THE PERFORMANCE OF MAIZE (*ZEA MAYS L.*) CULTIVARS UNDER DIFFERENT FERTILIZER RATES AND SOIL TYPES IN TWO AGRO-ECOLOGICAL ZONES IN SWAZILAND.

BY

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DECLARATION

I, George Mqoshwa Ndlangamandla hereby declare that the work presented in this dissertation was my own and has never been submitted for a degree at this or any other university

Signature ______________________

Date 26/01/98

APPROVAL

This thesis of Mr. GEORGE MQOSHWA NDLANGAMANDLA is approved as fulfilling part of the requirements of the award of the degree of Master of Science in Agronomy (Crop Science) by the University of Zambia.

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ABSTRACT

A blanket fertilizer recommendation is used for each agro-ecological zone in Swaziland irrespective of soil type and maize genotype. The objective of the study was to determine the response of grain yield and some yield components of maize cultivars to fertilizer rates applied to different soils in the Highveld and Middleveld agro-ecological zones of the country. Four sites with different soil types were selected. The soils differed in texture, cation exchange capacity, pH, organic matter content and in the content of N, P, K and Ca.

A split-plot design was used with fertilizer rate as the main plot factor and maize cultivar as the sub-plot factor. Four fertilizer rates were used, i.e., 0, 200, 400 and 600 kg ha^{-1} of compound fertilizer 2:3:2 (22) and a top-dressing of 45 kg N ha^{-1} with L.A.N.(28% N). The top-dressing was not applied to the 0 kg ha^{-1} rate. Five maize cultivars were used, i.e., R 201; RO 413 and SSM 2039; PAN 6479 and PHB 3427, chosen according to their maturity periods from early to late. The parameters measured were grain yield, canopy height, canopy width, harvest index and N, P and K concentrations in the leaves and grain.

The harvest index (HI), plant canopy height and canopy width each differed ($P \leq 0.01$) between the sites. The canopy heights for Dwalile, Hawane (Highveld), Mbelebeleni and Mdayane (Middleveld) were 129.6, 205.4, 159.1 and 178.7 cm, the canopy widths were 77.6, 116.0, 114.5 and 112.6 cm while the HIs were 54.4, 36.9, 42.4 and 47.0%, respectively for the sites. The maize cultivars also differed ($P \leq 0.01$) in the HI, canopy width and height. The cultivars PHB 3427 and R 201 had higher and wider canopies across the sites. Each of the parameters differed significantly between the fertilizer rates and tended to increase as fertilizer rate increased. The cultivars PAN 6479, PHB 3427, R 201, RO 413 and SSM 2039 had canopy heights of 166.6, 191.9, 180.0, 145.7 and 156.9 cm, respectively. The canopy widths were 99.3, 110.2, 108.5, 103.9 and 103.9 cm while the HIs were 43.2, 47.9, 49.0, 43.7 and 42.0%, respectively. The [N], [P] and [K] in the grain and leaf differed ($P \leq 0.01$) between sites, fertilizer rates and the maize cultivars. The grain [N] and leaf [N] were

higher at Dwalile and Hawane but lower at Mbelebeleni. Grain [P] and leaf [P] were lower at Dwalile and Mbelebeleni, respectively whereas they were higher at Mbelebeleni and Dwalile respectively. Grain [K] was higher at Hawane but lower at Dwalile and Mbelebeleni whereas leaf [K] was higher at Mbelebeleni but lower at the other sites.

The average grain yields of 2.36, 2.74, 3.34 and 3.23 mt ha^{-1} for Dwalile, Hawane, Mbelebeleni and Mdayane, respectively, were different ($P \leq 0.01$). This was a reflection of the differences in the respective sites with respect to soil type, residual fertility and climate. The yields differed between the fertilizer rates per site ($P \leq 0.01$)but increased with fertilizer rate. The average yields across the sites were 1.38, 2.46, 3.52 and 4.32 mt ha^{-1} for the 0, 200/150, 400/150 and 600/150 kg ha^{-1} rates of fertilizer, respectively. The cultivar R 201 gave a higher ($P \leq 0.05$) yield at Mdayane than at the other sites, showing that some cultivars were affected by sites.

From the results it can be concluded that the grain yield response was optimum at the 400 kg ha^{-1} rate of fertilizer irrespective of cultivar as observed at Dwalile, Mbelebeleni and Mdayane. Some cultivars can be tentatively recommended for some specific sites as the results showed that the cultivar R 201 performed better ($P \leq 0.05$) at Mdayane compared to the other sites.

DEDICATION

I dedicate this work to my wife Primrose and my only sons Ndumiso and Ncamiso for their moral support during the course of the study and for the many months I was away from them. My final dedication goes to my mother Elizabeth, because without her my academic career would not have been possible. She was the one who ensured that I, my brothers and sisters received as much education as would be possible. To her I say long live old lady!

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

APPENDICES

CHAPTER I

INTRODUCTION

Maize (*Zea mays L.*) is the staple food crop in Swaziland and it is grown in all the four agro-ecological zones, i.e., Highveld, Middleveld, Lowveld and Lubombo Plateau. In these zones, most of the arable land is planted to maize with the exception of the Lowveld, which is not suitable for maize. The crop is predominantly grown as a household staple food by small scale farmers who sell some of it if they have produced a surplus. Commercial production of the crop is done mainly by large scale farmers.

The highest production of the crop is in the Highveld and Middleveld zones where annual rainfall amounts and distribution are fair to good and temperatures are most favourable. The Highveld lies between 910 and 1830 meters above sea level and receives an annual rainfall of 1020 to 2285 mm (Central Statistics Office (CSO), 1996). It is found in the western part of the country. The Middleveld lies between 330 and 1070 meters above sea level and receives an annual rainfall of between 760 and 1190 mm. It lies east of the Highveld and west of the Lowveld. The Lubombo Plateau is in the eastern part of the country. It lies between 270 and 820 meters above sea level and receives between 635 and 1060 mm of rainfall annually. The Lowveld has an altitude of 60 to 730 metres above sea level and receives between 510 and 890 mm rainfall annually. It is west of the Lubombo Plateau. This zone has a very erratic rainfall distribution and intensity and maize will succeed in one out of five years (Murdoch, 1970). It is therefore, not suitable for dryland maize production but small-scale farmers plant continue to grow the crop.

Maize is planted on approximately 65000 to 85000 hectares in the four agro-ecological zones, with an annual production of between 75000 and 110000 metric tonnes during years with average to good rainfall, respectively (CSO, 1996). The national average yield per hectare is very low, at about 1.5 mt ha^{-1} (CSO, 1991) compared to more than 8.0 mt ha^{-1} from research trials (Agricultural Research Division (ARD), 1994). The main maize producing zones, the Highveld and Middleveld, have a potential of producing over 8.0 mt ha^{-1} due to the favourable combination of climate and soil types prevailing in these zones (Ministry of Agriculture and Cooperatives (MOAC), 1977; 1991). However, their average yield is only about 3.0 mt ha^{-1} (CSO, 1991) and has remained static for some time despite the many technologies developed by the ARD.

The wide gap between the actual and potential yield is due to many factors, including low or no fertilizer application, improper selection of suitable cultivars and inappropriate cultural practices under farmers' condition. Fertilizers costs are very high, such that most small-scale farmers can not afford to buy them with their financial resources (Blackie, 1995; Sallah *et al.*, 1996; ARD, 1993).

In an effort to improve yields, the research division of the MOAC has evaluated over 15 maize cultivars (Appendix 2) and as a result 90% of the maize seed used by farmers is hybrid seed (Pali-Shikhulu and Ndhlangamandla, 1995). The cultivars are meant to allow small scale farmers to a wide choice depending on agro-ecological zone, time of planting and the amount of rainfall expected. Cultivars differ in maturity (early, medium and late maturing) as well as in drought and disease tolerance. For example, cultivar TX 379 is well known for its maize streak virus tolerance while cultivars such as R 201 and CG 4141 have been selected for their earliness and drought tolerance. The cultivars PAN 6479, PAN 6549, SNK 2665, RO 413 and PAN 473 are known for their high yield potential (Pali-Shikhulu and Ndhlangamandla, 1995).

Apart from the issues of cultivar maturity and rainfall, there are different soil types within the agro-ecological zones. In this regard, a recent study funded by the Food and Agricultural Organization of the United Nations (Van Waverson *et al.*, 1993) revealed that the many soil types found in the country require different recommendations for crop production in order to maximize their potential. The study advocated for comprehensive overhaul of the present recommendations. The problem with this proposal is that people's habits and beliefs can not be changed over a short period of time. This calls for the introduction of acceptable modifications to the present cropping practices as opposed to an overhaul. The study also proposed that different soil types per agro-ecological zone should be planted to a crop that has a high yield potential at minimum risks. This idea may not be implemented over a short period of time since small-scale farmers in the Highveld and Middleveld grow maize predominantly. Only a small proportion of land is planted to other crops such as groundnuts (*Arachis hypogea L.*), cowpeas (*Vigna unguiculata* L.), Bambara groundnuts (*Vigna subterranea* (L.) Verdc) or beans (*Phaseolus vulgaris L.*) which are some of the crops the study has recommended. Technologies that lead to more benefits from maize production have a better chance of adoption.

Fertilizer recommendations also contribute to low maize yields. The current recommendations are not equitable with the resource capacity of small-scale farmers, just like in many of the SADC countries (Kumwenda *et al.*, 1996; Blackie, 1995; Lafitte and Edmeades, 1994). They are specific for each agro-ecological zone based on the intensity and distribution of rainfall and optimum yield. For the Middlveld and Highveld, 400 and 500 kg ha^{-1}, respectively, of compound fertilizer 2:3:2 (22) are recommended for maize production irrespective of the soil type and fertility status, expected yield and the selected cultivar. Very few small-scale farmers apply these recommended amounts. The fertilizer recommendations do not take into account the effect of soil types predominant in each agro-ecological zone. The different soil types may result in differing responses by some cultivars even within a single fertilizer rate. Cultivars that produce high yields with limited fertilizer application can better address soil fertility problems faced by developing nations (Botha *et al.*, 1973; Muruli and Paulsen, 1981; Moll *et al.*, 1987).

Fertilizer recommendations may be based on the soil fertility status of some specific soils and the response of some maize cultivars per fertilizer rate. The fertilizer application rates, if developed, can be adopted to suit farmers' economic situation and the possible yield potential without enhancing soil nutrient mining. Different soils are endowed with different physical and chemical properties which make them superior or inferior to other soils within a given locality as found in Swaziland by Murdoch (1970) and Van Waverson *et al.*(1993). Similarly, some maize cultivars are known to respond differently to different soil types as observed by soil scientists such as Harvey (1939); Hurd (1968); Murdoch (1970); Tisdale *et al.* (1985); Kumwenda *et al.* (1996); Hikwa *et al.* (1997).

There is, therefore, a need to assess existing and promising germplasm for adaptability to different nutrient levels where possible, and also assess the nutrient use efficiency of each cultivar based on the soil parameters and fertilizer rates. At the moment, there is very little work in Swaziland to assess the response of maize cultivars to different soil types and fertilizer rates (P.D. Mkhatshwa, and Edgar Nxumalo, 1995, personal communication).

The main objective of the study, therefore, was to determine the response of grain yield and yield components of five maize cultivars to fertilizer rates applied to different soil types in the Highveld and Middleveld agro-ecological zones of Swaziland.

CHAPTER II

LITERATURE REVIEW

2.1 Fertilizer Recommendations

Fertilizer recommendations should aim at providing maximum financial returns or a desired level of yield (Cooke, 1967). The desired yield can be either intentional or coincidental such as in the case of small-scale farmers and some commercial farmers as well. Therefore, a generalized recommendation may not be acceptable, especially for the small-scale farmer who does not aim for maximum yield attainable at high rates of fertilizer (Kumwenda *et al.*, 1996). Generalized fertilizer recommendations can be avoided by developing fertilizer curves which relate fertilizer rates to crop yields (Cooke, 1967). There are no such curves in Swaziland. Presently, it is not known how much fertilizer a farmer should apply if the aim is to obtain 2.0 or 3.0 mt ha^{-1}. Each country or region may need to develop its own fertilizer recommendations, since responses measured for a crop, may vary due to soil type and climate (Cooke, 1967). Cooke (1982) further argues that such fertilizer recommendations should in addition to accounting for a crop, soil type and climate, also fit into the local farming systems and the economic conditions that farmers face. The author further points out that maximum yields are in many cases established as targets while endeavouring to raise yields nearer to such levels.

Cooke (1967) observed that in order to find out how much fertilizer to apply to a crop, one should use field experiment results that show the quantities of crop yields obtained from each successive addition of fertilizer dressing. The author notes that these results will differ with soil type, crop, cultivar, season and previous use of the land. The final recommendations should account for either poor or fertile soils. On fertile soils, a general fertilizer recommendation may lead to waste of fertilizer and/or an economic loss to a farmer. Excessive application of fertilizer is an environmental hazard due to leaching of unused nutrients like nitrate into ground water.

Blanket fertilizer recommendations used in Swaziland do not correspond to the soil types and the responses of maize cultivars under different soil types within an agro-ecological zone (Jones and Wendt, 1995; Anderson, 1987; Robertson *et al.*, 1965). Jones and Wendt (1995) noted that blanket fertilizer recommendations for hybrid maize fail to differentiate between different maize growing ecologies, soil types and socio-economic circumstances of a farmers in an environment. Kumwenda *et al.* (1996) observed that in the Eastern and Southern Africa region, fertilizer recommendations often ignore the soil and climatic variations in the areas farmed by small-scale farmers and they are also not compatible with the farmers resources. Jones and Wendt (1995) have observed that blanket fertilizer rates have their short comings. They fail to account for the nutrients status of a soil and may add a nutrients that is not necessary for increased productivity.

In Swaziland the recommended compound fertilizers and a nitrogen top-dressing fertilizer may lead to excessive application of a rather optimally available nutrient in the soil (MOAC, 1977). Studies that can detect abnormal responses to some of the nutrient elements contained in the recommended fertilizers can be used to reduce or eliminate the application of a least required nutrient contained by a compound fertilizer currently being recommended, if further verfied.

In Zambia fertilizer recommendations are based on the response of maize varieties in a specific locality (Mwale, 1988). Some soils are well supplied with K while others are not. A response to K was not obtained in the Kalahari sandy soils of the Western and Northwestern Provinces and thus compound R (20:20:0 of N:P:K) was recommended. The Zambia Seed Company bases fertilizer recommendations on the relative fertility status of the soil (low, medium and high) (Zamseed, 1993). Fertilizer recommendations in Zimbabwe are area specific, based on the soil fertility status. However, these have not been reviewed for sometime although soil fertility is known to be dynamic in time and space (Jones and Wendt, 1995).

In Swaziland, Seubert (1988) observed that fertilizer recommendations were not based on soil type, and he suggested that they be reviewed. The author proposed a tentative basal fertilizer recommendation guide for low input maize production which did not consider the response of maize cultivars to such fertilizer rates in different soil types of an agro-ecological zone. In a socio-economic study by the ARD (1988) in Swaziland, it was observed that farmers do recognize the different soils occurring in their fields and that such differences have an impact on maize yields. However the study did not investigate if such farmers also observed any differences in the response of maize cultivars on these different soils.

2.2 **Soil Characteristics.**

Swaziland has been divided into 32 soil sets (Murdoch, 1970). Nineteen sets are found in the Highveld and the Middleveld. The soil sets of a country provide a basis for assessing the land capability because their differences impact directly or indirectly on the farming activities of an area (Murdoch, 1970). Direct effects are caused by the effective soil depth, texture, structure, consistency and other profile characteristics. Indirect attributes important for crop production are soil permeability and the general productivity of a soil type (Murdoch, 1970; Russell, 1973).

Soil characteristics have a profound effect on crop growth as the soil is the reservoir of moisture and nutrients. For the optimum growth of a plant the soil environment must be conducive to its requirements. Russell (1973) and Tisdale *et al.* (1985) confirmed that soil characteristics have a pronounced influence on the depth of root penetration and soils with a compact B horizon are highly restrictive to root penetration. The lithosol soils in Swaziland are shallow and very restrictive to root penetration of the B horizon due to the presence of a stoneline or sometimes a hard rock within 15 to 40 cm from the surface (Murdoch, 1970). Maize will do best if the effective depth of a soil is at least 60 cm (Murdoch, 1970; Donahue *et al.*, 1983).

Effects of soil sets on crop yield are caused by soil bulk density, organic matter content, acidity, plant nutrient content and oxygen supply (Baver *et al.*, 1972; Hamblin, 1985; and Russell, 1973). In Swaziland, the ferralitic soils at Dwalile are low in humus (1.87%) and are acidic (pH4.5) whereas kaolisols at Mdayane and elsewhere are high in humus and have good drainage. On the other hand lithosols found at Mbelebeleni are low in humus, are light and occasionally medium in texture with a rapid drainage (Murdoch, 1970). Schenk and Barber (1979) made similar observations elsewhere. Soils being so diverse and heterogeneous must be treated according to their merit and their effect on each crop species or cultivar where different responses have been established (De Willigen and Van Noordwijk, 1987; Lian, 1986).

The study by Murdoch (1970) on Swaziland soil sets, land capability and suitability for maize production and other crops that can be alternated with it (beans, groundnuts, sorghum and tobacco) revealed that suitable soils for maize should be of a medium texture, good to moderate permeability and should have a rooting depth of at least 60 cm. Such soils are not available to every farmer. Again not all maize cultivars are likely to respond homogeneously to every soil condition and soil type. Schenk and Barber (1979) observed that the dry matter content of maize roots and shoots grown in six different soil types varied considerably. Lower yields were associated with phosphorus (P) deficiency in a Chalmers soil which was low in P content and release. However, the team also observed that the yield variation in soils could not be related to P deficiency alone but also to the differences in soil physical conditions.

