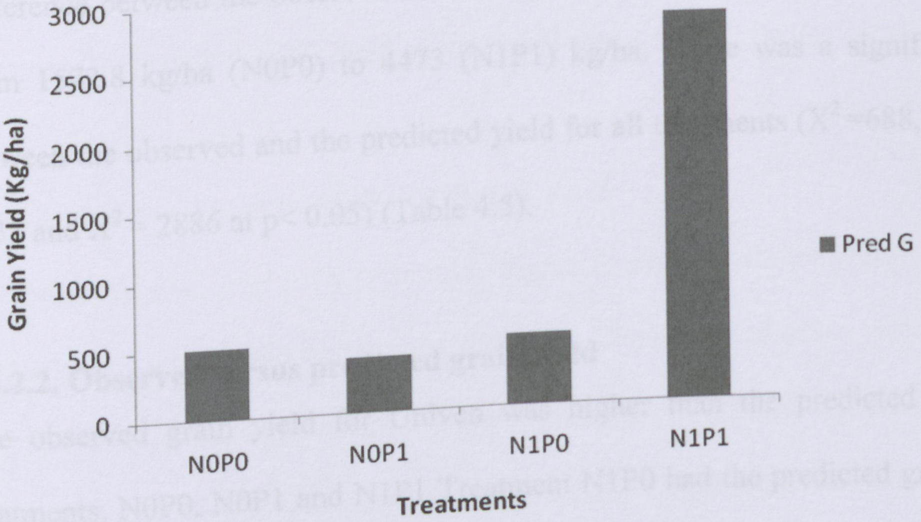


Figure 4 7: Predicted Grain Yield at Dzwerani site in 2005/6 season.

4.6.2. Univen observed versus predicted biomass and grain yield 2005/6

4.6.2.1. Observed biomass yield versus predicted biomass yield

The observed biomass yield at 6-8 weeks was lower than the predicted yield for all the treatments The predicted biomass yield was three folds higher than the observed yield in all treatments and there was a significant difference between the observed and predicted yield for all treatments (X^2=723, 462, 1720 and 801 at $p< 0.05$, for treatment N0P0, N0P1, N1P0 and N1P1 respectively) (Table 4.5). At tasseling, the predicted biomass yield was higher than the observed yield with the difference within the range 58.2 kg/ha to 1526.7 kg/ha. There was a significant difference between the predicted and the observed yield N0P0, N1P0 and N1P1(X^2= 78, X^2 =707, X^2 =278 at $p<0.05$) except for treatment N0P1 (X^2 =1 at $p<0.05$)(Table 4.5). At harvest the biomass accumulation was over predicted, the predicted yield was two to four times higher than the observed yield (Table 4.5). The difference between the observed biomass yield at harvest and the predicted yield ranged from 1572.8 kg/ha (N0P0) to 4473 (N1P1) kg/ha. There was a significant difference between the observed and the predicted yield for all treatments (X^2 =688, X^2= 1986 , X^2= 2938 and X^2 = 2886 at $p< 0.05$) (Table 4.5).

4.6.2.2. Observed versus predicted grain yield

The observed grain yield for Univen was higher than the predicted yield for three treatments, N0P0, N0P1 and N1P1 Treatment N1P0 had the predicted grain yield higher than the observed grain yield by 289.7 kg/ha. The observed grain yield for N0P0 and N0P1 were three times higher than the predicted yield. There was a significant difference between the observed and the predicted yields for all the treatments (X^2=1145, X^2= 3300, X^2= 51 and X^2= 1078 at $p< 0.05$) (Table 4.5).

4.6.3. Univen observed versus predicted biomass and grain yield in 2006/7 season

4.6.3.1. Observed versus Predicted biomass yield

The observed biomass accumulation for all treatments was lower than the predicted yield at 6-8 weeks and at tasselling. At harvest there was under prediction of biomass for four treatments, N0P0, N0P1, N2P0 and N2P1, but for treatments N1P0 and N1P1 the observed biomass was lower than the predicted biomass yield. There was a significant difference between the observed and the predicted yield at 6-8 weeks, at tasseling (excerpt for treatment N0P1) and at harvest (Table 4.6).

4.6.3.2. Observed versus predicted Grain Yield

The observed grain yield was extremely higher than the predicted yield. There was under prediction of grain yield in all the treatments. The observed grain yields for N0P0 and N0P1 were 14 times higher than the predicted yield (297.2 and 352.2 Kg/ha as predicted and 4179 and 4076 Kg/ha as observed). For the other treatments the observed yield varied from two to three fold the predicted yield. There was a significant difference between the observed and the predicted grain yield for all the treatments (X^2 =113266.5, X^2 = 115219.8, X^2= 13943.7, X^2= 127572, X^2= 9772.2, X^2= 4125.4 at $p< 0.05$) (Table 4.5).

Table 4. 5: The relationship between observed and predicted biomass for Univen in 2005/6 Season

UNIVEN 2005/6 Season

	Biomass at 6-8weeks			Biomass at tasseling			Biomass at harvest			Grain yield		
Treat	Obs	Pred	X^2	Obs	Pred	X^2	Obs	Pred	X^2	Obs	Pred	X^2
N0P0	145	992	723*	1519	1903	78*	2024	3596	688*	881	297	1145*
N0P1	406	1128	462*	2287	2345	1	1337	4238	1986*	1430	352	3300*
N1P0	181	2067	1720*	1769	3295	707*	2329	6798	2938*	1352	1642	51*
N1P1	709	1965	801*	2380	3344	278*	2459	6932	2886*	3004	1664	1078*

*Significant at $p < 0.05$. [OBS= Observed, PRED= Predicted, BM1= Biomass at 6-8 weeks, BM2= Biomass at tasseling, BM3= Biomass at harvest]

Table 4. 6: The relationship between observed and predicted biomass for Univen in 2006/7 Season.

	Biomass at 6-8weeks			Biomass at tasseling			Biomass at harvest			Grain yield		
Treat	Obs	Pred	X^2	Obs	Pred	X^2	Obs	Pred	X^2	Obs	Pred	X^2
N0P0	872	1353	171*	1666	2078	82*	4767	3597	381*	6099	297	113266.5*
N0P1	1344	1500	16*	2094	2250	11	8779	4238	4865*	6722	352	115219.8*
N1P0	1372	1926	159*	2111	3168	353*	5164	6798	393*	6426	1642	13943.7*
N1P1	1606	1965	66*	2250	3216	290*	5071	6932	500*	6272	1664	127572*
N2P0	1972	2303	47*	3603	4022	43*	10231	8403	398*	7871	2718	9772.2*
N2P1	2257	2364	5	3574	4269	113*	10165	8569	297*	6099	2738	4125.4*

*Significant at $p<0.05$.Obs =the observed yield, Pred =predicted yield

4.7. Correlation between the observed and predicted Biomass and Grain yield

The correlation between the observed and the predicted biomass yield was significant at 6-8 weeks at Dzwerani in 2005/2006 season (Figure 4.8). The observed biomass yield at 6-8 weeks (ObsBM1), tasseling (ObsBM2) were strongly related to the predicted yield (r^2=0.884 and r^2= 0.845) (Table 4.7., Figure 4. 9 a and b) at Univen in 2005/6 season. The observed bomassd at harvest (ObsBM3) at Univen were weakly related to predicited biomass yield at the 6-8 weeks, tasseling and at harvest in 2006/7 (Table 4.7, Figure 4.10c). The observed grain yield and predicted grain yield was weakly correlated for both seasons (Table 4.7, Figure 4.11). The observed biomass at 6-8 weeks, tasseling and at harvest were weakly correlated to the predicted biomass (r^2=0.125 and r^2=0.194 and r^2=0.533, respectively) at Univen in 2006/7 season (Figure 4.10 a, b and c). The observed grain yield at Univen 2006/7 season was weakly correlated to the predicted yield (Table 4.7, Figure 4.11b).