Oikeh *et al.* (1996), Patterson and Mackintosh (1976) and Robertson *et al.* (1965) noted that maize cultivars may respond differently to varying soil conditions. They indicated that it was essential to assess, quantify and qualify the extent of the differences in cultivar responses that occur. Generalizations can then be made about maize recommendation domains based on soil type and conditions under different fertilizer rates.

2.3 Cultivar Characteristics

A cultivar of the same species may yield better than another under similar conditions due to its inherent genetic attributes (Harvey, 1939; Pollmer *et al.*, 1979). Arnon (1972) and Harvey (1939) observed that there are considerable differences between and within plant species in their ability to take up mineral nutrients from the soil. Kumwenda *et al.* (1996) found that some high yielding maize cultivars tend to give higher yields with no added fertilizer than poor yielders. This may be due to the efficiency with which cultivars use the limited soil available nutrients (Veen *et al.*, 1992; Sallah *et al.*, 1996).

A study by Nielsen *et al.* (1978) showed that single crosses of maize grown on high P level soils had P concentrations that differed significantly. These crosses also differed in P utilization for dry matter production and/or root parameters important for P uptake. The authors argued that although their results did not indicate a cause and effect relationship, they indicated a possible relationship between maize root P uptake parameters and P nutrition. Arnon (1972) in another study, found that this was due to differences in the root system of some cultivars. The author, also stated that species or cultivars which have a higher cation exchange capacity in their roots take up more nutrients such as phosphorus from the soil. There are few research studies that have been conducted in Swaziland to assess the efficiency with which some maize cultivars take up nutrients from the soil.

The ability of one cultivar to mobilize nutrients from the soil better than another is exhibited by most gramineae species in iron deficient soils (Marschner, 1990; Zhang *et al.*, 1991). Some maize cultivars exude phytosiderophores which reduce Fe^{3+} into Fe^{2+} in the soil (Lytle *et al.*, 1991). These nonproteinogenic substances mobilize other micro-nutrients like zinc, manganese and copper (Mengel and Barber, 1974; Zhang *et al.,* 1991; Marschner, 1990; Moll *et al.*, 1982).

Srivastava (1970), Van Noordwijk *et al.*(1992), Hurd (1968) and Mengel and Kirkby (1987) stated that nutrient uptake from the soil is a function of the plant's root volume and the nutrient concentration in the soil solution as well as the soil-root contact effect. Tisdale *et al.* (1985) found that temperature, cultivar and tillage practices also affect nutrient uptake from the soil. The rate of nutrient uptake is enhanced by the efficiency of a cultivar. Maize cultivars which are efficient in nutrient uptake will yield higher under nutrient limited soil conditions. Hurd (1968) demonstrated this mechanism of different nutrient uptake by crops using seven wheat cultivars in two different soil types (clay and loam soils). Some wheat cultivars yielded higher in one type of soil than in another. Similar work undertaken by other researchers on other crops (i.e. maize and Irish potatoes) and soils show similar results (Veen *et al.,* 1992; Kooistra *et al.*, 1992; Geisler and Krutzfeldt, 1983).

Another attribute which renders one cultivar superior to others under similar conditions, is its ability to optimize the use of absorbed nutrients in meeting its metabolic functions such as dry matter accumulation (Chan-Seng, 1990). The ability of the plant to optimize the use of nutrients in enhanced by its photosynthetic efficiency under sub-optimal conditions (Patterson and Mackintosh, 1976).

2.4 Plant Canopy Height and Canopy Width.

There is a genetically determined upper limit to the size of a leaf for any crop species when growing conditions are favourable. Ontogeny and environmental factors like temperature, soil moisture, irradiance and nutrient supply control the leaf size (Kirkby *et al.*,1982). Nitrogen nutrition increases the size and duration of the canopy which leads to increased dry matter accumulation (Hay and Walker, 1989). Nitrogen affects the rate of leaf expansion and its final size (Milthorpe and Moorby, 1979). Crops like wheat, oats or maize which receive adequate fertilization usually have a larger leaf size (Milthorpe and Moorby (1979). Spiertz and Ellen (1978) observed an increase of canopy height and leaf spread when N fertilizer was increased from 50 kg ha^{-1} to 100 kg ha^{-1}. The utilization of N is enhanced if the supply of other nutrients is optimum (Stoskopf, 1981). Nutrients availability from a soil is dependent on supply, the soil reaction and its properties. Mineral deficiencies like P and K reduce leaf size even when N supply is adequate (Stoskopf, 1981; Hay and Walker, 1989).

When P is deficient in the soil, plant growth is retarded (Marschner, 1990). The growth of shoots and roots is restricted. The leaves are small and together with the stems become purplish, thus reducing the photosynthetic capacity of the crop. Purpling is enhanced by the formation of anthocyanin. Most soils in the Middleveld and Highveld agro-ecological zones of Swaziland are acidic and are thus P deficient for optimum crop growth.

Potassium is needed for cell division, growth and along with calcium, it is a neutralizing agent for organic acids (Marschner, 1990; Mengel and Kirkby, 1987). It is needed for osmoregulation and for the efficient synthesis of carbohydrates. It plays a role in the formation of sugars and starch as well as the transportation of these products. When K is deficient, shoot and root growth are restricted. K deficiency in the Highveld and Middleveld is aggravated by a higher incidence of rainfall (CSO, 1991) and low soil pH and its deficiency has been found in sandy soils.

2.5 Harvest Index

The harvest index (HI) is affected by environmental conditions which affect the crop during its development (Stoskopf, 1981). The index may be affected by soil moisture, nutrient supply, genotype and temperatures. Moisture stress at grain filling stage reduces the individual grain weights, thus reducing the harvest index (Hay and Walker, 1989). An environmental stress such as soil moisture at the early growth stage will reduce stover weight and the index increases as most photosynthates will be transported to the grain (Snyder and Carlson, 1984). The Highveld has a higher incidence of rainfall while the Middleveld has warmer temperatures and thus the HI of a maize genotype may differ between the two agro-ecological zones.

High nutrition, especially of N, tends to favour stover production at the expense of grain in cereals (Singh and Stoskopf, 1971). High stover production results in the shading of the ear, causing delayed silk development, leading to poor pollination (Stoskopf, 1981). The application of optimum N to cereals promotes vegetative growth which tends to be excessive under adequate soil moisture regimes, resulting in a reduced harvest index (Stoskopf, 1981). There are limited cases of high N nutrition in maize production in Swaziland and thus the HI of a maize cultivar is likely to respond to different levels of N application. The amount of residual N is related to the organic matter content of a soil. Soils with a high organic matter content such as the kaolisols in Swaziland are likely to have more N for crop uptake, thus affecting the HI.

Tesar (1988) found that crops with a favourable distribution of biological and economic yields will tend to maintain minimal variation in their HI over a wide range of environments. This characteristic of some cultivars indicates that partitioning of dry matter does not favour stover production at the expense of grain in the case of cereal crops. The effects of soil type are indirect as they affect root penetration, nutrient availability and soil moisture supply.

Fertilizer rates have been reported to affect the harvest indices of cereals. Spiertz and Ellen (1978) found that the HI of wheat increased from 0.40 to 0.44 when N fertilizer was increased from 50 kg ha^{-1} to 100 kg ha^{-1} while Pearman et al. (1978) found that it decreased with increasing N application. At 0 N the HI was 0.49 whereas at 210 kg N it was 0.46. Downes (1988) found similar responses of the HI to increasing soil fertility under some environments.

2.6 Leaf and Grain Concentration of N, P and K.

The analysis of plant materials to evaluate and to help in explaining some crop responses to some fertilizer application rates under some conditions have been carried out for many years. It is now an acceptable norm that the composition of elements in the plant tissue is a more sensitive indicator of crop response to environmental changes although it may be difficult to interpret (Melsted *et al.*, 1969).

In evaluating plant tissue concentration or contents of some key elements of interest, it should be realized that several variables are usually acting on the results that may be observed (Martin-Prevel *et al.*, 1984). These variables may be unknown or cannot be definitely evaluated by the interpreter. Some of these variables are crop cultivar, soil type, season, crop management and fertilizer treatment. In most cases, the objective of plant tissue analyses is to assess a soil or fertilizer and crop management practices (Melsted *et al.*, 1969). Melsted *et al.* (1969) confirmed that even if treatments may be the same, if the soil type, season and variety are different, the N, P and K concentrations of a plant tissue will differ between locations and within varieties. Tsai *et al.*(1984) evaluated the deposition of N in plant tissue of three maize cultivars in relation to maize grain yield. They observed that some maize cultivars differed in their accumulation of N depending on N fertilization. They found that the N concentration of one cultivar, B73 x Mo17 increased with increasing N fertilization whereas the N concentration in tissues of Pioneer 3732 remained the same even at higher N fertilization.

Chancy and Kamprath (1982) observed that sandy soils affect the content of N in leaves and grain. They found that under less precipitation, more N was recovered by the grain and leaves and yet under high precipitation less N was recovered due to loss of N by leaching except where they had applied nitrapyrin (a nitrification inhibitor) with urea. The N concentration of the maize leaves increased with increasing fertilizer rates applied to three soils, but the differences were statistically significant only with nitrapyrin. The study also showed that N additions should take into account soil reserves of N as they contribute to uptake during the growing season.

Hanway (1962ab) observed that nutrient deficiencies resulted in greater differences in total percentages of N, P and K in maize leaves and leaf sheaths than in any other part of the plant. The differences were found to be persistent throughout the season although N and P differences were less early in the season than the latter part. The study also showed that %N, %P and %K decreased gradually throughout the season. The decline was caused by the increased demand at the grain filling stage. The decline was more severe in the N deficient treatment. Rapidly increasing plant biomass results in dilution of the percent nutrients in most cases.

Schenk and Barber (1979) observed that soils with a low P buffering capicity tend to be P deficient for uptake by the growing crop. These soils rapidly release P into the soil solution and it is depleted before the plant attains maturity.

CHAPTER III

MATERIALS AND METHODS

The study was conducted in two of the four agro-ecological zones of Swaziland, i.e. the Highveld and Middleveld. Two sites representing different soil types were selected in each agro-ecological zone. All the sites were on farmers' fields, and the experiment was conducted under rainfed conditions for one season (1996/97).

3.1 Site Description

In the Highveld the selected sites were Dwalile and Hawane.

Dwalile: It is 10 km South of the Sandlane border post in the western border with South Africa. It is 1400 m above sea level. It was at Mr Philip Shabalala's farm. It had been continuously planted to maize for the previous three years with little basal fertilizer and no top-dressing. The average basal fertilizer rate applied per season was between 100 to 150 kg ha^{-1} of a compound fertilizer 2:3:2 (22) which contains N, P, K and Zn, compared to the recommended 500 kg ha^{-1} (MOAC, 1977).

The soil belongs to the QH-set, which is composed of a ferralitic soil, which is predominantly low in humus and has a high percentage of sand (Table 1) and is thus referred to as a Sandy Clay Loam (Murdoch, 1970). It is deep (120 cm) with no stoneline. The soil covers about 53200 ha in the Highveld and Middleveld. About 57% of the set occurs in areas with over 14% slopes.

Hawane: It is 25 km East of the Mbabane city. It is 1380 m above sea level. It was at Mrs Jeanerah Motsa's farm. Prior to the study, the site had been continuously planted to maize over the same period as Dwalile and had received a basal application of kraal manure in 1994 prior to planting. A basal inorganic fertilizer 2:3:2 (22) at the rate of 150 kg ha^{-1} was last applied in 1993, and it was less than the recommended amount of 500 kg ha^{-1}.

Its soil belongs to the NH-set which consists of a ferralitic soil having a silty loam texture. The soil is yellow or reddish orange, with a gradual colour change at 40 to 90 cm. It differs from that at Dwalile in that it has a thin quartz stoneline at a depth of 45 to 60 cm. The top-soil has a high humus content. It has a high proportion of clay (Table 1) with moderate to good drainage. The soil is found in areas with over 14% slopes where 62% of the set occurs. It covers about 40800 hectares of the Highveld and Middleveld agro-ecological zones.

In the Middleveld, the two sites selected for the study were Mdayane and Mbelebeleni. Mbelebeleni: The site is 45 km North-East of the Manzini city at Mr Elias Khumalo's farm, and it is 510 m above sea level. The site had been planted to maize for one season and was followed by two years of cotton (*Gossypium hirsutum*). The maize crop received 200 kg ha^{-1} of the basal fertilizer 2:3:2 (22) instead of 300 kg ha^{-1} whereas cotton was fertilized with 150 kg of 2:3:2 (22) ha^{-1} instead of 250 kg ha^{-1} as recommended. Both crops did not receive any top-dressing of N fertilizer. No kraal manure had been applied during the three years preceding the experiment.

The soil at the site belongs to the O-set which consists of a lithosol soil. It is very shallow (about 40 cm deep) with a light or occasional medium texture and it is Loamy Sand. The soil is low in humus and high in sand (Table 1) with very good drainage. It is weakly horizonated. It covers 94400 hectares of the soils found in the Middleveld and Highveld although much more occurs in the Middleveld agro-ecological zone (Murdoch, 1970).

Table 1: Soil chemical and physical properties of the different sites used in the study

Site	pH ($CaCl_2$)	Chemical Properties							Textural Properties (%)			Soil Texture
		N (%)	P (ppm)	K (cml kg^{-1})	Mg (cml kg^{-1}	Ca (cml kg^{-1})	CEC (cml kg^{-1})	O.M. (%)	Clay	Silt	Sand	
Dwalile (Highveld)	3.9	0.12	4.97	0.18	0.48	0.20	3.10	2.02	34.3	3.8	66.2	Sandy Clay Loam
Hawane (Highveld)	4.5	0.22	3.21	0.36	0.79	1.14	5.10	6.98	66.2	7.2	28.1	Clay Loam
Mbekelweni (Middleveld)	4.9	0.07	1.86	0.14	0.81	1.63	3.65	0.23	18.5	3.1	80.3	Sandy Loam
Mdayane (Middleveld)	4.7	0.14	2.87	0.13	1.96	2.54	8.80	4.10	55.8	5.7	43.0	Sandy Clay

CEC: Cation exchange capacity
O.M.: Organic matter content

Mdayane: The site is 30 km North-East of Manzini city at Mr Zachariah Mavundla's farm, and it is 870 m above sea level. It had been planted mainly to maize over the past three years but was planted to groundnuts (*Arachis hypogea* L.) during the 1994/95 cropping season. The groundnut crop did not receive any fertilizer dressing while maize received about 200 kg ha^{-1} of compound fertilizer 2:3:2 (22) at planting every season compared to the recommended 400 kg ha^{-1}. There was no top-dressing with N fertilizer. Kraal manure was not applied during the period but the crop stover was ploughed under soon after harvesting for two years prior to the experiment.

Its soil belongs to the M-set which consists of a deep red or orange kaolisol soil which is predominantly deep to a maximum of 300 cm. The soil has a comparative amount of sand and clay (Table 1). It has a sandy loam texture. The soil has a moderate to low humus content with good drainage. It has low or no weatherable minerals. It occupies 79200 hectares of soils in the Highveld and Middleveld and about 35% of this set occurs on slopes of over 14% (Murdoch, 1970).

3.2 Land preparation

All land preparation was done using a tractor plough prior to planting. Furrows for planting were opened using hand hoes at Hawane and Mdayane while at Dwalile and Mbelebeleni an ox-plough was used.

3.3 Experimental design

A split-plot design was used for the experiment. The fertilizer rates and cultivars constituted the main and sub-plots, respectively. Three replications were used at each location. There were four fertilizer rates and five maize cultivars. Each main plot measured 30 X 6 m and they were spaced 50 cm apart. The sub-plot was 6 X 5.4 m

3.4 Fertilizer Application

Four compound fertilizer (basal) rates and one straight nitrogen fertilizer (top-dressing) rate were used in the experiment. Table 2 shows the total of N, P and K applied when using the combination of the two fertilizer sources. The basal dressing was applied in the form of compound fertilizer 2:3:2 (22) at planting and the top-dressing was applied five weeks after planting (plants were 45 cm to 60 cm high) in the form of Limestone Ammonium Nitrate (L.A.N. 28% N) and was covered.

3.5 Maize cultivars

Five maize cultivars were used for the study. These were the short, medium and long duration genotypes with 125 to 135, 140 to 145 and 150 to 160 days to physiological maturity, respectively (Maturity is based on criteria used by the Replublic of South Africa). The selected cultivars were R 201 (short); RO 413 and SSM 2039 (medium) and PHB 3427 and PAN 6479 (late). These cultivars are recommended for planting in the two agro-ecological zones selected for the study (Appendix 1). All the cultivars are 3-way crosses.

3.6 Planting

The experiment was planted in December, 1996. The four sites were planted on different dates. The Hawane site was planted on the 5th while the Mdayane site was planted on the 6th. Both the Dwalile and the Mbelebeleni sites were planted on the 11th. Planting furrows were 90 cm apart and 5.0cm to 6.0 cm deep. Two seeds per station were sown along the furrow at 25 cm apart and covered with soil to a depth of 5 cm. A total of 6 rows were planted per sub-plot. The basal fertilizer was applied along the planting furrow according to the fertilizer rate for the main plot. It was then slightly covered with soil prior to planting the seeds. Plants were thinned to one per station one week after emergence to give a maize plant density of 44400 plants ha^{-1}.