Table 4. 7: Correlation of the observed versus predicted biomass and grain yield.

Year	Variable OBS VS PRED biomass and Grain yield	Correlation coefficient(r^2)
2006	ObsBM1 and Pred BM1	0.884*
2006	ObsBM2 and Pred BM2	0.845**
2006	ObsBM3 and Pred BM3	0.257
2006	ObsGY and Pred GY	0.428
2007	ObsBM1 and Pred BM1	0.125
2007	ObsBM2 and Pred BM2	0.194
2007	ObsBM3 and Pred BM3	0.533
2007	ObsGY and Pred GY	0.132

Note ** correlation is significant at the 0.01 level

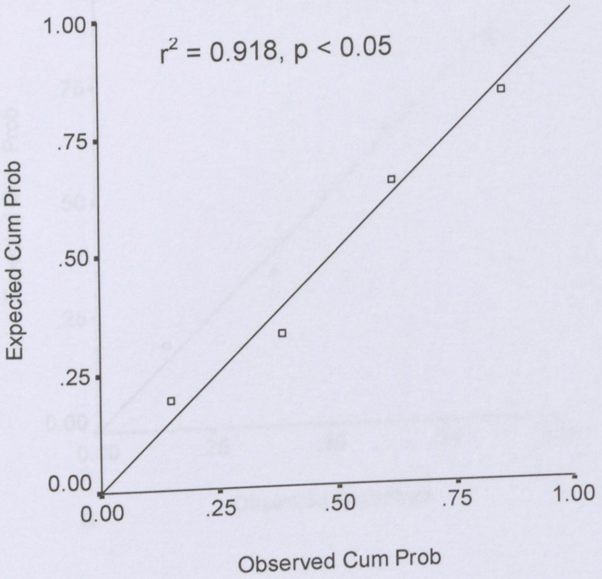


Figure 4 8: The relationship between the observed and the predicted biomass yield at Dzwerani site in 2005/6 season at different stages of growth.

Note: a= observed and predicted biomass at 6-8 weeks, b= observed and predicted biomass at tasseling.

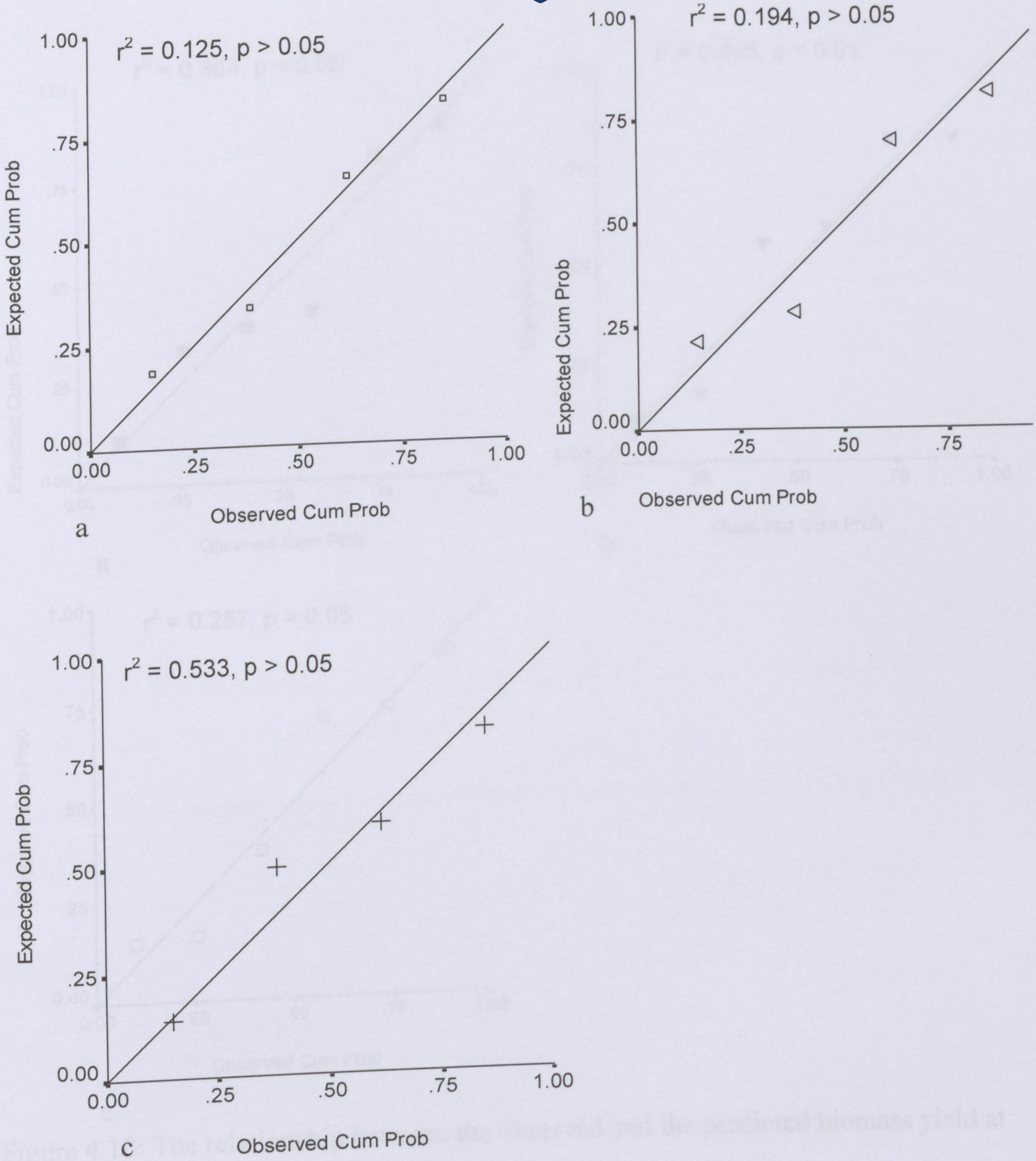
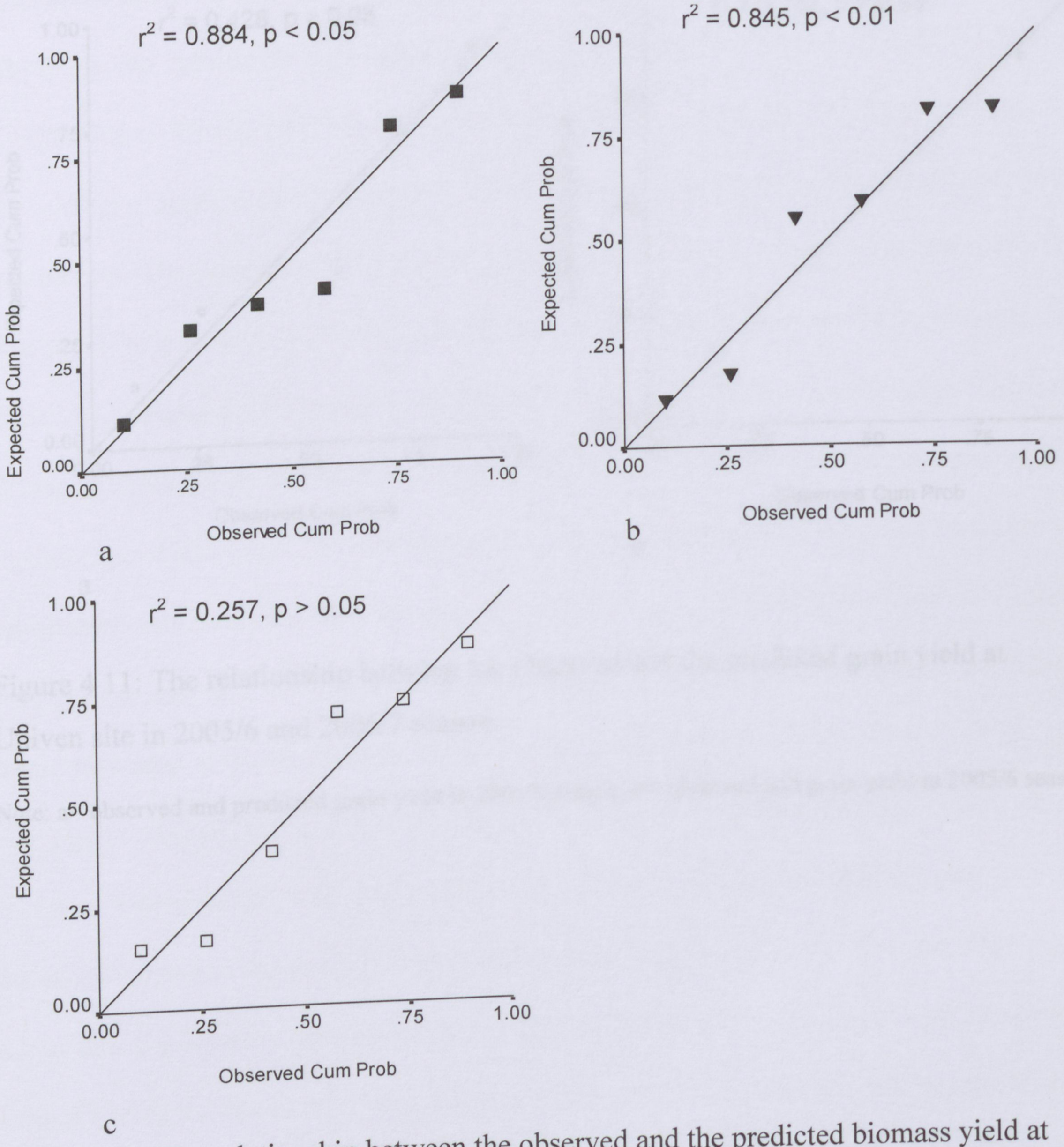