Table 2: Application rate (kg ha^{-1}) of N, P and K using the compound fertilizer 2:3:2 (22) with zinc and the top-dressing fertilizer L.A.N. (28% N)

Fertilizer Rate (kg ha^{-1})	Basal Dressing (kg ha^{-1})			Top-dressing (kg ha^{-1})			Nutrient Totals (kg ha^{-1})		
	N	P	K	N	P	N	N	P	K
0/0[1]	0	0	0	0	0	0	0	0	0
200/160	13	19	13	42	0	0	55	19	13
400/160	22	38	26	42	0	0	64	38	26
600/160	39	57	39	42	0	0	81	57	39

[1]Number before the slash represents the compound fertilizer rate while the number after the slash represents the L.A.N (28% N) fertilizer top-dressing rate.

3.7 **Weeding**

Early weeding was carried out at all the sites. An ox-drawn cultivator was used to remove most weeds between the rows. This operation was followed by hand-hoeing to remove the remaining weeds between and within the rows at all the sites. The first weeding at all the sites was done three weeks after planting while the second weeding was done as and when weeds became a problem due to rainfall intensity. The second weeding was done early at Mbelebeleni, six weeks after planting. At Dwalile, Hawane and Mdayane the second weeding was done during the seventh week after planting.

3.8 **Pest control**

Pests and diseases were controlled as and when necessary. The stalk-borer (*Busseola* and *Chilo sp.*) was controlled using a spray of deltamethrin (decis) prepared with 2.0 ml of insecticide in 3.0 litres of water while the cutworm (*Agrotis sp.*) was controlled with sodium fluosilicate (10%) granules applied as a bait on the soil surface soon after planting. At Hawane, deltamethrin was used to spray against a late outbreak of cutworms two to three weeks after emergence at the rate of 2.0 ml/3.0 litres of water.

3.9 **Data Collection**

3.9.1 **Soil Physical and Chemical Properties**: These properties were taken after planting. The soil physical properties determined were percent silt, clay and sand (Piper, 1955), while the chemical properties were calcium (Ca), magnesium (Mg), phosphorus (P), potassium (K), (cation exchange capacity (CEC), pH and organic matter. The soil pH was determined in calcium chloride ($CaCl_2$).

3.9.1.1 **Soil Chemical Properties**

A) The total N in the soil samples was determined by the Kjeldahl procedure (Whelan, 1969).

B) The P content in the soil samples was determined using $NaHCO_3$ following the Olsen procedure with colour development in 30 minutes and readings taken at 650 nm on a colorimeter (Whelan, 1969).

C) Exchangeable K, Ca and Mg in the soil samples were determined by extraction with 1M ammonium acetate (NH_4AC) solution and the concentration of each ions was measured using the atomic absorption spectrophotometer (Whelan, 1969).

D) The organic matter content of the soil was determined by the Walkley-Black Method (Walkley, 1947).

3.9.1.2 **Soil Physical Properties**

The sand, silt and clay contents of the soils were determined by the hydrometer method (Piper, 1955).

3.9.2 **Canopy height and canopy width**

The canopy height was determined from the soil surface to the whorl of the flag leaf when the tassel had formed. Measurements were made on five randomly selected plants from a sub-plot. The canopy width was measured from the edges of two widest leaves per plant from the same five plants per sub-plot.

3.9.3 **Harvesting**

This was done when the black layer of the maize grain was fully developed in the cobs of the respective plots. Three cobs per sub-plot from the border rows were randomly observed by removing six grains from the centre of the cob. A Munsell colour chart was used to determine the colour change of the layer for two weeks at intervals of three days per week. When no colour change was observed the grain was assumed to be fully mature.

Four of the 6 rows were harvested while the remaining two outside rows were left as border rows. For the harvested rows, one meter at each end was left out as border plants. The total harvest plot area was therefore, 32.0 m^2.

3.9.4 **Grain yield**: This was corrected to 12.5% moisture content at full physiological maturity based on the development of the black layer in the grains (Ritchie, 1989). The yield of the net plot (32.0 m^2) was weighed before and after shelling and a grain sample from the net plot was weighed and dried in the oven for 72 hours at 100°C (Whelan, 1969). The dry weight of the sample was taken to determine the loss in moisture content. The loss in moisture content was used to calculate the dry weight of the net plot yield after the shelling percentage of 10 randomly selected cobs had been obtained to determine the moist grain weight. Then the grain dry weight was adjusted to 12.5% moisture content (Whelan, 1969).

Calculation: shelling % = (weight of shelled grain/weight of grain + rachis) X 100%.

Grain yield (moist) per plot = shelling % X unshelled plot yield.

Dry grain yield per plot = (grain moist weight X 100 - M.C.)/100 - 12.5)

(M.C. =moisture content)

3.9.5 Stover and rachis dry weight

This was taken from the net plot at full maturity. The stover was cut at ground level and weighed. The rachis weight was determined using the shelling percentage of 10 randomly selected cobs per net plot. A sample weight of the moist stover and rachis was put in the oven and dried to constant weight at 100°C. The weights of the stover, rachis and grain were used to calculate the harvest index (HI) of each treatment. The calculation of the stover and rachis dry weight was done using the same method for dry grain weight per plot.

3.9.6 N, P and K concentrations in the grain and leaves

The ear leaf samples were taken at 60 days after tasselling while the grain samples were taken at full physiological maturity. Phosphorus and K were determined by the wet digestion method. The leaves and grain were separately dried in the oven at 65°C for 48hrs according to the treatments. To obtain homogeneous samples, the samples were ground using a Wiley Mill, fitted with a 1.0 mm sieve. After grinding each sample the mill was cleaned to avoid cross contamination. The ground samples were kept in labelled and tightly wrapped paper bags.

For the determination of P and K, a gram of oven-dry and ground sample of plant tissue was first digested in 10 ml of concentrated HNO_3 at 250°C, then in 10 ml $HClO_4$ until the solution was clear. The solution was cooled and diluted to 100.0 ml with distilled water. The concentration of K was thereafter determined by the atomic absorption spectrophotometer after calibration of the instrument with standards. Phosphorus was determined in a single solution read at 882 nm on a spectrophotometer (Cottenie, *et al.*,1982).

To determine total N, a gram of oven-dried and ground sample of plant tissue was digested in

To determine total N, a gram of oven-dried and ground sample of plant tissue was digested in 7 ml of concentrated H_2SO_4-salicyclic acid mixture for 30 minutes after which 1.0g Na_2SO_3 was added. After 15 minutes 3 ml H_2SO_4 and 1.0g catalyst were added. This was done following the modified Kjedahl method (Cottenie *et.al*, 1982).

3.10 **Data Analysis Methods**

3.10.1 **Analysis of variance (ANOVA)**

The ANOVA was used to test for treatment effects on mean grain yields, canopy height, canopy width, harvest index and the percentage concentration of potassium, phosphorus and nitrogen in the grain and leaves. Depending on the treatment effect, the Duncan Multiple Range Test (DMRT) was employed to separate treatment means (Gomez and Gomez, 1984).

3.10.2. **Regression Analysis**

This analysis was used to establish the response of each cultivar to the four fertilizer rates and to identify which cultivar had the highest response (Goulen, 1952) at each fertilizer rate.

3.10.3 **Trend Analysis**

The analysis was used to determine the trend response of each cultivar across the fertilizer rates per site. The yield response curve of each cultivar would then be used to identify the response pattern of each cultivar with respect to others at low, high or across the fertilizer rates.

CHAPTER IV

RESULTS

4.1 **General**: At planting, soil moisture was adequate and thus emergence was fair to good at all the four sites. Gap-filling was not done. The stalkborer (*Busseola* and *Chilo* sp.) and cutworms (*Agrotis* sp.) were well controlled. The granules were applied as a bait after planting.

The rainfall amount and distribution was within the normal range during the course of the season (Appendices 3-5). At Hawane a total of 1160 mm of rainfall was received, which was within the range for the Highveld. There was no rain gauge at Dwalile but since the rainfall during the season did not result in a moisture deficit in the Highveld (Appendix 3), it can be assumed to have been adequate at this site. The rainfall amounts recorded at Mdayane and Mbelebeleni were 910 and 1029 mm, respectively. The amounts for the two sites were therefore, within the annual rainfall range for the agro-ecological zone.

The temperature data was available from only two meteorological stations (Appendices 5-9). Temperature data from Mbabane (1182 m) was used for the Highveld while the data from Matsapha (646 m) was used for the Middleveld. Each station is centrally situated in the respective agro-ecological zones and it is within the normal altitude range of each zone.

4.2 Plant canopy height

Fertilizer rate affected ($P \leq 0.01$) the plant canopy height of the maize cultivars at all the sites. The canopy height of each maize cultivar increased as the fertilizer rate increased. The maize cultivars also differed ($P \leq 0.01$) in plant canopy height at each site (Figure 1) irrespective of fertilizer rate.

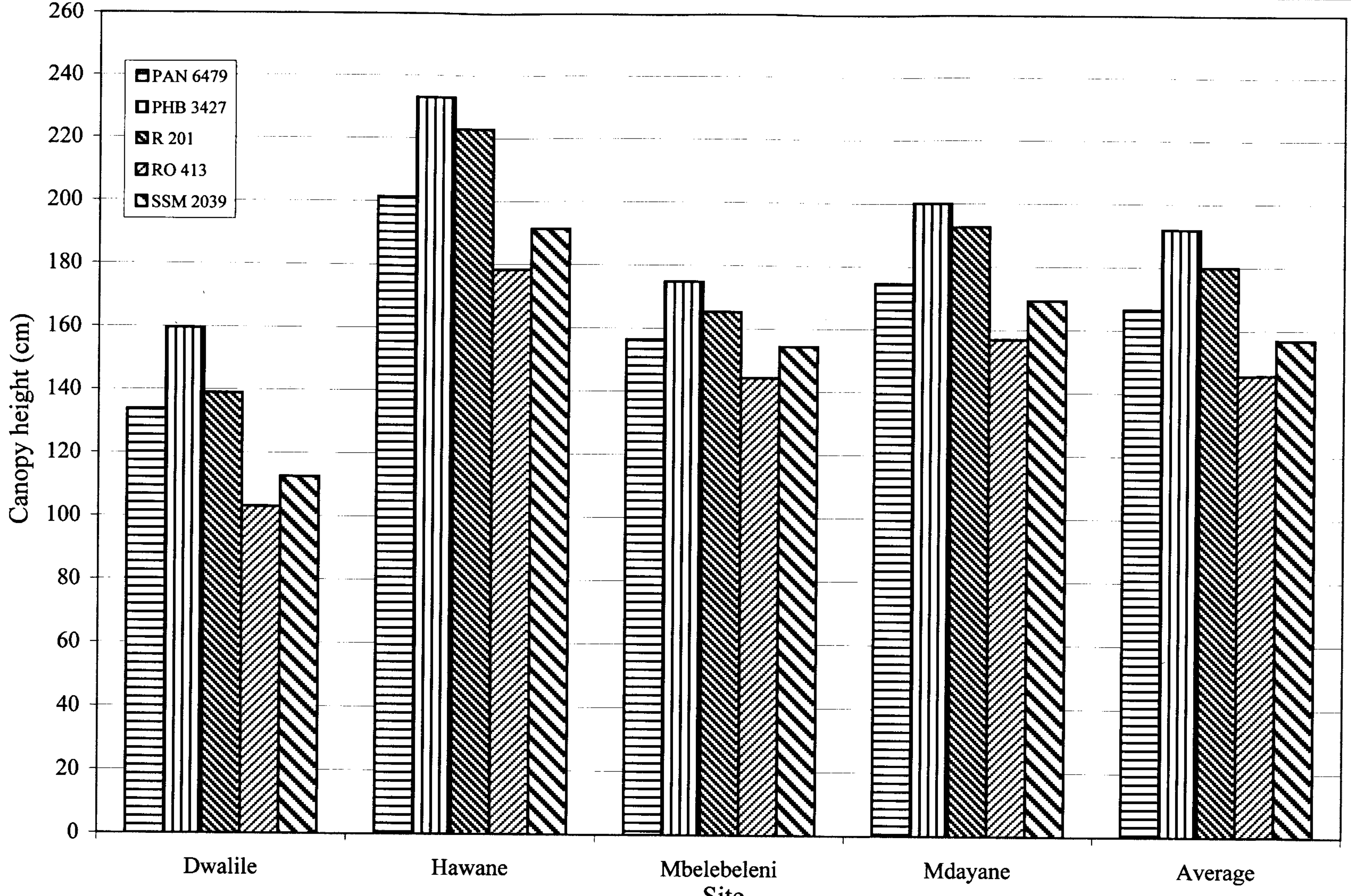

Figure 1: Canopy heights (cm) of five maize cultivar per site and across sites averaged over four fertilizer rates

Across the sites, the canopy height was affected ($P \leq 0.01$) by fertilizer rate and cultivar. The average canopy height with 0/0 kg ha^{-1} rate of fertilizer was the lowest (143.9 cm) while with the 600/160 kg ha^{-1} rate it was 182.9 cm. The canopy heights (170.3 and 175.8 cm) with the 200/160 and 400/160 kg ha^{-1} rates were not significantly different. With respect to cultivar effect ($P \leq 0.01$), PHB 3427 had the tallest canopy of 191.9 cm while RO 413 had the shortest canopy height of 145.8 cm (Figure 1). The average canopy heights of the maize cultivars were statistically different.

The effect of site on the canopy height of the maize cultivars was also significant ($P \leq 0.01$) (Figure 1). Hawane had the tallest average plant canopy height (205.4 cm) while the canopy heights for Mbelebeleni, Mdayane and Dwalile were 159.1, 178.7 and 129.6 cm, respectively and were significantly different. The interaction between site and cultivar was significant ($P \leq 0.05$), showing that some cultivars grew taller at some sites while others performed poorly with respect to canopy height.

4.3 Plant canopy width

The canopy widths of the maize cultivars were affected by fertilizer rate at Dwalile ($P \leq 0.05$) and Mbelebeleni ($P \leq 0.01$). At these sites the canopy widths were significantly narrower with the 0/0 kg ha^{-1} rate of fertilizer whereas at 200/160 kg, 400/160 and 600/160 kg ha^{-1} they were statistically similar. Fertilizer rate affected ($P \leq 0.01$) plant canopy width across the sites (Figure 2). The 0 kg ha^{-1} rate had the lowest canopy (93.6 cm) whereas the canopy widths for the other rates of fertilizer (107.9, 108.3 and 110.9 cm, respectively) were not statistically different.

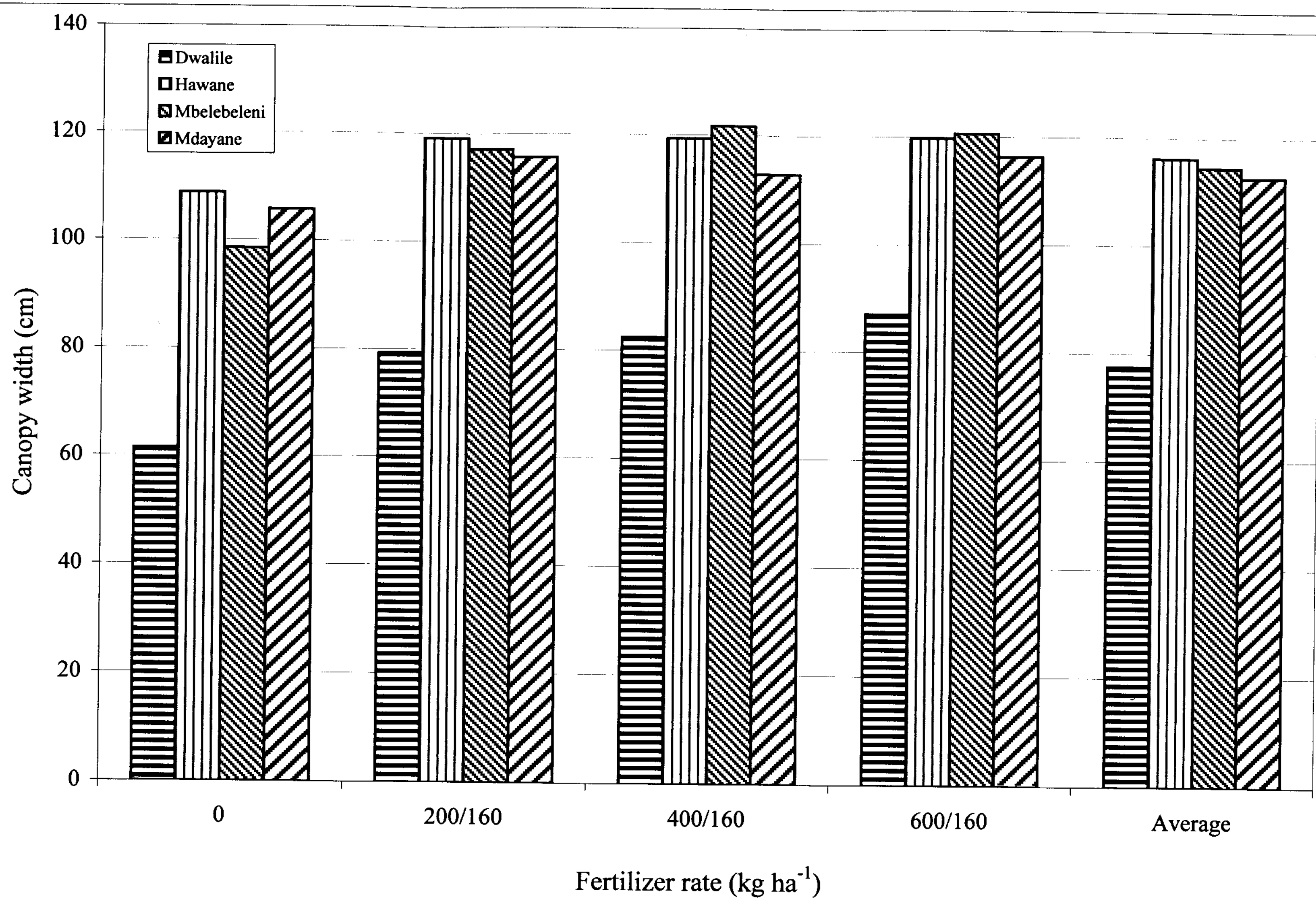

Figure 2: Site canopy widths (cm) per fertilizer rate and across the rates averaged over five maize cultivars

The cultivar effect was significant ($P \leq 0.05$) at all the sites except at Mbelebeleni (Figure 3). The cultivar PHB 3427 had the widest canopy at two of the three sites which was not statistically different from R 201. Its average canopy width at Dwalile, Hawane and Mdayane was 80.1, 123.8 and 119.9 cm, respectively but the canopy widths for R 201 were 81.1, 117.6 and 113.0 cm, respectively at the three sites. Cultivar PAN 6479 tended to have a narrower canopy at each site. The cultivar effect ($P \leq 0.01$) was observed across the sites. The canopy width of 99.3 cm for PAN 6479 was the lowest. The canopy widths of 110.2 and 108.5 cm for PHB 3427 and R 201 were the highest whereas RO 413 and SSM 2039 had the same (103.9 cm each).