Figure 4 9: The relationship between the observed and the predicted biomass yield at Univen site in 2005/6 season at different stages of growth.

Note: a= observed and predicted biomass at 6-8 weeks, b= observed and predicted biomass at tasseling and c= observed and predicted biomass at harvest.



a

b

c

Figure 4 10: The relationship between the observed and the predicted biomass yield at Univen site in 2006/7 season at different stages of growth.

Note: a= observed and predicted biomass at 6-8 weeks, b= observed and predicted biomass at tasseling and c= observed and predicted biomass at harvest.

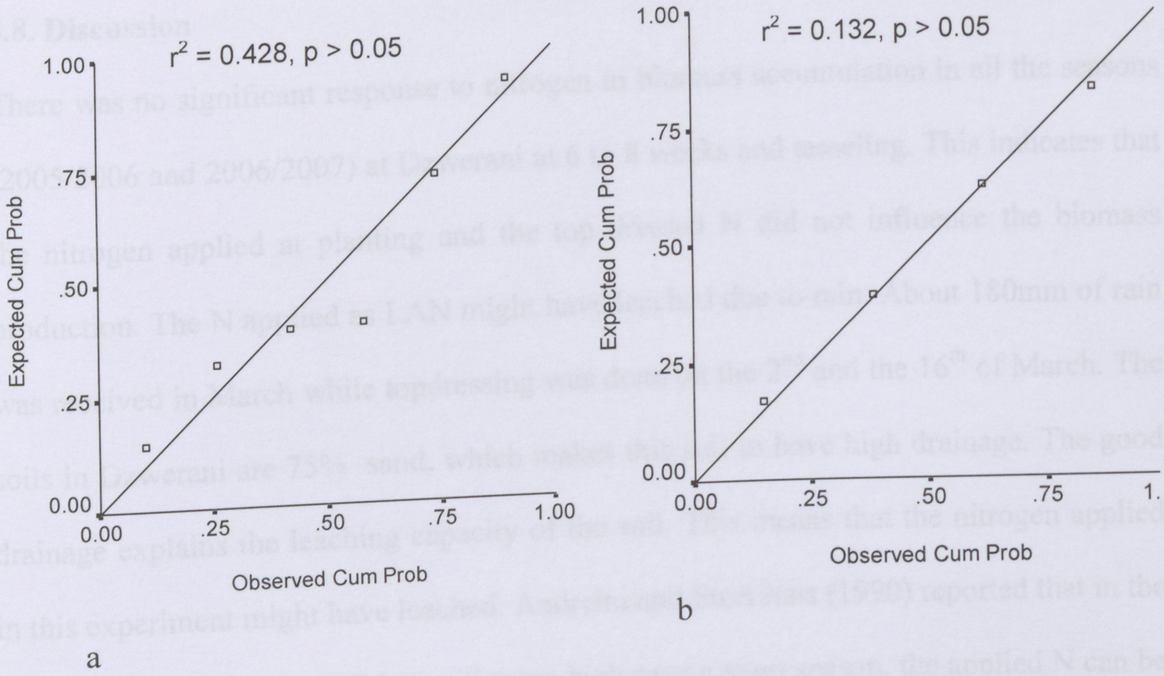


Figure 4 11: The relationship between the observed and the predicted grain yield at Univen site in 2005/6 and 2006/7 season.

Note: a= observed and predicted grain yield in 2005/6 season, b= observed and grain yield in 2005/6 season.

4.8. Discussion

There was no significant response to nitrogen in biomass accumulation in all the seasons (2005/2006 and 2006/2007) at Dzwerani at 6 to 8 weeks and tasseling. This indicates that the nitrogen applied at planting and the top dressed N did not influence the biomass production. The N applied as LAN might have leached due to rain. About 180mm of rain was received in March while topdressing was done on the 2nd and the 16th of March. The soils in Dzwerani are 75% sand, which makes this soil to have high drainage. The good drainage explains the leaching capacity of the soil. This means that the nitrogen applied in this experiment might have leached. Andreini and Steenhuis (1990) reported that in the environments where rainfall intensities are high over a short season, the applied N can be lost by leaching and /or bypass flow. The loss of N during the crop growth period can cause low crop response to fertlilizer N (Schanabel and Stout, 1994). Quaye (1999), and Sigunga *et al* (2002), found that the response of maize to applied N levels depend on the moisture stored in the soil. The high percentage of sand in Dzwerani suggests that the pores are large and the porosity affects the water holding capacity of the soil. This might mean that the water escape easily in this soil to below root zone, where the plant roots cannot access it. Power (1990), noted that the available soil water has a high influence on the utilization of soil N by plants. The available soil water at Dzwerani was found to be zero at depth 0-900mm, and the drainable soil water was 94.5mm. This therefore confirms the high rate of leaching at this site.

These results are in contrast with the findings by Ayuke, *et al* (2004) who found that increasing N significantly increased maize biomass and grain yields. Possibly there was no significance of N leaching in their study. There were no records of biomass at harvest due to the animal damage. Dzwerani site was a farmer owned field and the fencing in the field was not adequate.