A combined site analysis showed that site affected ($P \leq 0.01$) the canopy widths of the maize cultivars (Figure 3). The average canopy width of 77.6 cm for Dwalile was the lowest (Figure 2). The average canopy widths of 116.0, 114.5 and 112.6 cm for Hawane, Mbelebeleni and Mdayane, respectively, were not statistically different.

4.4 Harvest Index (HI)

Fertilizer rate affected ($P \leq 0.05$) the HIs of the maize cultivars at Mdayane, Hawane and Dwalile but not at Mbelebeleni. The indices were generally (statistically) lower at the 0/0 kg ha^{-1} rate of fertilizer whereas at the other rates they were not significantly different at each site. Across the sites, fertilizer rates also affected ($P \leq 0.01$) the HI of the maize cultivars. The lowest HI (36.2%) was found with the 0 kg ha^{-1} whereas the HIs with the other rates (45.5%, 48.6% and 50.4%, respectively) were not significantly different.

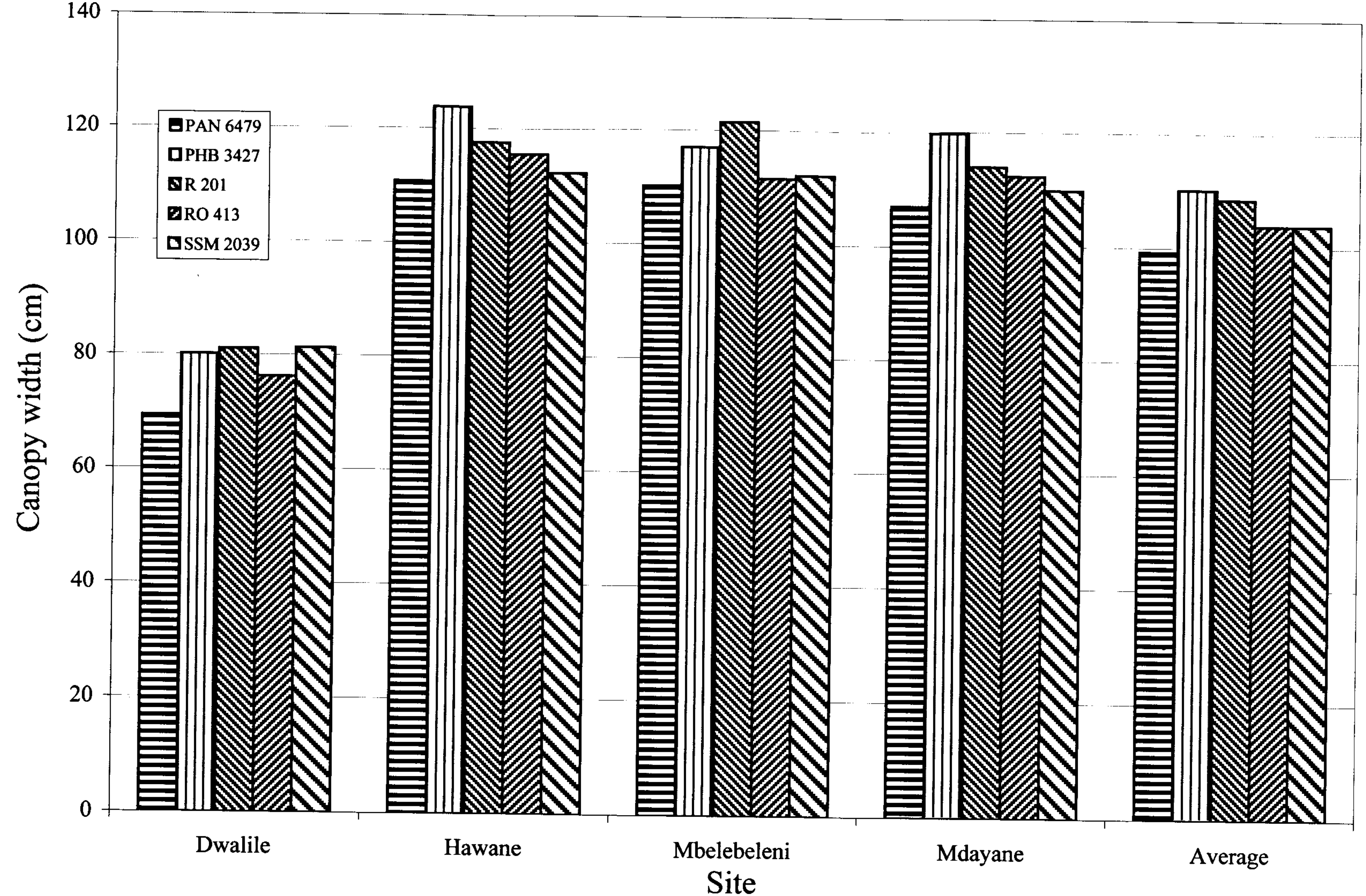

Figure 3: Canopy widths (cm) of five maize cultivars per site and across the sites averaged over four fertilizer rates.

The effect of cultivar on HI was observed at Mbelebeleni and Mdayane ($P \leq 0.01$) (Figure 4). The HIs for PHB 3427 and R 201 were significantly higher than for the other cultivars at both sites. A combined site analysis also revealed that the HIs of the maize cultivars were significantly ($P \leq 0.01$) affected by cultivar. The HIs for PHB 3427 and R 201 (47.9% and 49.0%, respectively) were the highest and statistically similar (Figure 4). The HIs for PAN 6479, RO 413 and SSM 2039 (43.2%, 43.7% and 42.0%, respectively) were not significantly different. The HIs of the maize cultivars were also affected by site ($P \leq 0.01$) (Figure 4). Hawane had the lowest HI (36.9%) while Dwalile had the highest (54.4%). The HIs for Mbelebeleni and Mdayane were not statistically different (42.4% and 46.9%, respectively). The site x cultivar interaction was significant ($P \leq 0.01$) on the HIs of the maize cultivars. The HIs were generally lower at Hawane but higher at Dwalile compared to the other sites.

4.5 Grain N, P and K Concentration

4.5.1 Grain N concentration [N]

The grain [N] of the maize cultivars was highly affected ($P\leq 0.01$) by fertilizer rate at Hawane but less so at the other sites ($P\leq 0.05$). The effect of fertilizer rate was also observed across the sites ($P\leq0.01$) (Figure 5). The grain [N] increased as fertilizer rate was increased. The increase was in the order: 1.19%<1.29%<1.37%<1.49 % with the 0/0, 200/160, 400/160 and 600/160 kg ha^{-1} rates of fertilizer. Only the grain [N] with the 200/160 and 400/160 kg ha $-^{1}$ were not significantly different.

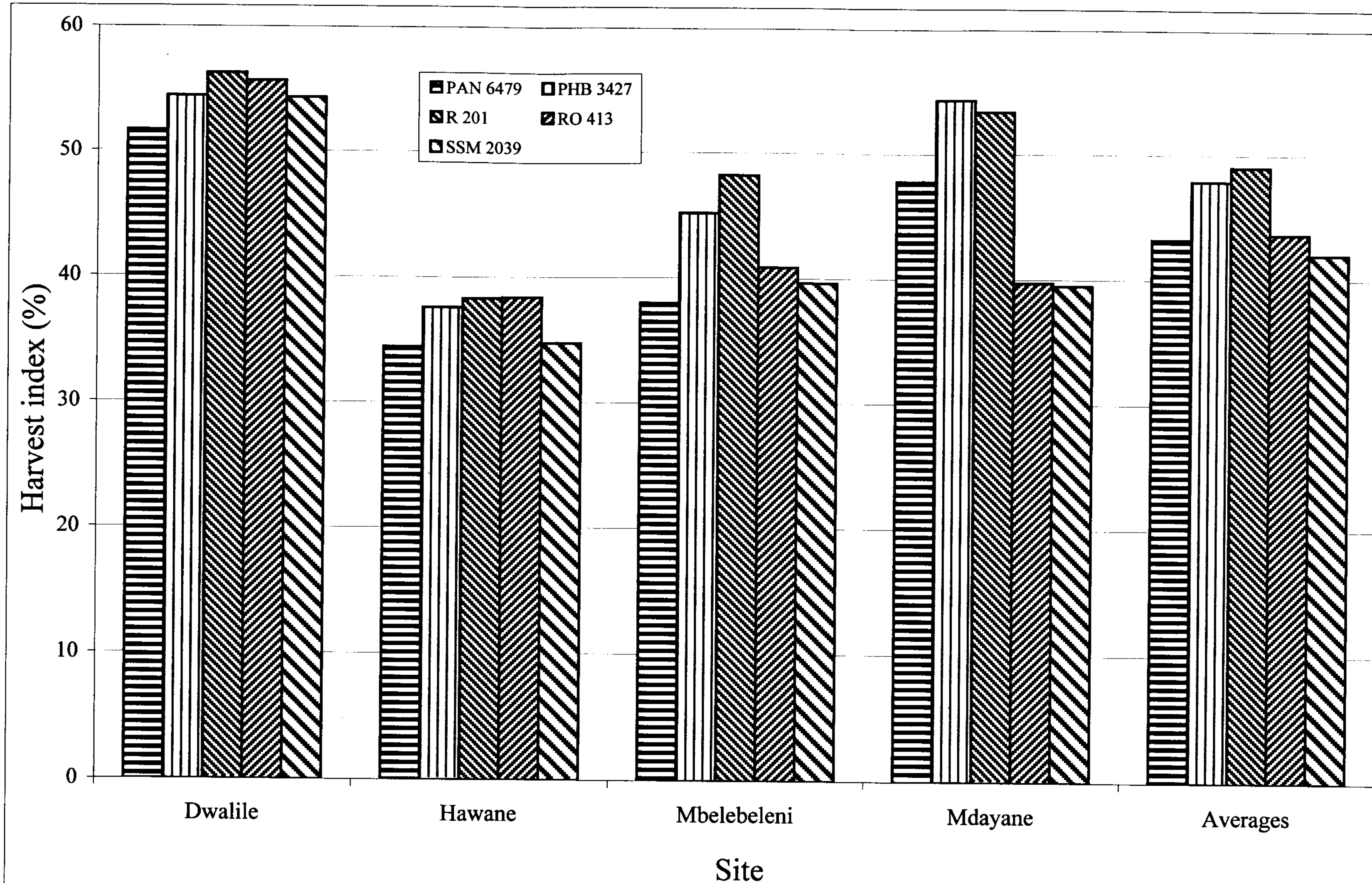

Figure 4: Cultivar harvest index (%) per site and across sites averaged over four fertilizer rates

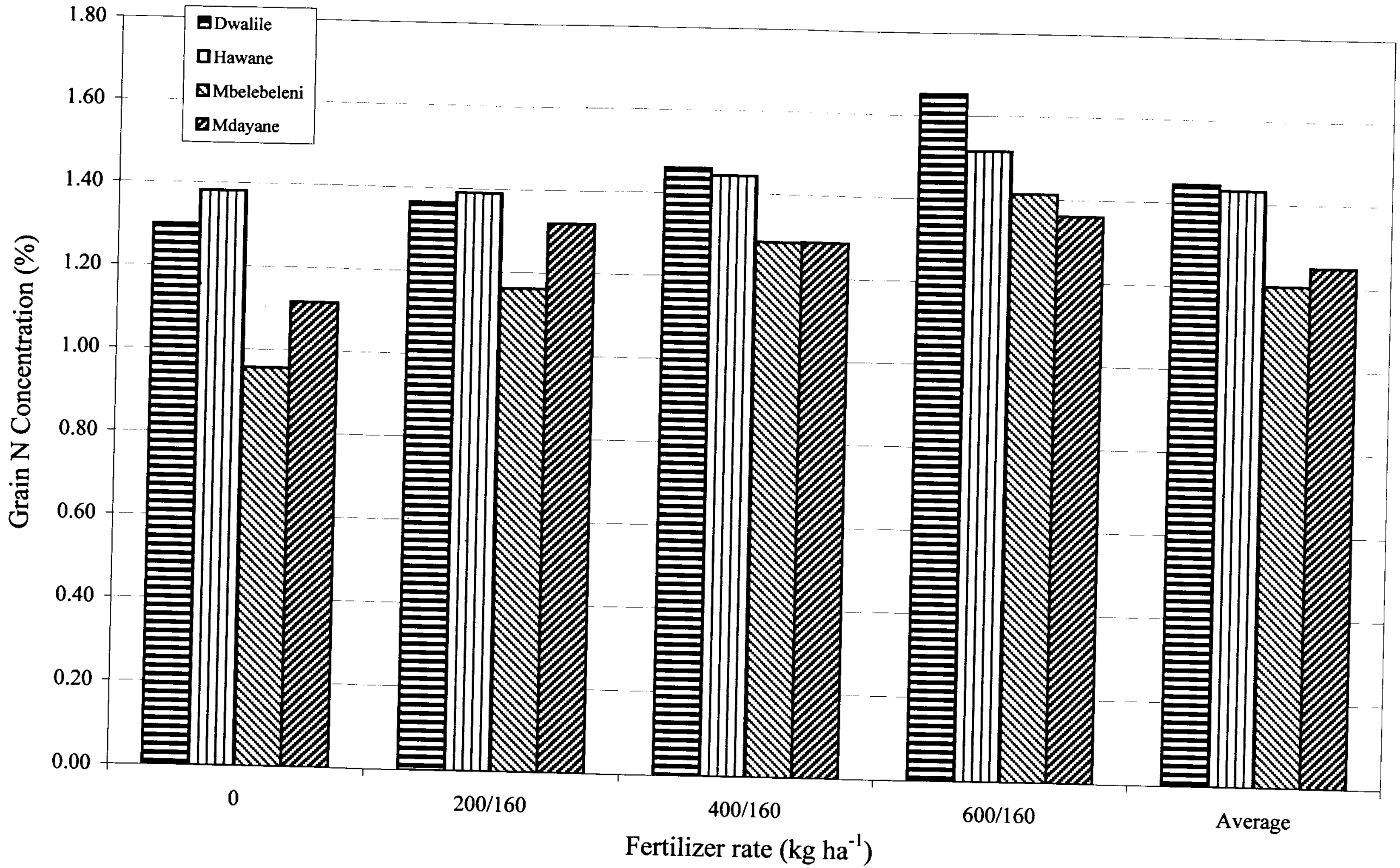

Figure 5: Site grain [N] per fertilizer rate and across the rates averaged over five maize cultivars

The cultivar effect on grain [N] was significant ($P \leq 0.01$) at Dwalile and Hawane. It was also equally significant across the sites. The cultivar PHB 3427 had a significantly higher grain [N] (1.43%) than the other cultivars across the sites (Figure 6). The variety x site interaction also affected ($P \leq 0.01$) the grain [N] of the maize cultivars (Figure 6). The cultivars tended to have a higher grain [N] at Dwalile and Hawane (Figure 5). The cultivar PHB 3427 had a significantly high grain [N] (1.69%) at Dwalile than all the other cultivars across the sites except at Hawane. Although it had a higher average grain N] (1.55%) at Hawane, it was not significantly different from that for R 201 (1.49%) and SSM 2039 (1.43%) at the same site. The cultivar tended to have a higher grain [N] at all the sites except at Mdayane.

4.5.2 Grain P concentration [P]

The grain [P] of the maize cultivars was affected ($P \leq 0.01$) by fertilizer rate at all the sites except at Dwalile (Figure 7). Across the sites, the fertilizer rate also affected the grain [P] of the maize cultivars. The average grain [P] with the 0/0 and 200/160 kg ha^{-1} rates were lower but statistically different (0.101% and 0.119%, respectively). The grain [P] with the 600/160 kg ha^{-1} rate (0.230%) was higher than for the other rates. Across the sites, Mbelebeleni had a significantly higher grain [P] (0.195%) than the other sites. The grain [P] for Hawane and Mdayane (0.162% and 0.145%) were not statistically different although they were significantly higher than for Dwalile(0.102%). This is further shown by the high site x cultivar interaction ($P \leq 0.01$) which implies that site affected the grain [P] of the maize cultivars. The site x fertilizer rate effect was also significant ($P \leq 0.01$) (Figure 7). The grain [P] of the maize cultivars was significantly higher at Mbelebeleni than all the other sites at the 600/160 kg ha^{-1} rate of fertilizer.