There was a significant difference in biomass produced at 6-8 weeks after planting at Univen in both seasons. This indicates that the amount of N added at planting influenced the biomass accumulation in the N treatments. These results are in agreement with the findings by Kamara *et al* (2005), who reported that the biomass yield for 90 kg N application differed, by 77%-90% as compared to the 0 N applications. There was no significant difference in biomass production at tasseling and at harvest in both seasons at Univen site. The biomass production for all nitrogen treatments was higher than the zero N treatments but not significantly different. This therefore suggests that the N applied after 6-8weeks stage could not be utilized efficiently for the production of biomass. The biomass accumulation of the N- treatment being not statistically different as compared to the zero-N treatment, might have been influenced by the rate of N (75 kg/ha) applied. Muhammad *et al* (2004) reported a significant increase in maize biomass at tasselling where 150 kg of N was applied in a clay-loam soil, the amount of N (150 kg) is double the amount added in this research (75 kgN/ha).

The other effect might be due to the loss of N through leaching and N mineralization. Nitrogen mineralization is said to increase the release of plant N. Nivong *et al* (2007) , reported that the mineralization in highly weathered soils is slow as compared to the slightly weathered soils. The soils at Univen site are highly weathered, and therefore there is a possibility that mineralization is slow at this site, thus the N release is slow.

There was no interaction between N and P in biomass production. There was no significant difference in biomass produced by all treatment with respect to P in both seasons at both sites. These results are contradictory with the findings of Muhammad *et al* (2004) who reported significant increase in maize biomass and grain yield at 25 kg/ha P application in saline soil. However, Hoeft and Peck (1991), reported that for the production of 2t/ha of stover and grain, a minimum, of 45 kg/ha P_20_5 must be added in South African soils. The amount of P applied in this experiment might have been low to make a significant difference in the biomass yield. The P applied might also have been affected by the fixation at Univen site. Johnston *et al* (1991), reported that the highly weathered soils have a high P fixing capacity. Highly weathered soils contain Fe and Al oxides that can reduce the solubility of P, as they react with P to form insoluble phosphates. Van der Laan *et al* (2009) reported that the P fixation is proportionally related to the clay content in the soil. Univen soil falls under the clay soils (Kaolinite) with 60 % clay (Non-Affiliates Soil Analysis Work Committee, 1991); therefore P fixation might have occurred.

The grain yield was not significantly higher for N treatments as compared to the zero N treatment, i.e. there was no significant response in grain production to fertilizer nitrogen. Maize genotypes perform differently under low N due to high N-uptake efficiency. Some genotypes might be efficient in utilizing N taken up to produce grain. In this study, maize yield did not significantly increase with the increase in N. This might be due to the rate of N application (0 and 75kg/ha) in this study. The fertilizer recommendations by Hoeft and Peck (1991) suggest that in south Africa, for the production of 8t ,3t and 2t/h, the N applied should be 170, 45 and 20 kgN/ha N respectively. The fact that with an addition of 75 kgN/ha, the grain production was 3t/ha and 7t/ha in 2005/6 and 2006/7 respectively, shows that the soil has a potential to produce. The rate of N might have affected the production. The soil at both sites is highly oxidized and leaching of nitrate nitrogen can occur at a higher rate (Hoeft and Peck, 1991). In both seasons, the month when topdressing was done, there was high rainfall received and this possibly led to the leaching of nitrogen from the soil. The other cause of low grain yield with response to N might be due to the fact that the field (Univen) was exposed to monkeys that also fed on the grain prior harvest. This led to very few samples collected from some plots and thus the possibility of either underestimating or overestimating the actual yield/ha due to the small sample size. The lack of significant differences in this study could have been due to low error in this study. The rate of N applied should be revisited and increased as per soil analysis.

The plant tissue N concentration was high in the N applied treatment as compared to the no N treatment but it was not statistically significant. The reason for this might be that N in the soil was leached out due to rainfall. There was a high amount of rainfall received in February and March. The rainfall was received when topdressing was applied; hence the possibility that the top dressed fertilizer N was not utilized by the plant was high. The current study is in contrast with the findings by Killorn and Zourarakis (1992) who reported the increase in leaf N concentration with increased N fertility. There was a negative correlation between soil N and plant tissue N at different stages of growth. There was a strong relationship between soil P and plant tissue P content.

APSIM prediction for biomass in the first season was in agreement with the observed yield. The biomass at the third stage was overpredicted. Similar results were found by Chivenge *et al* (2004) where there was a serious over-prediction of data by APSIM. There was an under prediction for dry matter yield at the second stage of sampling (tasseling).

The predicted biomass yield in all the years was in agreement with the observed biomass yield at 6-8 weeks after planting and at tasseling. The predicted yield was higher than the observed yield, since the field experimentation is exposed to various conditions such as flooding, retarded growth and natural enermies that the model does not take into consideration. The predicted biomass yield showed no response to P but there was a slight response to N. This might be because the P level was not sufficient enough to affect the yield. This in contrast with the findings by Whitebread *et al* (2004) who found that P increased dry matter from 4t/ha (no P) to 10t/ha (with P).

At harvest (2006 season) there was an over prediction by 1596 to 2527 Kg/ha of biomass yield for N treatments. In the case of the Univen experimental observation, there was a destruction of crops by the monkeys before samples for biomass at harvest was taken. This also led very small sample size collected from some plots, hence the possibility of overestimating or underestimating the actual yield. The over prediction was also found in the study by Whitebread *et al* (2004), where APSIM over predicted the grain yield. The prediction for grain in the current study was lower than the observed grain yield by 573 Kg/ha to 1393 Kg/ha, but there was a slight response to N. This might also be because of the calibration of the model's N utilization and N use to convert the N to grain accumulation, apart from the damage caused by the monkeys.

There was a significant difference between the predicted and the observed biomass yield at all stages of growth and grain yield at both seasons. The correlation between the observed and the predicted biomass yield was not significant at all stages of growth at Univen in 2005/2006 season. In 2006/2007 season, there was a strong relationship between the observed and the predicted biomass yield at 6-8 weeks and at tasseling. There was a partial agreement between the observed and predicted grain yield in both season.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

Fertilizer N improved biomass production at Univen site and in two seasons at the first stage of growth (6-8 weeks). At tasselling and at harvest, biomass accumulation was high for N treatment, but not significantly higher than the zero N treatments. The rate of N applied should be revisited and increased as per soil analysis. This could also be due to the low error in the current study, therefore future studies could either increase the factor level or to raise the error.

The grain yield was not affected by the application of N at both sites and in all the seasons. The grain yield was high for N fertilizer treatments though not significant because of the damage caused by the monkeys at Univen and by the livestock at Dzwerani. This means that there should be extra monitoring during the experimentation and a proper fencing should be constructed.

Plant tissue P was affected by P fertilizer application because it was high in P treatments. Plant tissue N was not affected by fertilizer N application. Soil NO_3-N was found to be high at 6-8 weeks than at tasseling for N treatments, but for zero N treatment it was high at tasseling than at 6-8 weeks.

APSIM model has proved to be applicable in simulating biomass and grain yields. The model provided acceptable results for 2005/2006 season. However, there were some under and over predictions for 2006/2007 in grain and biomass yield that might have been caused by the absence of pest management window in APSIM. For APSIM to estimate more acceptable results, the environmental management window should be incorporated.

This calls for further studies with regard to APSIM simulations especially under farmer managed condition which may be subject to many external interferences which may be uncontrollable.

REFERENCES

Adediran J.A., and Banjoko V.A., 1995. Response of Maize to nitrogen, phosphorus and potassium fertilizers in the savanna zone of Nigeria. Comm. Soil Sci. Plant Anal., 26: 593-606.

Adepetu J. A., 1970. The relative importance of organic phosphorus to crop nutrition in soils of Western Nigeria. M. Phil. Thesis. *Univ.of. Ife, Ile-Ife*, Nigeria.

Adepetu J. A., and Corey R. B., 1976. Organic Phosphorus as a predictor of plant available phosphorus in soils in Southern Nigeria. *Soil Sci*. 122 (3) 159-164.