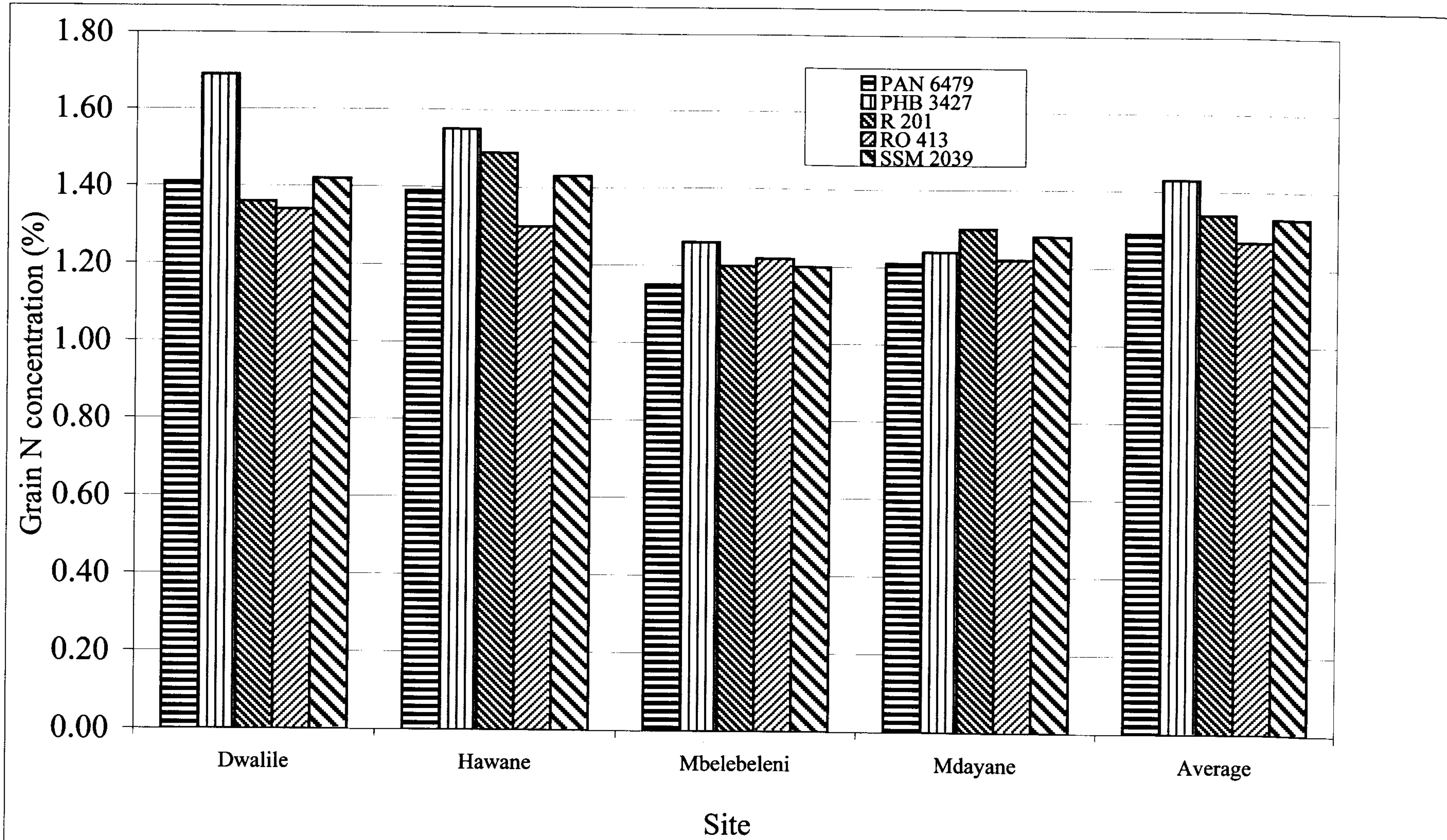

Figure 6: Cultivar grain [N] (%) per site and across the sites averaged over four fertilizer rates

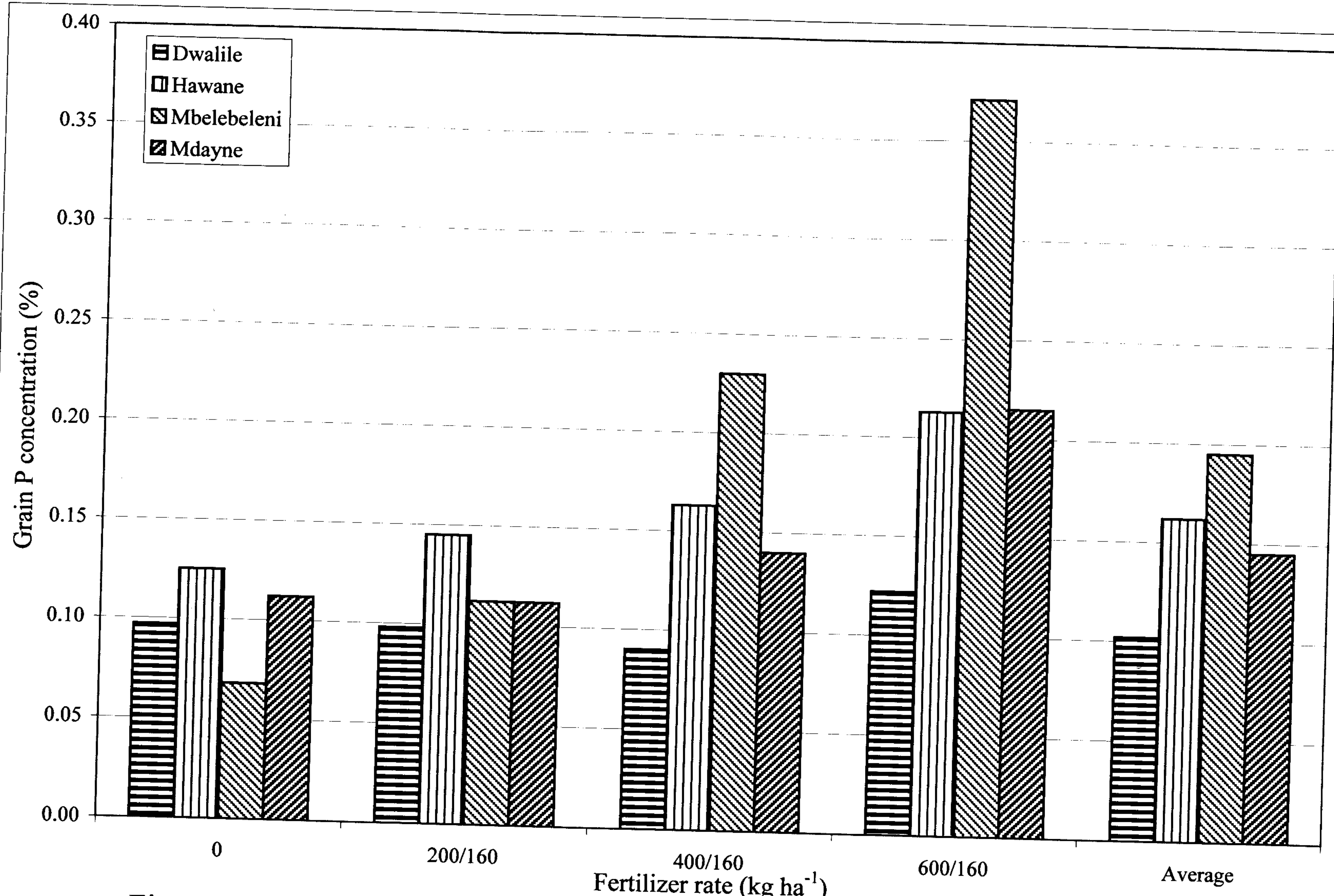

Figure 7: Site grain [P] per fertilizer rate and across the rates averaged over five maize cultivars

The cultivar effect on grain [P] was significant ($P \leq 0.05$) at Dwalile, Mbelebeleni and Mdayane (Figure 8). The cultivar PHB 3427 had a statistically higher grain [P] (0.121%) at Dwalile but at Mbelebeleni its grain [P] (0.141%) was statistically lower than for R 201 and RO 413 (0.242% and 0.246%, respectively). Across the sites, the cultivar effect on grain [P] was significant ($P \leq 0.01$) (Figure 8). The grain [P] for RO 413 (0.180%) was significantly higher than for SSM 2039 (0.131%) but not for the other cultivars.

4.5.3 Grain K concentration [K]

The fertilizer rates affected ($P \leq 0.01$) the grain [K] of the maize cultivars at each site although the effect was lower at Hawane ($P \leq 0.05$). At Dwalile and Mdayane the average grain [K] differed significantly between the fertilizer rates and increased as the rates were increased.

Across the sites, the effect of fertilizer rate was significant ($P \leq 0.01$) (Figure 9). At Hawane the average grain [K] of the fertilizer rates tended to be higher than at the other sites. The site had a significantly higher average grain [K] (0.509%) than the other sites while Mbelebeleni had a statistically lower [K] (0.340%) in the grain, although it did not differ significantly from that for Dwalile (0.356%). At Mbelebeleni the grain [K] with the 0/0 kg ha^{-1} (0.139%) was significantly the lowest but with the 600/160 kg ha^{-1} rate (0.522%) it was significantly higher, although it did not differ from that for Hawane (0.545%) at the same rate. The average grain [K] for the fertilizer rates increased in the order: 0.318%<0.365%<0.425<0.475% as the rates were increased. The effect of site x fertilizer rate interaction was also significant ($P \leq 0.01$).

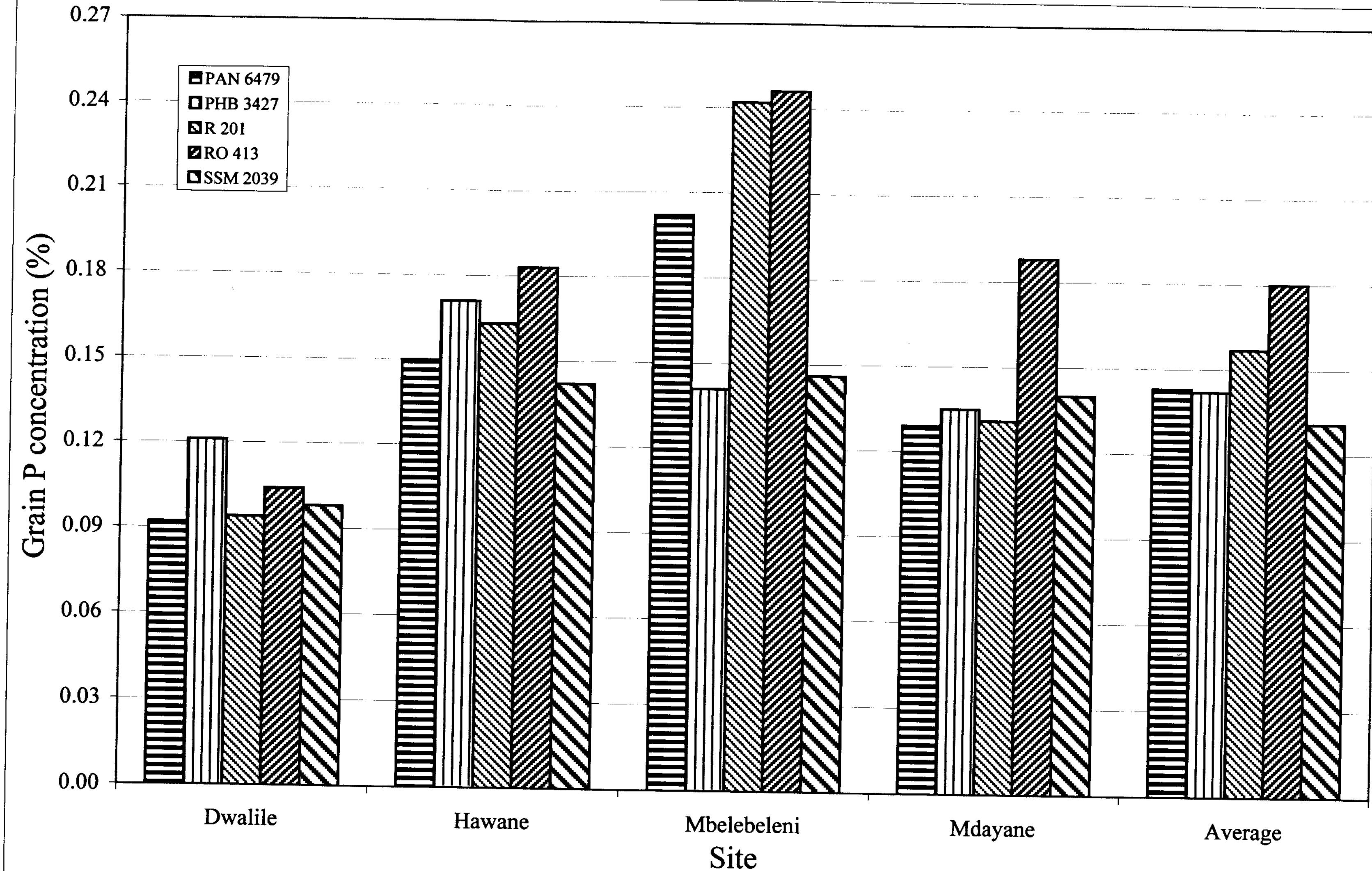

Figure 8: Average grain [P] (%) of five maize cultivars per site and across the sites averaged over four fertilizer rates

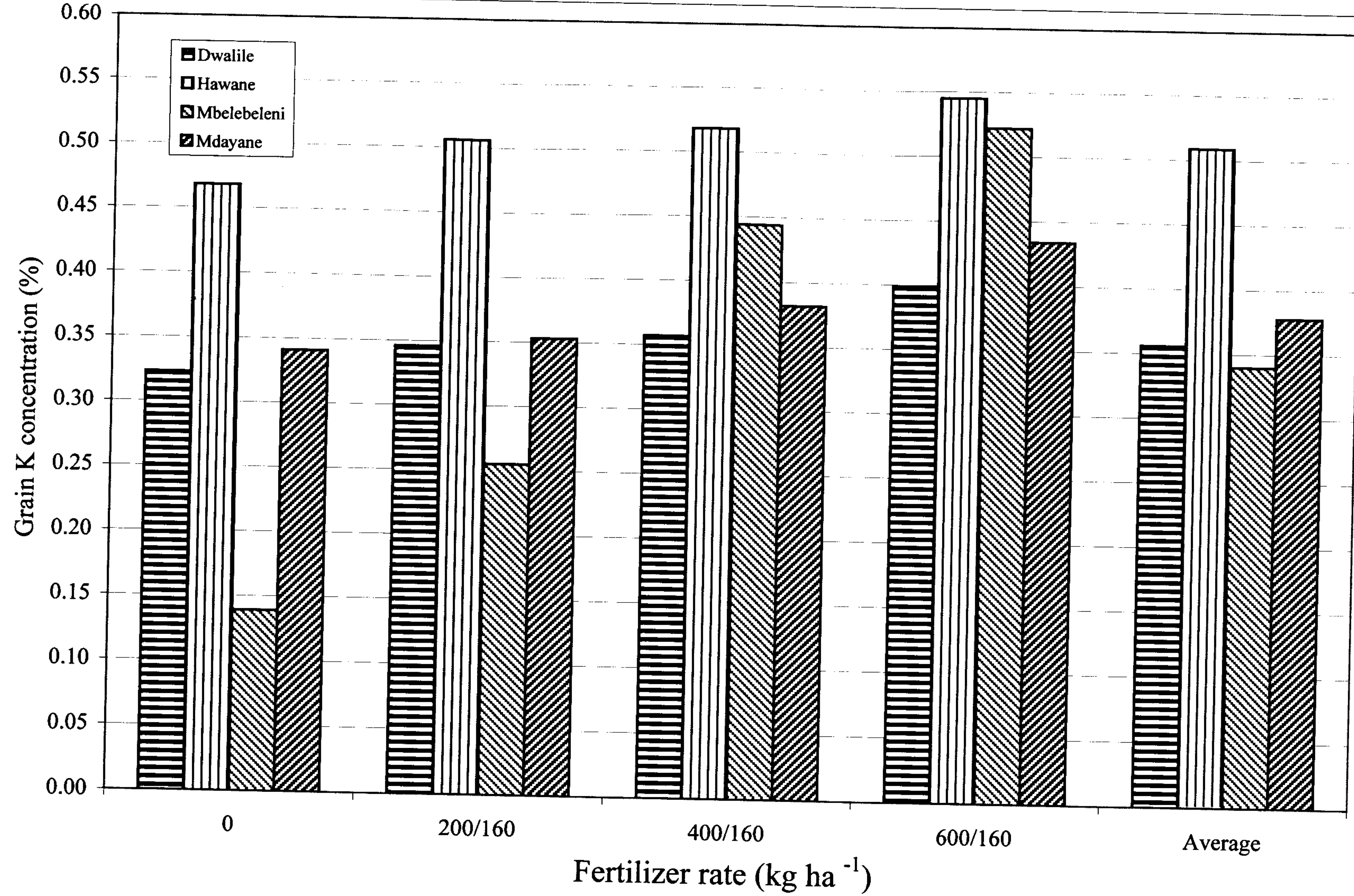

Figure 9: Site grain [K] per fertilizer rate and across the rates averaged over five maize cultivars

The cultivar effect was significant ($P \leq 0.01$) at Dwalile and Hawane (Figure 10). At Dwalile the grain [K] (0.310) for PAN 6479 was significantly lower while the other cultivars were not statistically different (Figure 10). At Hawane the same cultivar had a significantly lower grain [K] (0.465%) although it did not differ from that for R 201 and RO 413 (0.474% and 0.476%, respectively). Across the sites, the effect of cultivar was still significant ($P \leq 0.01$) (Figure 10). The cultivar PAN 6479 had a significantly lower average grain [K] (0.357%) than for all the other cultivars which did not differ statistically (Figure 10). On the overall, the maize cultivars tended to have a higher grain [K] at Hawane than at the other sites. The cultivar PAN 6479 had a lower grain [K] at all the sites but at Mdayane its grain [K] did not differ significantly from the other maize cultivars. The site x cultivar effect was also significant ($P \leq 0.01$) showing that the grain [K] of the maize cultivar was influenced by site as well.

4.6 Leaf N, P and K concentrations

4.6.1 Leaf N concentration [N]

The leaf [N] of the maize cultivars was affected ($P \leq 0.01$) by the fertilizer rate at all the sites. At Dwalile, Mbelebeleni and Mdayane the average leaf [N] of the maize cultivars did not differ significantly between the 400/160 and 600/160 kg ha^{-1} rates of fertilizer. A significant difference was not realised between the 200/160 and 400/160 kg ha^{-1} rates at Dwalile while at Mbelebeleni it was not observed between the 0/0 and 200/160 kg ha^{-1} rates of fertilizer. The average leaf [N] was significantly different between the fertilizer rates at Hawane. Across the sites, it was also significantly ($P \leq 0.01$) affected by the fertilizer rates (Figure 11). It increased significantly as the fertilizer rates were increased and the increase was in the order: 1.81%<1.95%<2.06% <2.15%, respectively for the fertilizer rates.

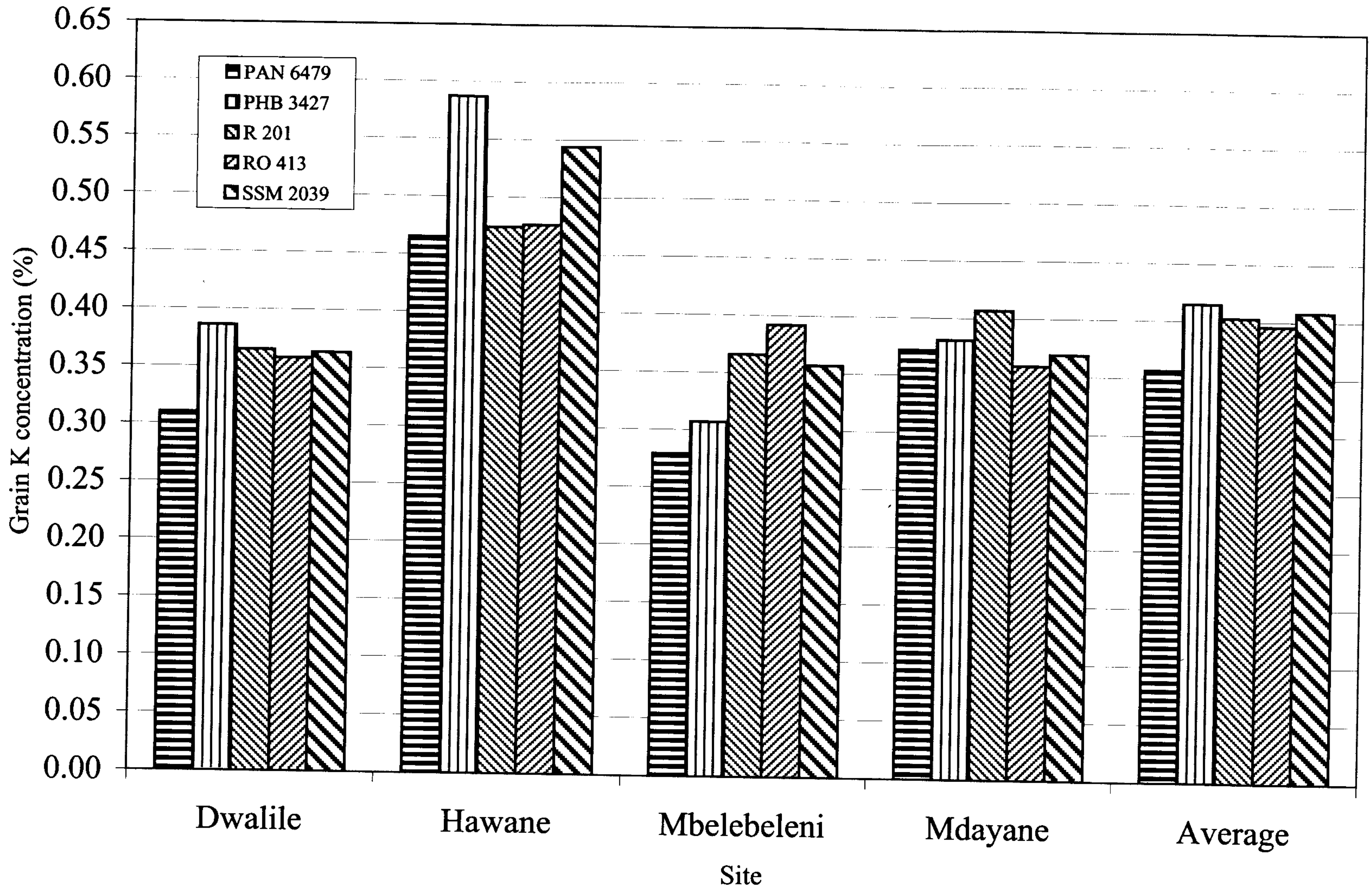

Figure 10: Grain [K] (%) of five maize cultivars per site and across the sites averaged over four fertilizer rates

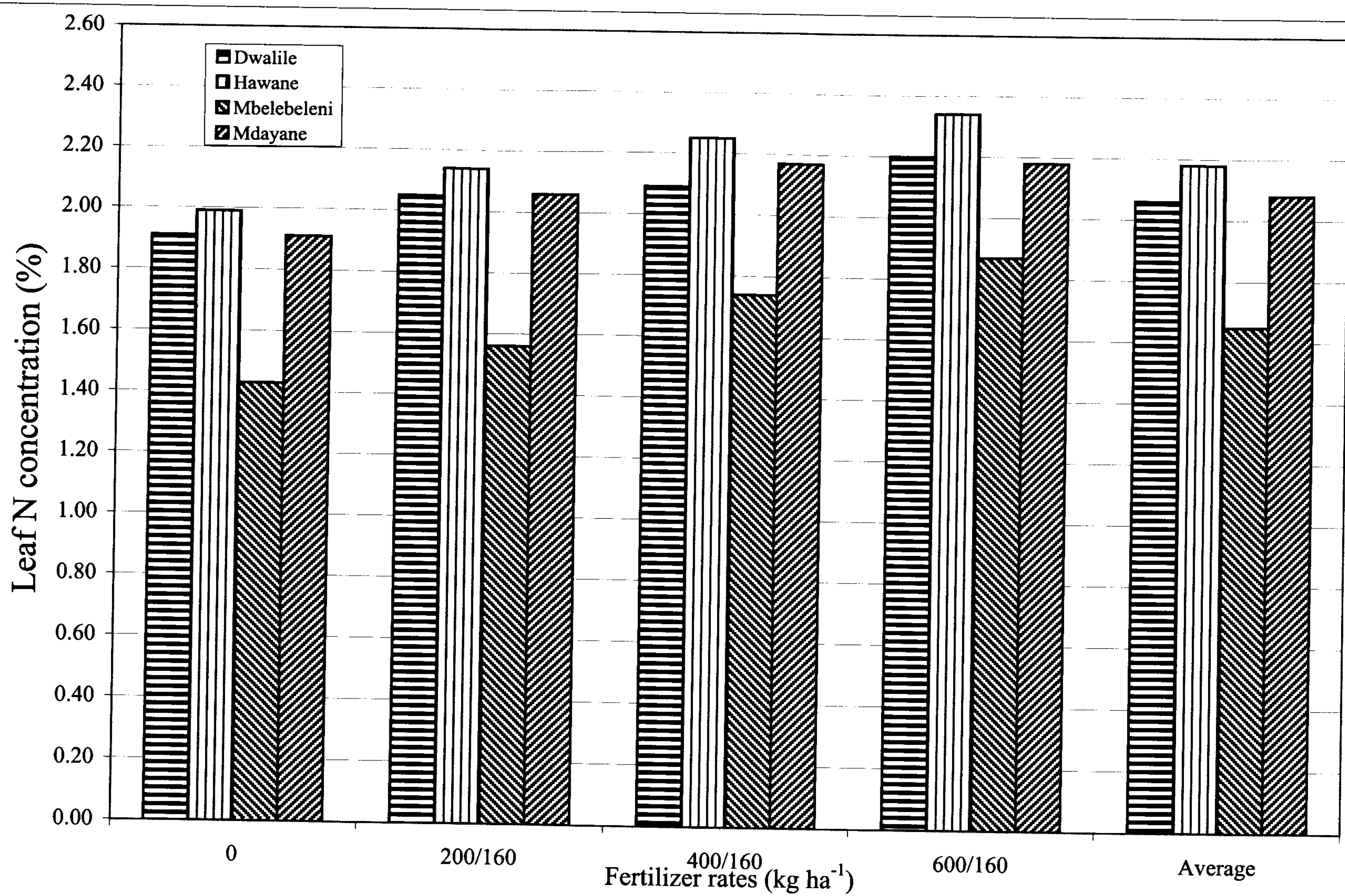

Figure 11: Site leaf [N] (%) per fertilizer rate and across the rates averaged over five maize cultivars

The cultivar effect was significant ($P \leq 0.01$) at all the sites. The average leaf [N] for PAN 6479 was significantly high at each site while that for PHB 3427 was significantly lower except at Dwalile. At Hawane and Mdayane the leaf [N] (2.05% and 1.97%, respectively) for PHB 3427 was not significantly different from that for RO 413 (2.12% and 1.95%, respectively). The cultivar effect across the sites was still significant ($P \leq 0.01$) (Figure 12). The cultivar PAN 6479 had a statistically higher average leaf [N] while PHB 3427 had the lowest (statistically) leaf [N] than the other cultivars although it did not differ significantly from that for RO 413.

The site effect on the leaf [N] was significant ($P \leq 0.01$). Hawane had the highest average leaf [N] (2.15%) while Mbelebeleni had the lowest (1.65%). The leaf [N] for Dwalile and Mdayane (2.06% and 2.08%, respectively) were not statistically different (Figure 11).

4.6.2 Leaf P concentration [P]

The [P] in the leaves of the maize cultivars was only affected by the fertilizer rate at Hawane and Mbelebeleni ($P \leq 0.01$) but not at the other two sites. At these sites the average leaf [P] of the fertilizer rates differed significantly. The effect of fertilizer rate ($P \leq 0.01$) was also realised across the sites (Figure 13). With the 600/160 kg ha^{-1} (0.147%) rate a significantly higher leaf [P] was found than with the other rates except the 400/160 kg ha^{-1} (0.134%). The 0 and 200/160 kg ha^{-1} rates did not differ significantly in leaf [P] (0.116% and 0.123%, respectively) while with the 200/160 and 400/160 kg ha^{-1} rates a significant difference was not found.

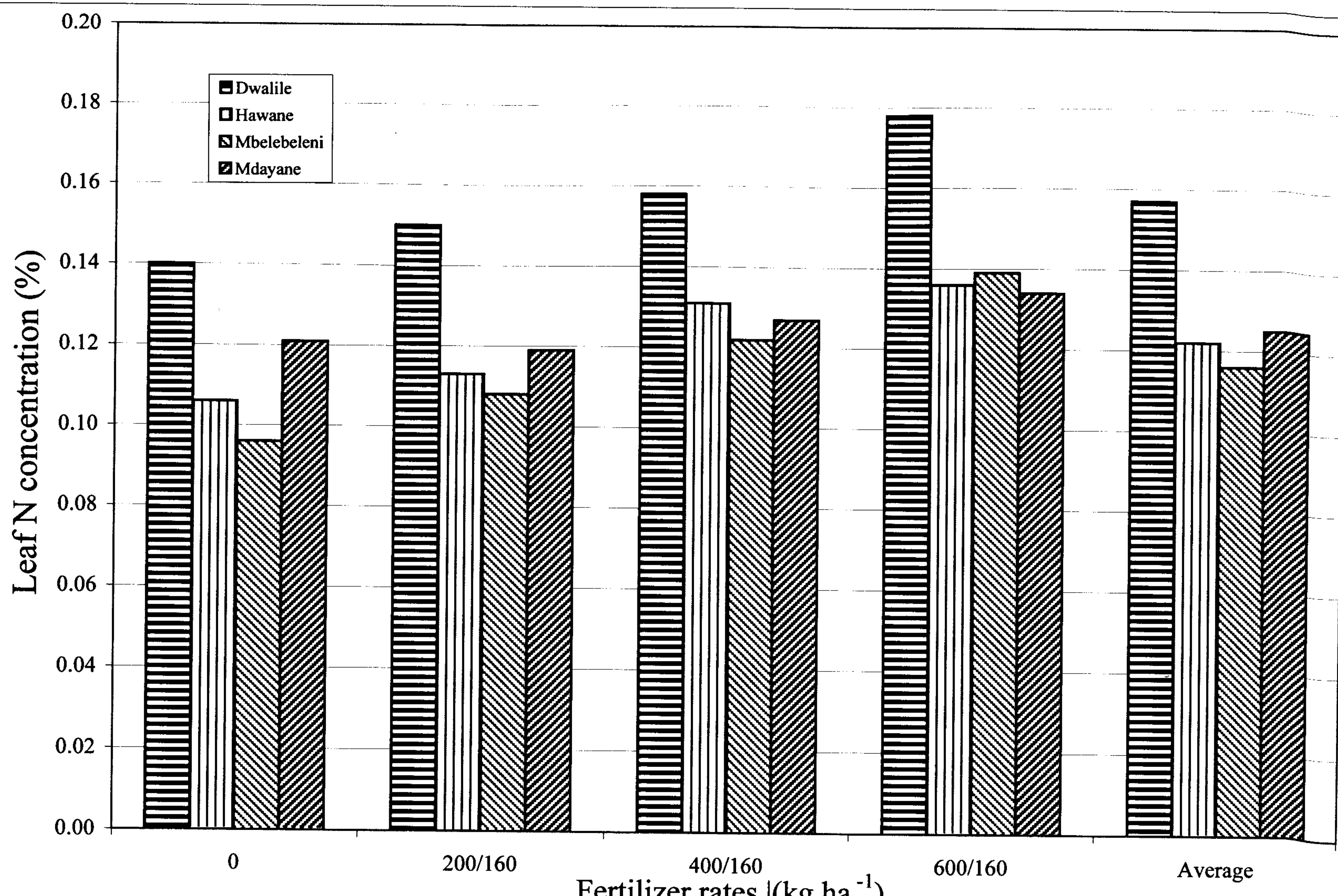

Figure 12: Site leaf [P] (%) per fertilizer rate and across the rates averaged over five maize cultivars

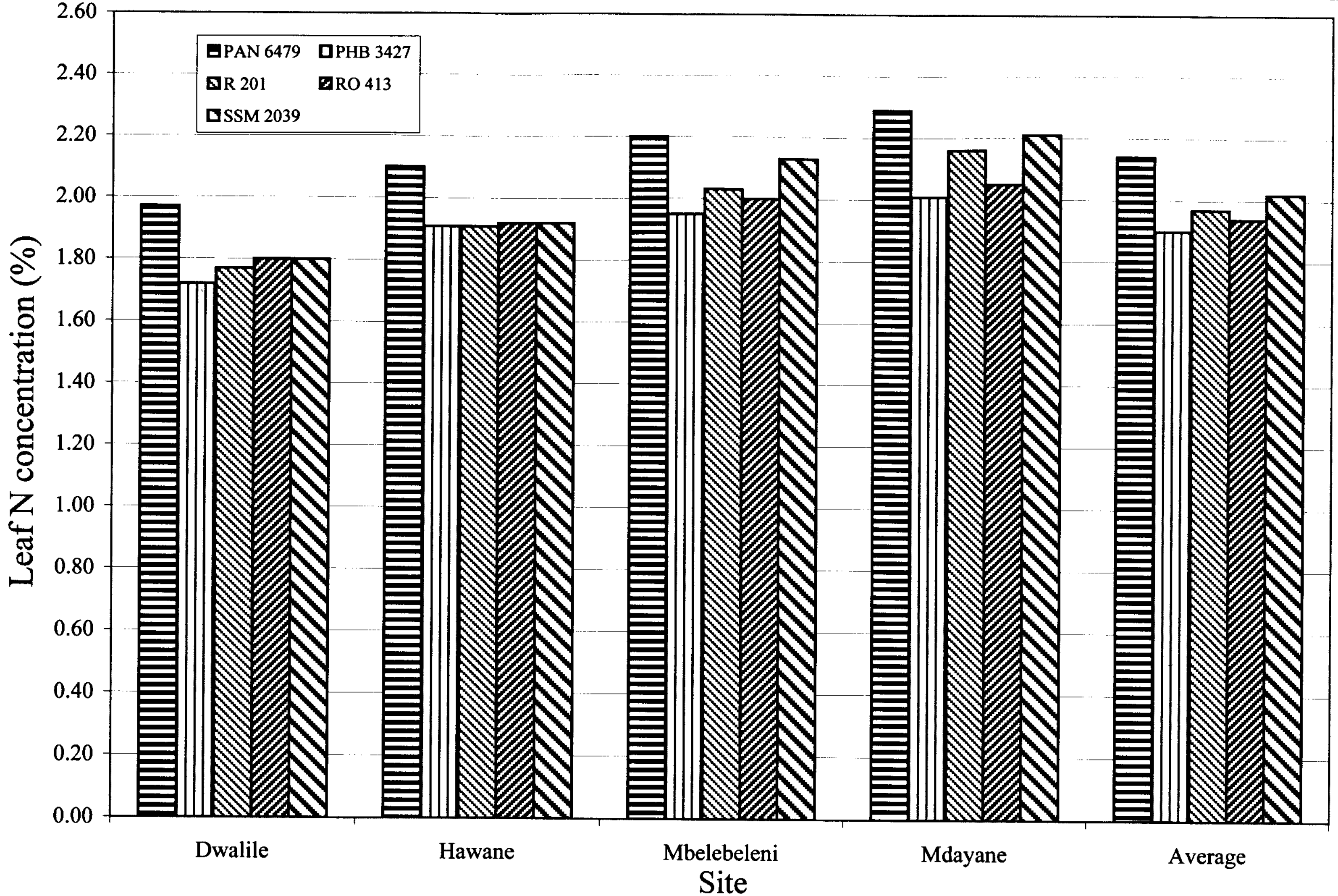

Figure 13: Leaf [N] (%) of five maize cultivars per site and across the sites averaged over four fertilizer rates

The cultivar effect on leaf [P] was only significant ($P \leq 0.01$) at Dwalile. The leaf [P] of the maize cultivars differed significantly. The cultivar PHB 3427 had the highest leaf [P] (0,181%) while R 201 had the lowest (0.140%). Across the sites, the effect of cultivar on leaf [P] was not significant but an effect was observed in the site x cultivar interaction ($P \leq 0.01$) (Figure 14). At Dwalile cultivars tended to have more [P] in the leaves than at the other sites. The leaf [P] differed significantly between the maize cultivars at each site except for PAN 647 and SSM 2039 (0.126% each) at Mdayane. They both had the lowest average leaf [P] at this site.