Adiku S. K., Carberry P. S., Rose C. W., McCown R. L., and Braddock R., 1993. Assessing the performance of maize (*Zea mays* cowpea (*Vigna unguiculata*) intercrop under variable soil and climate conditions in the tropics. Proceedings of the Seventh Australian *Society of Agronomy Conference*, September, Adelaide, South Australia, p. 382.

Ali J., Bakht J., Shafi M., Khan S., and Ali W., 2002. Uptake of nitrogen as affected by various combination of nitrogen and phosphorous. Asian J. Plant Sci. 1: 367-369.

Amon B. O. E., 1965. The response by crops in relation to nitrogen, phosphorus and potassium in savanna zone of Western Nigeria. *Proceedings of O.A.U. STRC symposium on the maintenance of soil fertility Publication* No. 98, Lagos, Nigeria.

Andreini J.K., and Steenhuis T.S., 1990. Preferential paths of flow under conventional and conservation tillage. *Geoderma* 46:85-102.

Anonymous, 2000. "Fertilizers and their use", FAO, International Industry Association, Rome. P 35-38.

Arain A.S., Alam S., and Tunio A.K.G., 1989. Perfomance of maize genotypes under varying nitrogen and phosphorus application rates. Fertilizer environments, Sarhad J. Agric., 5: 623-626.

Assuero S. G., Mollier A., and Pellerin S., 2004. The decrease in growth of phosphorus deficient maize leaves is related to a lower cell production. *Plant, Cell and Environment* 27: 887-895.

Ayuke F.O., Opondo-Mbai M.L., Rao M.R., and Swift M.J., 2004. Effect of organic and inorganic sources of nutrients on soil mineral Nitrogen and maize. New York. *Agron*

Benhin J. K. A., 2006. Climate change and South African agriculture: Impact and adaptation options. CEEPA. Discussion Paper #21. University of Pretoria, South Africa.

BFAP (Bureau for Food and Agricultural Policy)., 2007. Modelling the economic impact of climate change on the South African maize industry. BFAP Report #2007-02.

Brar S. P. S., Bhajan S., Benbi D. I., and Sing B., 1989. Effect of long-term application of N and P on crop yield, nitrogen uptake and soil nitrogen status in maize wheat rotation. *J. Res.*, 26: 572-580.

Bray, R.H. and Kurtz, L.T., 1945. Determination of total, organic and available forms of phosphorus in soils. Soil Sci. 59, 39-45.

Brinton W. F., 1985. Nitrogen response of maize to fresh and composted manure. *Biol. Agric. Hortic*. 3:55-64

Carberry P. S., and Abrecht D. G., 1991 Tailoring crop models to the semi-arid tropics. Climatic risk in crop production: models and management for the semi-arid tropics and subtropics. Eds RC Muchow, JA Bellamy pp. 157–182. CAB International: Wallingford.

Chevalier P., and Schrader L. E., 1977. Genetic differences in nitrate absorption and partitioning of N among plant parts in maize. Crop Sci. *J.*17: 897-901

Chiera J., Thomas J., and Rufty T., 2002. Leaf initiation and development in soybean under phosphorus stress. Journal of Experimental Botany 53: 473–481.

Chivenge P., Dimes J., Nhamo N., Nzuma J.K., Murwira H.K., 2004 Evaluation of APSIM to simulate maize response to manure inputs in wet and dry regions of Zimbabwe. In: Delve RJ, Probert ME (eds) Modelling nutrient management in tropical cropping systems, ACIAR Proceedings 114: 85–91

Dahiya S.S, Snunil G., Antil R.S., Snoop S., Singh A., and Goel S., 1991. Effect of Cd and nitrogen on dry matter yield and uptake of nutrients in corn. Annals of Biology Ludhiana, 7: 205-208.

Du Toit W., 1999. Guide for the production of maize in summer rainfall area. ARC. Pretoria.

Du Toit A. S., Prinsloo M. A., Durand W., and Kiker G., 2002. Vulneraility of maize production to climate change and adaptation assessment in South Africa. Combined Congress: South African Society of Crop Protection and South African Society of Horticulture Science; Pietermaritzburg, South Africa

Durand W., 2006. Assessing the impact of climate change on crop water use in South Africa. CEEPA Discussion Paper #28. University of Pretoria, South Africa.

Dwyer L. M., Ma B. L., Gregorich E., and Tollenaar M., 1993. Field maize N levels and relationships to growth and yield. p. 133. *In* Agronomy abstracts 1993. ASA, Madison, WI.

Epstein E., 1972. Mineral nutrition of plants: Principles and perspectives. John Wiley & Sons, New York.

Fedotkin I. V., and Kravtsov I. A., 2001. Production of grain maize under irrigated conditions. Kukuruza-I-Sorgo. 2001. 3: 5-8.

Food and Agricultural Organization of the United Nations (FAO)., 1994a. *Cereal Policies Review, 1993-94.* Rome.

Food and Agricultural Organization of the United Nations (FAO)., 1994b. *Medium-term Prospects for Agricultural Commodities, Projections to the Year 2000.* FAO Economic and Social Development Paper No. 120. Rome.

Food and Agricultural Organization of the United Nations (FAO)., 1995. White Maize as a Traditional Staple Food: Situation, Outlook and Issues. 26th Session of the Intergovernmental Group on Grains, 30 May - 2 June. Rome.

Gbetibouo G., and Hassan R., 2006. Economic impact of climate change on major South African field crops: A Ricardian approach. *Global and Planetary Change* 47:143-152.

Glass A. D. M., Bomke J. D., 1980. Role of Phosphorus in plant nutrition. Proceedings of the Western Canada Phosphate Symposium. The Western Canada Soils Coordinating Committee and the Western Canada Fertilizer Association, Calgary, Canada, 1980; 357-368.

Glass ADM, Thompson RG, Bordeleau L. 1985. Regulation of NO$^-_3$ influx in barley: studies using ^{13} NO$^-_3$. Plant Physiology 77: 379–381.

Gokmen S., Sencar O., and Sakin M. A., 2001. Response of popcorn (*Zea mays* everta) to nitrogen rates and plant densities. Turk. *J. Agric*. and Forest. 25: 15-23.

Heisey P. W., and Smale M., 1995. *Maize Technology in Malawi: A Green Revolution in the Making.* CIMMYT Research Report No. 4. Mexico, D.F.: CIMMYT.

Heisey P. W. and Mwangi W. 1996. Fertilizer Use and Maize Production in Sub- Saharan Africa. CIMMYT Economics Working Paper 96-01, CIMMYT, Mexico.

Hoeft R.G., and Peck T.R., 1991. Soil testing and fertility. Illinois Agronomy Handbook, Circular 1311, University of Illinois, Urbana-Champaign, IL, USA (1991).

Jayne T. S., Jones S., Mukumbu M., and Jiriyengwa S., 1997. "Maize Marketing and Price Policy in Eastern and Southern Africa." D. Byerlee and C.K. Eicher (eds.), *Africa's Emerging Maize Revolution.* Boulder, Colorado: Lynne Rienner Publishers.

Johnston M.A., Miles N., and Thibaud G.R., 1991. Quantities of phosphorus fertilizer required to raise the soil test value. *S. Afr. J. Plant Soil* 8: 17-21.

Jones J. W., Keating B. A, and Porter C., 2001. Approaches for modular model development. Agric. Syst. 70, 421-444.

Kamara A. Y., Menkir A., Ajala S.O., and Kureh I., 2005. Performance of diverse maize genotypes under nitrogen deficiency stress in the northern Guinea savanna of Nigeria. Exp. Agric. 41:199–212.