4.6.3 Leaf K concentration [K]

The effect of fertilizer rate was significant ($P \leq 0.01$) at all the sites although it was less so at Mbelebeleni ($P \leq 0.05$). At Dwalile, Hawane and Mdayane the average leaf [K] did not differ significantly between the 0/0 and 200/160 kg ha^{-1} as well as between the 400/160 and 600/160 kg ha^{-1} rates. At Hawane the difference in leaf [K] was not significant between the 200/160 and 400/150 kg ha^{-1} rates of fertilizer. Across the sites, the effect of fertilizer rate remained significant ($P \leq 0.01$) on the leaf [K]. The average leaf [P] increased (in the order: 0.807%<0.932%<1.06%<1.20%) as the rates were increased. The site x fertilizer rate interaction affected ($P \leq 0.01$) the leaf [K] of the maize cultivars (Figure 15). The leaf [K] was significantly higher at Mbelebeleni than at the other sites, except with the 0/0 kg ha^{-1} rate (1.02%) which did not differ statistically from the 600/160 kg ha^{-1} rate at Dwalile, Hawane and Mdayane (1.05%, 0.997% and 1.02%, respectively and from the 400/160 kg ha^{-1} rate at Dwalile (0.963%).

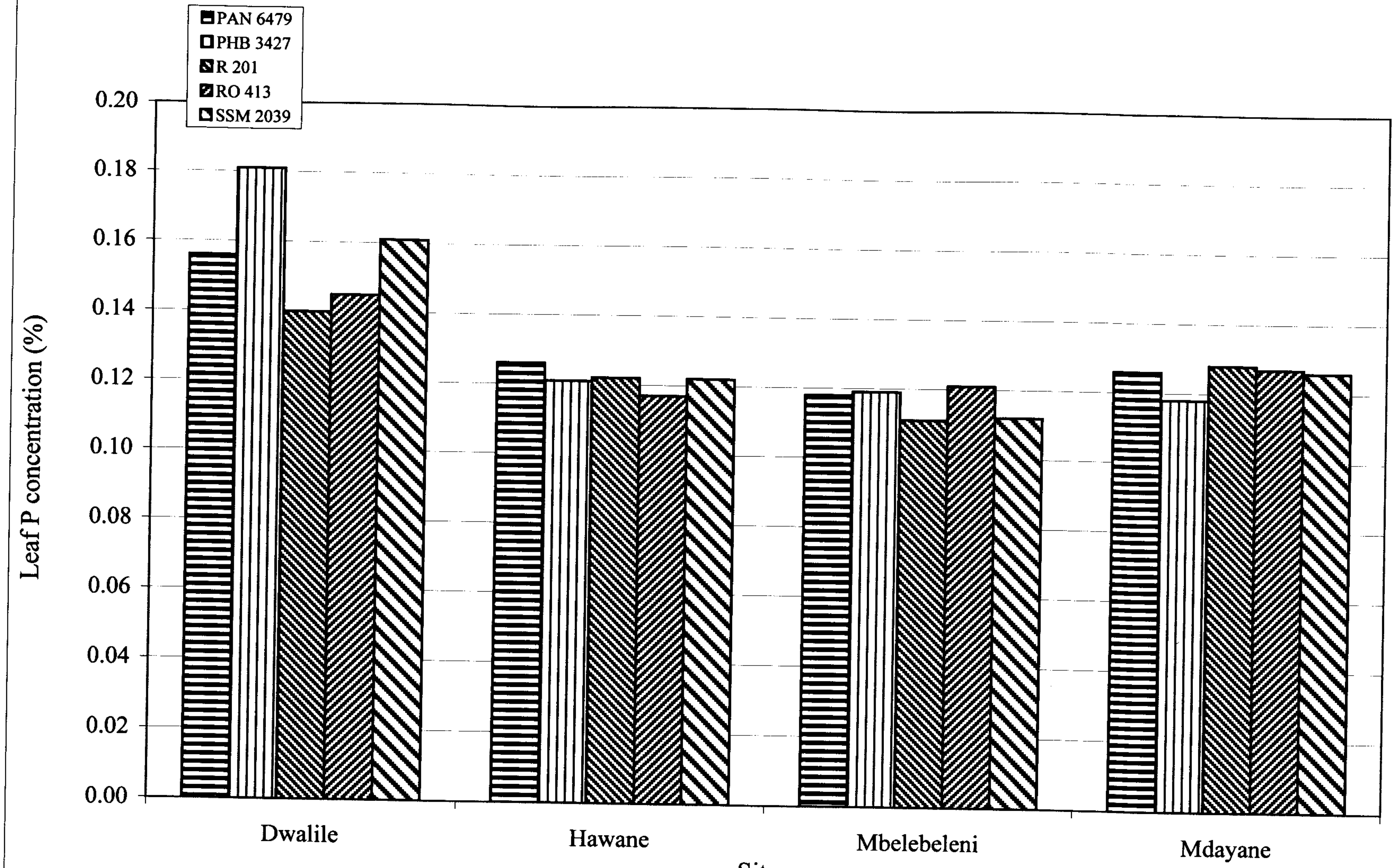

Figure 14:Leaf [P] (%) of five maize cultivars per site averaged over four fertilizer rates

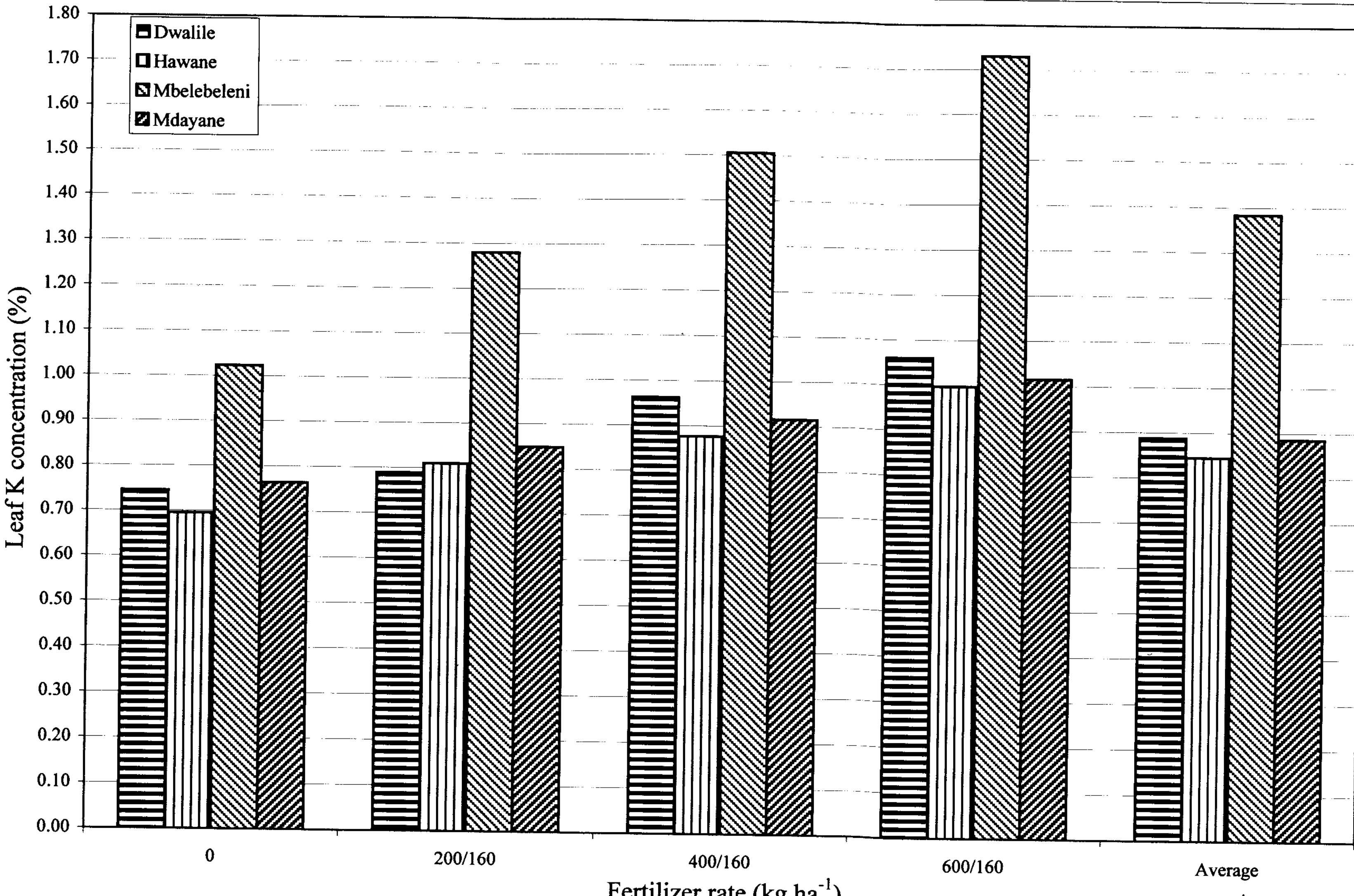

Figure 15: Site leaf [K] (%) per fertilizer rate and across th rates averaged over five maize cultivars

The cultivar effect on the leaf [K] of the maize cultivars was significant at Hawane, Mbelebeleni ($P \leq 0.01$) and Mdayane ($P \leq 0.05$). At Hawane and Mbelebeleni, PHB 3427 had a significantly lower leaf [K] (0.753% and 1.15%, respectively) which did not differ statistically from the leaf [K] of the other cultivars except for RO 413 (0.950%) at Hawane. Its [K] did not differ from that for R 201 (1.23%) at Mbelebeleni where RO 413 had a significantly higher [K] (1.63%) than the other cultivars. Across the sites, the cultivar effect on leaf [K] remained significant ($P \leq 0.01$). The leaf [K] (1.13%) for RO 413 was statistically higher than the other cultivars while that for PHB 3427 (0.885%) was statistically lower but similar to that for R 201 (0.941%).

The site x cultivar interaction had an effect on the leaf [K] (Figure 16) of the maize cultivars. Each of the cultivars had a significantly higher average leaf [K] at Mbelebeleni compared to the other sites. The leaf [K] for RO 413 was consistently higher at each site.

4.7 Maize grain yield

The grain yield of the maize cultivars was significantly affected ($P \leq 0.01$) by the fertilizer rate at each site (Figure 17). The grain yield generally increased as the fertilizer rate was increased at each site. At Dwalile and Mbelebeleni the grain yields ha^{-1} with the 0/0 and 200/160 kg ha^{-1} rates of fertilizer were lower and statistically similar. The grain yields ha^{-1} with the 400/160 and 600/160 kg ha^{-1} rates were not significantly different at Dwalile, Mbelebeleni and Mdayane. At Hawane and Mdayane, the yields for with the 0/0 kg ha^{-1} rate of fertilizer were statistically lower whereas with the 600/160 kg ha^{-1} rate Hawane had a statistically higher grain yield ha^{-1} than the other rates. The grain yields with the 200/160 and 400/160 kg ha^{-1} rates did not differ statistically at Hawane and Mdayane.

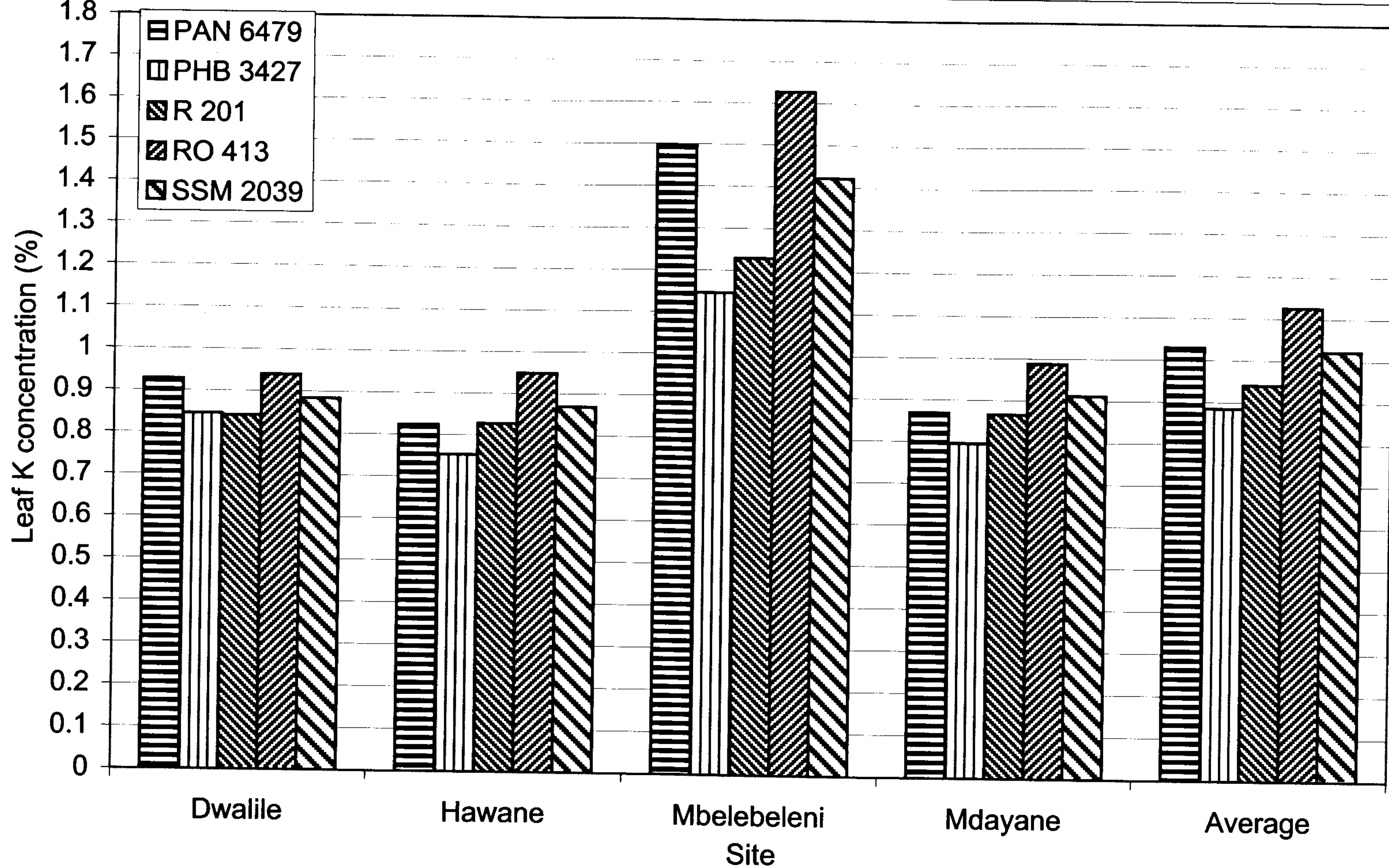

Figure 16: Leaf [K] (%) of five maize cultivar per site and across sites averaged over four fertilizer rates