Kavanová M., Grimoldi A. A., Lattanzi F. A., and Schnyder H., 2006. Phosphorus nutrition and mycorrhiza effects on grass leaf growth. P status- and size-mediated effects on growth zone kinematics. Plant, Cell and Environment 29:511–520.

Keating B. A., Carberry P. S., Hammer G. L., Probert M. E., and Robertson M. J., 2003. An overview of APSIM, a model designed for farming systems simulation. *European Journal of Agronomy* 18, 267–288.

Khamis S., Chaillau S., and Lamaze T., 1990. CO_2 assimilation and partitioning of carbon in maize plants deprived of ortho-phosphate. Journal of Experimental botany. 41, 1619-1625.

Killorn, R., and Zourarakis D., 1992. Nitrogen fertilizer management effect on corn grain yield and nitrogen uptake. Journal of Production Agriculture 5:142-148

Kurukulasuriya P., and Mendelson R., 2006. Endogenous irrigation: The impact of climate change on farmers in Africa. CEEPA Discussion Paper #18. University of Pretoria, South Africa.

Liang B. C., and MacKenzie A. F., 1994. Corn yield, nitrogen uptake and nitrogen use efficiency as influenced by nitrogen fertilization. Can. *J. Soil Sci*. 1994; 74:235-240.

Mahmood M. T., Maqsood M., Awan T. H., Rashid S., and Sarwar R., 2001. Effect of different levels of nitrogen and intra-row plant spacing on yield and yield components of maize. Pak. J. Agric. Sci. 38: 48-49.

Majid A., Shafiq M., and Iqbal M., 1986. Deep tillage and sowing techniques in maize production under high rainfed conditions. Pak. J. Agric. Res. 7: 181-185.

Mallarino A. P. and Rueber D., 2001. Impacts of crop rotation and nitrogen fertilization on crop production [Online]. Annual report—Northern Research and Demonstration Farm. ISRF01–22. Iowa State Univ., Ames.

McCown R. L., Hammer G. L., Hargreaves J. N. G., Holzworth D.P., and Freebairn D. M., 1996. APSIM : a novel software system for model development, model testing and simulation in agricultural research. Agricultural Systems, 50, 255-271.

McCullough D. E., Girardin P., Mihajlovic M., Aguilera A., Tollenar M., 1994. Influence of N supply on development and dry matter accumulation of an old and a new maize hybrid. Canadian Journal of Plant Science, V. 74 (2) : 471-478.

Moll R. H., Kamprath E. J., and. Jackson W.A., 1982. Analysis and interpretation of factors which contribute to efficiency of nitrogen utilization. Agron. J. 74, 562- 564.

Muhammad R., Ali H., and Mahmood T., 2004. Impact of nitrogen and sulphur application on growth and yield of maize crop. Journal of Research (science), Bahauddin Zakariya University, Multon, Pakistan. Vol. 15 (2): 153-157.

Negrila M., and Negrila E., 1994. Nitrogen and phosphorus ratio in wheat and maize crop. Statistica, si Applicata, 16: 119-133.

Nivong s., Tasnee A., and Russell Y., 2007. Nitrogen fertilizer response of maize on some important soils from DSSAT software prediction. Kasetsart J. (Nat. Sci.) 41:21-27.

Non-Affiliated Soil Analysis Working Committee, 1991. Methods of soil analysis. SSSSA, Pretoria.

Nunes G. H. S., Silva P. S. L., and Nunes S. G. H., 1996. Response of maize to nitrogen levels and weeds control. Ciencia-e-Agrotecnologia. 20: 205-211.

Oikeh S. O., Kling J. G., Horst W. J., and Chude V. O., 1997. Yield and N-use efficiency of five tropical maize genotypes under N levels in the moist savanna of Nigeria. Ransom KJ, Palmer AFE, Zambezi BT, Mduruma ZO, Waddington SR, Pixley KV, Jewell DC (eds) Maize Productivity Gains Through Research and Technology Dissemination.

Proceedings 5th Eastern and Southern Africa Regional Maize Conf. Arusha, Tanzania, 3-7 June 1996. CIMMYT, Addis Ababa, Ethiopia, pp.163–167.

Ojiem J. O., Mureithi J. G., and Okwuosa E. A., 2000. Intergrated management of legume green manure, farm yard manure and inorganic nitrogen for soil fertility improvement in Western Kenya. Proceedings of the 2nd Scientific Conference of the Soil Management and Legume Research Network Projects, Mombasa, Kenya, pp: 77-102.

Okalebo J.R., Gathua K.W., and Woomer P.L., 2002. *Laboratory methods of soil and plant analysis: A working manual.* 2nd Edn. TSBFCIAT and SACRED Africa, Nairobi, Kenya. 128 .

Olson R. A., and Sander D.H., 1999. Corn production. In G.F. Sprague and J.W. Dudley (eds). Corn and Corn Improvement. pp. 639-686.

Onasanya R.O., Aiyeri O.P., Onasanya A., Oikeh S., Nwilene F.E., and Oyelakin O.O., 2009. World Journal of Agricultural Sciences. ISSN. Vol 4: pp 400-407

Onisie T., Timariu G., and Jitareanu G., 1993. Studies on the Influence of different fertilizer rates on yield of phaseolus and maize grown together on sloping lands subject to erosion. Cercetari Agronomica in Moldova, 26:73-78.

Onken A. B., and Wendt C.W., 1989. Soil fertility management and water relationships. *Soil, crop, and water management systems for rainfed agriculture in the Sudano-Sahelian zone*. Proceedings of an international workshop, 11-16 January 1987, ICRISAT Sahelian Center, Niamey, Niger. 99-105.

Plénet D., Etchebest S., Mollier A., and Pellerin S., 2000. Growth analysis of maize field crops under phosphorus deficiency. I. Leaf growth. Plant and Soil . *Ann. of Agric. Res.*

Power J.F. 1990. Fertility management and nutrient cycling. Singh R.P., Parr J.F., and Stewart (Eds), *Dry land Agriculture, strategies for sustainability. Advances in soil science*, Springer Vol 13, Verlag, New York. *Agron J* 92:690

Probert M. E., Dimes J. P., Keating B. A., Dalal R. C., and Strong W.M., 1998. APSIM's water and nitrogen modules and simulation of the dynamics of water and nitrogen in fallow systems. *Agric. Syst*. 56, 1-28.

Quaye A.K. 1999. Soil water and nitrogen interaction on maize grown on a Vertisol. B.Sc. Thesis, Soil science Department, Univesity of Ghana, Legon.

Radin J. W., and Eidenbock M. P., 1984. Hydraulic conductance as a factor limiting leaf expansion of phosphorus-deficient cotton plants. *Plant Physiology* 75: 372–377.

Raghothama K.G., 1999. Phosphate Acquisition. Annual Review of Plant Physiology and Plant Molecular Biology. 50: 665-693. [CrossRef][Web of Science].

Rehm, G.W. and R.A. Wiese. 1975. Effect of method of N application on corn (*Zea mays* L.) grown on irrigated sandy soil. *Soil Sci. Soc. Am. Proc*., 39: 1217-1220.

Robertson M. J., Carberry P. S., Slim S., Chauhan Y. S., Ranganathan R., and O'Leary G. J., 2001. Predicting growth and development of pigeonpea: a simulation model. Field Crops Research, 71: 195-210.

Rosolem C. A., Assis J. S., and Santigo A. D., 1994. Root growth and mineral nutrition of corn hybrids as affected by phosphorus and lime. Communications in Soil Science and Plant Analysis. 25: 2491-2499.

Rubey L., Ward R., and Tschirley D., 1997. "Maize Research Priorities: The Role of Consumer Preferences." D. Byerlee and C.K. Eicher (eds.), *Africa's Emerging Maize Revolution.* Boulder, Colorado: Lynne Rienner Publishers.

Sanjeev K., Bangarwa A. S., and Kumar S., 1997. Yield and yield components of winter maize (*Zea mays* L.) as influenced by plant density and nitrogen levels. *Agric. Sci. Dig.* Karnal. 17: 181-184.

Schanabel R.R., and Stout W.I., 1994. Denitrification losses from two Pennsylvania floodplain soils. *J. Environ. Qual*. 23:344-348.

Schollenberger, C.J. and Simon, R.H., 1945. Determination of exchange capacity and exchangeable cations in soil with ammonium acetate. Soil Sci. 59, 13-24

Shamudzarira Z., and Robertson M. J., 2002. Simulating the response of maize to N fertilizer in semi-arid Zimbabwe. Exp. Agric. 38, 79-96.

Shanti K. V. P., Rao M. R., Reddy M. S., and Sarma R. S., 1997. Response of maize (*Zea mays*) hybrid and composite to different levels of nitrogen. India J. Agric. Sci. 67: 424-425.

Shivay Y. S., and Singh R. P., 2000. Growth, yield attributes, yields and nitrogen uptake of maize (*Zea mays* L.) as influenced by cropping systems and nitrogen levels. *Ann. of Agric. Res*. 21: 494-498.

Sigunga D.O., Jassen B.H., and Oenema O. 2002. Effect of improved drainage and nitrogen source on yields, nutrient uptake and utilization efficiencies by maize (*Zea mays* L.) on Vertisols in sub-humid environments. *Nutrient Cycling in Agroecosystems*, 62(3): 263-275.

Sobulo R. A., (1980). Nitrogen and potassium balance in maize in the humid tropics. *Proceedings of International conference on Nitrogen Cycling in Western Africa's Ecosystems*, pp. 311-375.

Soil Classification Working Group., (1991). Soil classification: a taxonomic system for South Africa. Department of Agricultural , Pretoria, RSA.

Steiner J. L., Schomberg H. H., Douglas C. L., Black A.L., 1994. Standing stem persistence in no-tillage small-grain fields. Agron. J. 86:76-81.

Sugiharto B., Miyata K., Nakamoto H., Sasakawa H., and Sugiyama T., 1990. Regulation of expression of carbon-assimilating enzymes by nitrogen in maize leaf. Plant Physiol. 92:936–969.

Ticconi C., and Abel S., 2004. Short on phosphate: plant surveillance and countermeasures. Trends Plant Sci 9:548-555

Vance C. P., Uhde-Stone C., Allan D.L., 2003. Phosphorus acquisition and use: critical adaptations by plants for securing a nonrenewable resource. *New Phytologist* 157: 423–447.

Van der Laan M., Annandale J.G., du Preez C.C., and Lorentz S.L., 2009. Obtaining the parameters required to model labile P for South African soils. S. Afr. J. Plant and Soil, 26, 213-219.

Walkey, A., Black, I.A., 1934 an examination of degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. Soil Sci. 37, 29-38

Weber M., Tschirley D., Varela R., Santos A. P., and De Murrule H.F., 1992. "Reflections on Relationships Between Food Aid and Maize Pricing/Marketing in Mozambique." Draft Paper. East Lansing, Michigan State University, USA.

Whitbread A. M., Jiri O., and Maasdorp B., 2004. The effect of managing improved fallows of Mucuna pruriens on maize production and soil carbon and nitrogen dynamics in subhumid Zimbabwe. Nutrient Cycling in Agroecosystems. 69: 59-71.

Yamazaki, M., Watanabe A., and Sugiyama T., 1986. Nitrogen-regulated accumulation of mRNA and protein for photosynthetic carbon-assimilating enzymes in maize. Plant Cell Physiol. 27:443–452.

Zhang J., and Barber S. A., 1992. Maize root distribution between phosphorus fertilized and unfertilized soil. Soil Sci. Soc. Am. J. 56, 819-822

Appendix A. Univen Summary file (2005/2006)

```
          Soil Water Holding Capacity
     ---------------------------------------------------------
         Depth    Unavailable Available  Max Avail.  Drainable
                     (LL15)   (SW-LL15)  (DUL-LL15)  (SAT-DUL)
                       mm        mm          mm          mm
     ---------------------------------------------------------
       0.-  150.      18.00     21.00       21.00       34.50
     150.-  300.      19.50     24.00       24.00       30.00
     300.-  450.      19.50     24.00       24.00       30.00
     450.-  600.      19.50     28.50       28.50       25.50
     600.-  750.      19.50     28.50       28.50       25.50
     750.-  900.      19.50     28.50       28.50       25.50
     ---------------------------------------------------------
          Totals     115.50    154.50      154.50      171.00
     ---------------------------------------------------------


          Initial Surface Organic Matter Data
     ----------------------------------------------------------------------
         Name     Type         Dry matter    C        N        P    Cover
Standing_fr
                                 (kg/ha)  (kg/ha)  (kg/ha)  (kg/ha) (0-1)     (0-
1)
     ----------------------------------------------------------------------
      maize      maize            1000.0   400.0      5.0      0.0  0.330     0.0
     ----------------------------------------------------------------------
                  Crop Sowing Data
     -------------------------------------------------------
     Sowing   Depth  Plants Spacing Skiprow Cultivar    FTN
     Day no    mm     m^2     m      code     name       no
     -------------------------------------------------------
        353   20.0    8.0    0.9     0.0   pan6671      0.00
     -------------------------------------------------------
```

```
Root Profile
          ------------------------------------------------
            Layer       Kl      Lower  Exploration
            Depth               limit    Factor
            (mm)        ()     (mm/mm)     ()
          ------------------------------------------------
           150.000    0.060    0.120    1.000
           150.000    0.060    0.130    1.000
           150.000    0.060    0.150    1.000
           150.000    0.050    0.150    1.000
           150.000    0.050    0.150    1.000
           150.000    0.050    0.150    1.000
           ------------------------------------------------
```

Appendix B: Dzwerani Summary file (2005/2006)

```
      Soil Profile Properties
  ---------------------------------------------------------------------
       Depth  Air_Dry  LL15   Dul    Sat     Sw     BD   Runoff  SWCON
        mm     mm/mm   mm/mm  mm/mm  mm/mm  mm/mm  g/cc    wf
  ---------------------------------------------------------------------
      0.-  150.0.060  0.120  0.260  0.400  0.120  1.470  0.762  0.700
    150.-  300.0.110  0.130  0.270  0.320  0.130  1.670  0.190  0.700
    300.-  600.0.170  0.170  0.330  0.440  0.170  1.360  0.048  0.700
    600.-  900.0.170  0.170  0.330  0.440  0.170  1.400  0.000  0.700
  ---------------------------------------------------------------------

      Soil Water Holding Capacity
    ---------------------------------------------------------
       Depth    Unavailable Available  Max Avail.  Drainable
                   (LL15)   (SW-LL15)  (DUL-LL15)  (SAT-DUL)
                    mm         mm          mm          mm
    ---------------------------------------------------------
      0.-  150.     18.00       0.00       21.00       21.00
    150.-  300.     19.50       0.00       21.00        7.50
    300.-  600.     51.00       0.00       48.00       33.00
    600.-  900.     51.00       0.00       48.00       33.00
    ---------------------------------------------------------
         Totals    139.50       0.00      138.00       94.50
    ---------------------------------------------------------

       Initial Soil Parameters
    ---------------------------------------------------------
          Insoil        Salb     Dif_Con   Dif_Slope
    ---------------------------------------------------------
            0.00        0.15      250.00       22.00
    ---------------------------------------------------------

        Initial Surface Organic Matter Data
    ----------------------------------------------------------------------
      Name     Type        Dry matter    C        N        P     Cover
Standing_fr
                            (kg/ha)  (kg/ha)  (kg/ha)  (kg/ha)  (0-1)     (0-
1)
    ----------------------------------------------------------------------
    maize      maize            0.0      0.0      0.0      0.0   0.000      0.0
    ----------------------------------------------------------------------

             Effective Cover from Surface Materials =   0.0
```

```
------- Dzwerani_Venda Nitrogen Initialisation ---------------------------------

        ------------------------------------------------
          Layer   pH     OC     NO3     NH4     Urea
                        (%)  (kg/ha) (kg/ha) (kg/ha)
        ------------------------------------------------
            1    6.50  1.23    0.22    0.22    0.00
            2    6.50  1.23    0.25    0.25    0.00
            3    5.50  1.00    0.41    0.41    0.00
            4    5.60  0.40    0.42    0.42    0.00
        ------------------------------------------------
          Totals               1.30    1.30    0.00
        ------------------------------------------------
```

Appendix C: Univen Summary File (2006/2007)

```
          Soil Profile Properties
     ---------------------------------------------------------------------
          Depth  Air_Dry  LL15   Dul    Sat     Sw     BD   Runoff  SWCON
            mm    mm/mm   mm/mm  mm/mm  mm/mm  mm/mm  g/cc    wf
     ---------------------------------------------------------------------
         0.-  150.  0.060  0.120  0.260  0.490  0.260  1.100  0.762  0.500
       150.-  300.  0.080  0.130  0.290  0.490  0.290  1.200  0.190  0.500
       300.-  450.  0.130  0.130  0.290  0.490  0.290  1.200  0.048  0.700
       450.-  600.  0.130  0.130  0.320  0.490  0.320  1.200  0.000  0.700
       600.-  750.  0.130  0.130  0.320  0.490  0.320  1.200  0.000  0.700
       750.-  900.  0.130  0.130  0.320  0.490  0.320  1.200  0.000  0.700
     ---------------------------------------------------------------------



     Soil Water Holding Capacity
       ---------------------------------------------------------
           Depth    Unavailable Available  Max Avail.  Drainable
                       (LL15)    (SW-LL15)  (DUL-LL15)  (SAT-DUL)
                         mm         mm          mm         mm
       ---------------------------------------------------------
         0.-  150.      18.00      21.00       21.00      34.50
       150.-  300.      19.50      24.00       24.00      30.00
       300.-  450.      19.50      24.00       24.00      30.00
       450.-  600.      19.50      28.50       28.50      25.50
       600.-  750.      19.50      28.50       28.50      25.50
       750.-  900.      19.50      28.50       28.50      25.50
       ---------------------------------------------------------
            Totals     115.50     154.50      154.50     171.00
       ---------------------------------------------------------



            Initial Surface Organic Matter Data
       ----------------------------------------------------------------------
          Name    Type        Dry matter    C        N        P      Cover
Standing_fr
                               (kg/ha)   (kg/ha)  (kg/ha)  (kg/ha)  (0-1)     (0-
1)
       ----------------------------------------------------------------------
         maize     maize         1000.0    400.0      5.0      0.0    0.330     0.0
       ----------------------------------------------------------------------



                Effective Cover from Surface Materials =   0.3
```

```
------- Station_UniVenda Nitrogen Initialisation -----------------------------

     Soil Profile Properties
     ---------------------------------------------------------
          Layer    pH     OC     NO3      NH4     Urea
                         (%)  (kg/ha)  (kg/ha)  (kg/ha)
     ---------------------------------------------------------
            1     5.70   1.23    0.16     0.16     0.00
            2     5.50   1.00    0.18     0.18     0.00
            3     5.40   0.40    0.18     0.18     0.00
            4     5.30   0.40    0.18     0.18     0.00
            5     5.30   0.40    0.18     0.18     0.00
            6     5.30   0.40    0.18     0.18     0.00
     ---------------------------------------------------------
          Totals                 1.06     1.06     0.00
     ---------------------------------------------------------
```

Appendix D: Dzwerani Site Biomass production 2005/2006

Tests of Between-Subjets Effects

Dependent Variable: Bio1

Source	df	F	Sig
Corrected Model	3	2.489	0.135
Intercept	1	47.148	0.000
Treatcomb	3	2.489	0.135
Error	8		
Total	12		
Corrected Total	11		

a. R Squared = 0.483(Adjusted R Square =0.289)

Tests of Between-Subjets Effects

Dependent Variable: Bio2

Source	df	F	Sig
Corrected Model	3	0.693	0.582
Intercept	1	40.371	0.000
Treatcomb	3	0.693	0.582
Error	8		
Total	12		
Corrected Total	11		

a. R Squared = 0.206(Adjusted R Square =-0.92)

Appendix E: Univen site Biomass production season 2005/2006

Tests of Between-Subjets Effects

Dependent Variable: Bio1

Source	df	F	Sig
Corrected Model	3	4.520	0.039
Intercept	1	34.782	0.000
Treatcomb	3	4.520	0.039
Error	8		
Total	12		
Corrected Total	11		

a. R Squared = 0.629 (0.490)

Tests of Between-Subjets Effects

Dependent Variable: Bio2

Source	df	F	Sig
Corrected Model	3	1.238	0.358
Intercept	1	114.863	0.000
Treatcomb	3	1.238	0.358
Error	8		
Total	12		
Corrected Total	11		

a. R Squared = 0.317 (0.061)

Dependent Variable: Bio3 Tests of Between-Subjets Effects

Source	df	F	Sig
Corrected Model	3	1.197	0.371
Intercept	1	79.186	0.000
Treatcomb	3	1.197	0.371
Error	8		
Total	12		
Corrected Total	11		

a. R Squared = 0.310 (Adjusted R Square =0.051)

Appendix F: Univen site Grain Yield production season 2005/2006

Tests of Between-Subjects Effect

Dependent Variable: Grain Yield

Source	df	F	Sig
Corrected Model	3	2.185	0.168
Intercept	1	28.454	0.001
Treatcomb	3	2.185	0.168
Error	8		
Total	12		
Corrected Total	11		

a. R Squared = 0.450 (Adjusted R Square = 0.244)

Appendix G: Univen site Biomass production season 2006/2007

Tests of Between-Subjects Effect

Dependent Variable: Bio 1

Source	df	F	Sig
Corrected Model	5	13.878	0.000
Intercept	1	847.111	0.000
Treatcomb	5	13.878	0.000
Error	12		
Total	18		
Corrected Total	17		

a. R Squared = 0.853 (Adjusted R Square = 0.791)

Tests of Between-Subjects Effect

Dependent Variable: Bio2

Source	df	F	Sig
Corrected Model	5	1.788	0.190
Intercept	1	929.269	0.000
Treatcomb	5	1.788	0.190
Error	12		
Total	18		
Corrected Total	17		

a. R Squared = 0.427 (Adjusted R Square = 0.188)

Tests of Between-Subjects Effect

Dependent Variable: Bio3.

Source	df	F	Sig
Corrected Model	5	0.385	0.850
Intercept	1	21.118	0.001
Treatcomb	5	0.385	0.850
Error	12		
Total	18		
Corrected Total	17		

a. R Squared = 0.138 (Adjusted R Square = -0.221)

Appendix H: Univen site Grain Yield production season 2006/2007

Tests of Between-Subjects Effect

Dependent Variable: Grain Yield

Source	df	F	Sig
Corrected Model	5	0.165	0.971
Intercept	1	105.537	0.000
Treatcomb	5	0.165	0.971
Error	12		
Total	18		
Corrected Total	17		

a. R Squared = 0.064 (Adjusted R Square = -0.325)