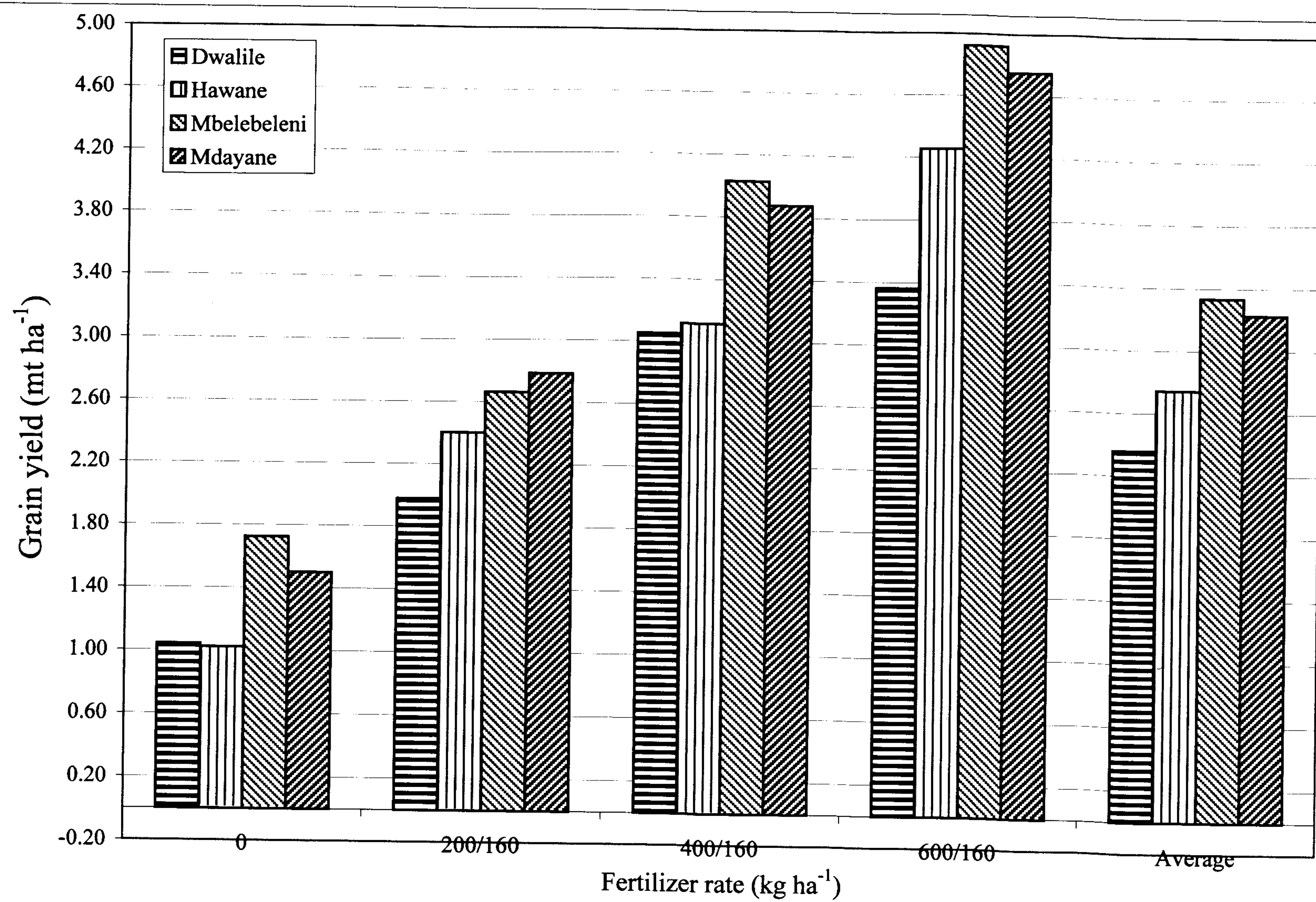

Figure 17: Site grain yield (mt ha^{-1}) per fertilizer rate and across the rates averaged over five maize cultivars

Across the sites (Appendix 1), the grain yield of the maize cultivars was affected by fertilizer rate ($P \leq 0.01$). The average yield increased significantly as fertilizer rate increased. The yields increased in the following order: 1.36< 2.46< 3.50< 4.32 mt ha^{-1}, respectively, according to fertilizer rate and they were all significantly different from each other.

The cultivar effect ($P \leq 0.05$) on grain yield was observed at Mdayane only. The cultivar R 201 gave a significantly higher grain yield (3.61 mt ha^{-1}) than the other cultivars except for PHB 3427 and RO 413 (3.27 and 3.21 mt ha^{-1}, respectively). The cultivar x site interaction ($P \leq 0.05$) affected the grain yield (Figure 18). Most cultivars gave significantly lower yields at Dwalile while at Hawane, Mbelebeleni and Mdayane they gave significantly higher yields. The cultivar R 201 had a significantly higher yield (3.61 mt ha^{-1}) at Mdayane than for PAN 6479 and SSM 2039 (3.01 and 3.04 mt $ha^{-1,}$, respectively). At Mbelebeleni its yield was lower although it did not differ significantly from the yield of the other cultivars. The site effect was highly significant ($P \leq 0.01$), with Dwalile giving the lowest yield (2.36 mt ha-1) which did not differ significantly from that obtained at Hawane (Figure 17). The average grain yields for Hawane, Mbelebeleni and Mdayane (2.74, 3.34 and 3.23 mt ha^{-1}, respectively) were not statistically different. The cultivar x fertilizer rate interaction on grain yield was not significant indicating that the maize cultivars used for the study performed similarly at each fertilizer rate per site.

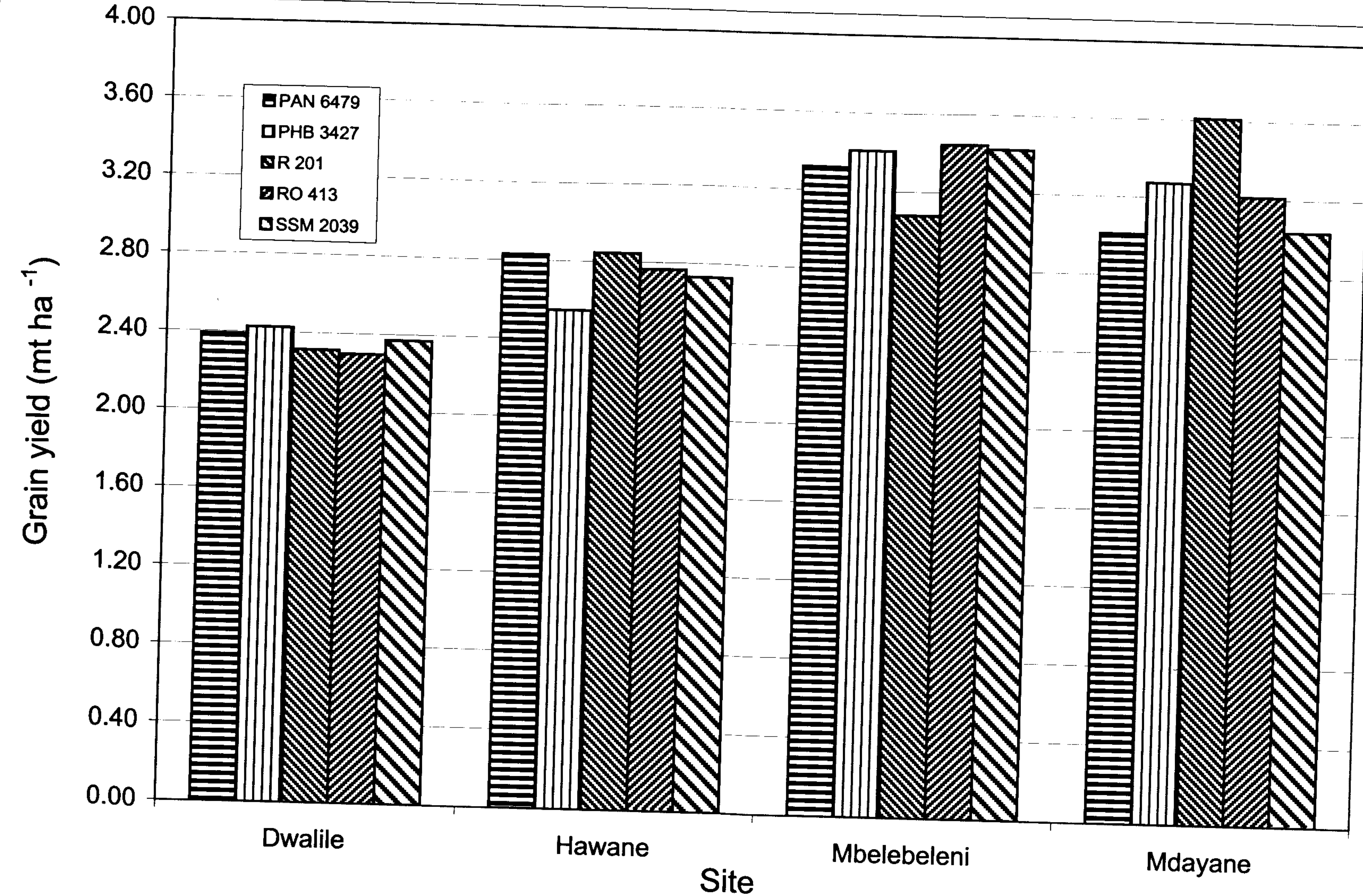

Figure 18: Grain yield (mt ha^{-1}) of five maize cultivars per site averaged over four fertilizer rates

4.8 Trend Comparison

The method of orthogonal polynomials (Goulen, 1952; Gomez and Gomez, 1984;) revealed that within the four fertilizer rates used for the experiment, the average grain yield response of the maize cultivars was linear ($P \leq 0.01$) over the fertilizer rates used at each site (Tables 3, 4, 5 and 6). At Dwalile the quadratic response was significant but at a lower probability level ($P \leq 0.05$).

The regression coefficients for the grain yield response per kilogram of fertilizer for each cultivar per site over the fertilizer rates were all significant ($P \leq 0.01$). This indicates a strong relationship between the fertilizer rate applied and the increase in yield kg^{-1} of fertilizer applied.

The regression lines of the cultivars per site (Figures 19, 20, and 21) are very close together. This indicates that the yield response of each cultivar per fertilizer rate was statistically similar to other cultivars although some cultivars yielded superior. Some cultivars had a higher response under the low fertilizer rates but had a lower response under the higher fertilizer rates compared to others. At Mdayane the regression lines (Figure 22) are almost clear from each other. The regression line for R 201 at this site is higher than those for the other cultivars across all the fertilizer rates (Figure 22). This is an indication that this cultivar had a superior response compared to the other cultivars. The yield of this cultivar (R 201) was the highest at all the fertilizer rates except at the 200/160 kg ha^{-1} rate of fertilizer (Table 11). This shows that this cultivar yielded better than the other cultivars. The regression line for PHB 3427 was lower than for R 201 at Mdayane. The cultivar had a superior response than R 201 at the 200/160 kg ha^{-1} rate of fertilizer and gave the second highest yield after R 201 under the 400/160 kg ha^{-1} rate (Table 11). It gave the lowest yield at the 600/160 kg ha^{-1} rate and it had the third lowest yield after RO 413 and PAN 6479 under the 0/0 kg ha^{-1} rate of fertilizer.

The regression line for RO 413 was the third highest across the fertilizer rates. This cultivar gave the second highest yield under the 0/0 kg ha^{-1} and the 600/160 kg ha^{-1} rates of fertilizer but gave the lowest yield under the 200/160 kg ha^{-1} rate, while under the 400 kg ha^{-1} rate it gave the second lowest yield. The regression lines (Figure 19) of the average responses of the maize cultivars per fertilizer rate per site indicate that the cultivars responded differently to the same fertilizer rates depending on site.

Table 3: Trend comparison of grain yield response at Dwalile based on Analysis of Variance.

Sources of Variation	Degrees of Freedom	Sum of Squares	Mean Square	Computed F-value	Tabular F-value	
					5%	1%
Replication	2	2.376				
Fertilizer rate	3	50.535	16.845	139.5**	2.90	4.46
Maize Cultivars	4	0.136	0.034	0.281ns	2.67	3.91
Linear	1	24.235	24.235	201.0**	4.15	7.50
Quadratic	1	0.726	0.726	6.01*	4.15	7.50
Cubic	1	0.306	0.306	2.53ns	4.15	7.50
Error	32	3.864	0.121			
Total	59	65.923				

ns: not significant
*: significant
**: highly significant

Table 4: Trend comparison of grain yield response at Hawane based on Analysis of Variance.

Sources of variation	Degrees of Freedom	Sum of Squares	Mean Square	Computed F-value	Tabular F-value	
					5%	1%
Replication	2	1.494				
Fertilizer rate	3	73.813	24.604	262.4**	2.90	4.46
Maize cultivars	4	0.689	0.172	1.84ns	2.67	3.91
Linear	1	36.595	36.595	390.3**	4.15	7.50
Quadratic	1	0.008	0.008	0.810ns	4.15	7.50
Cubic	1	0.031	0.031	3.25ns	4.15	7.50
Error	32	3.000	0.094			
Total	59	85.569				

ns: not significant

**: highly significant

Table 5: Trend comparison of grain yield response at Mbelebeleni based on Analysis of

Variance.

Sources of variation	Degrees of Freedom	Sum of Squares	Mean square	Computed F-value	Tabular F-value	
					5%	1%
Replication	2	4.132				
Fertilizer rate	3	90.720	30.240	84.71**	2.90	4.46
Maize cultivars	4	1.086	0.272	0.761ns	2.67	3.91
Linear	1	45.013	45.013	126.1**	4.15	7.50
Quadratic	1	0.003	0.003	0.091ns	4.15	7.50
Cubic	1	0.299	0.299	0.838ns	4.15	7.50
Error	32	11.420	0.357			
Total	59	121.593				

ns: not significant

**: highly significant

Table 6: Trend comparison of grain yield response at Mdayane based on Analysis of Variance.

Sources of variation	Degrees of freedom	Sum of squares	Mean square	Computed F-value	Tabular F-value	
					5%	1%
Replication	2	7.870				
Fertilizer rate	3	88.877	29.626	42.60**	2.90	4.46
Maize cultivars	4	2.795	0.699	3.090*	2.67	3.91
Linear	1	44.121	44.121	195.4**	4.15	7.50
Quadratic	1	0.300	0.300	1.33ns	4.15	7.50
Cubic	1	0.003	0.003	0.015ns	4.15	7.50
Error	32	7.228	0.226			
Total	59	121.775				

ns: not significant

*: significant

**: highly significant

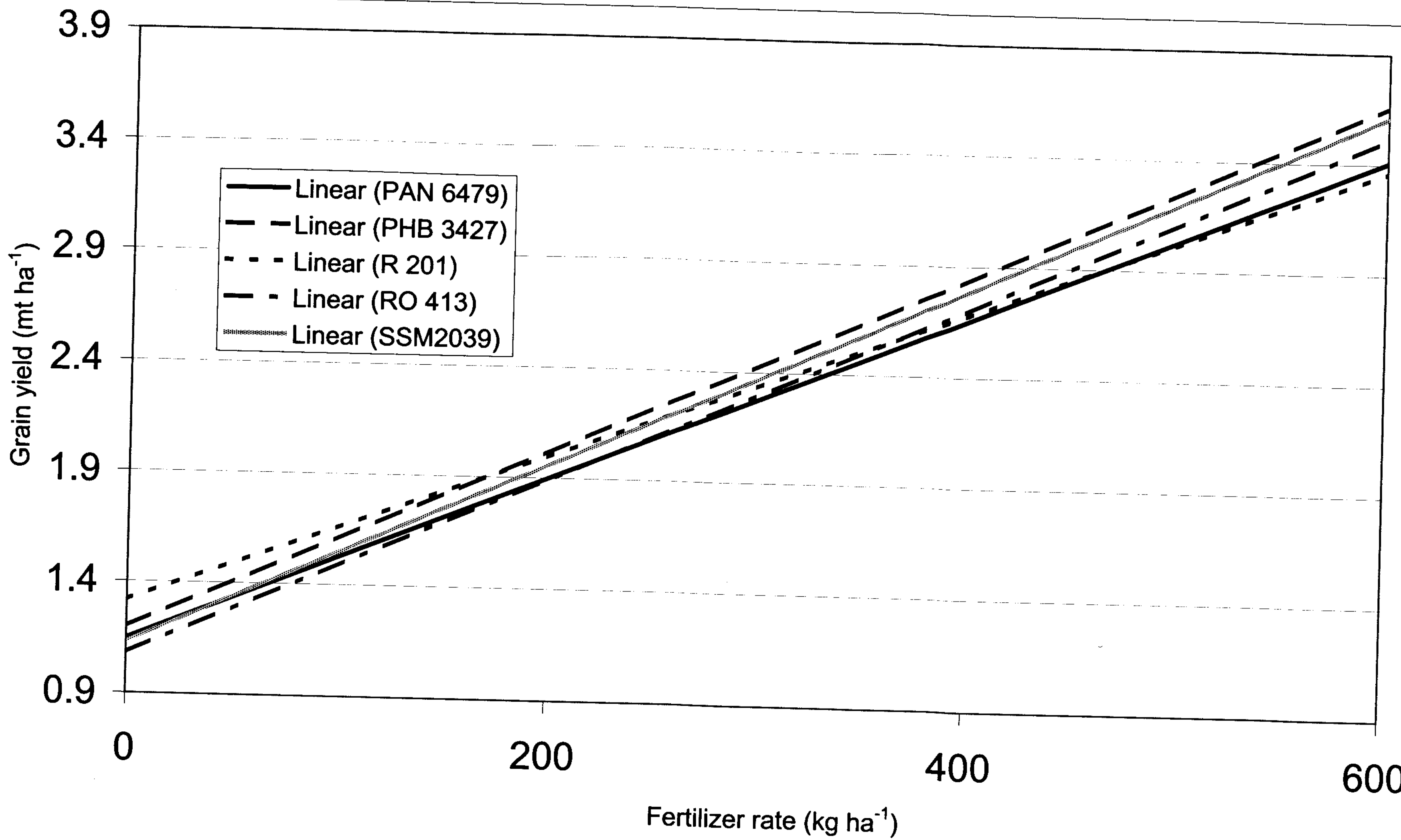

Figure 19: Regression of grain yield (mt/ha) of five over four fertilizer rates at Dwalile

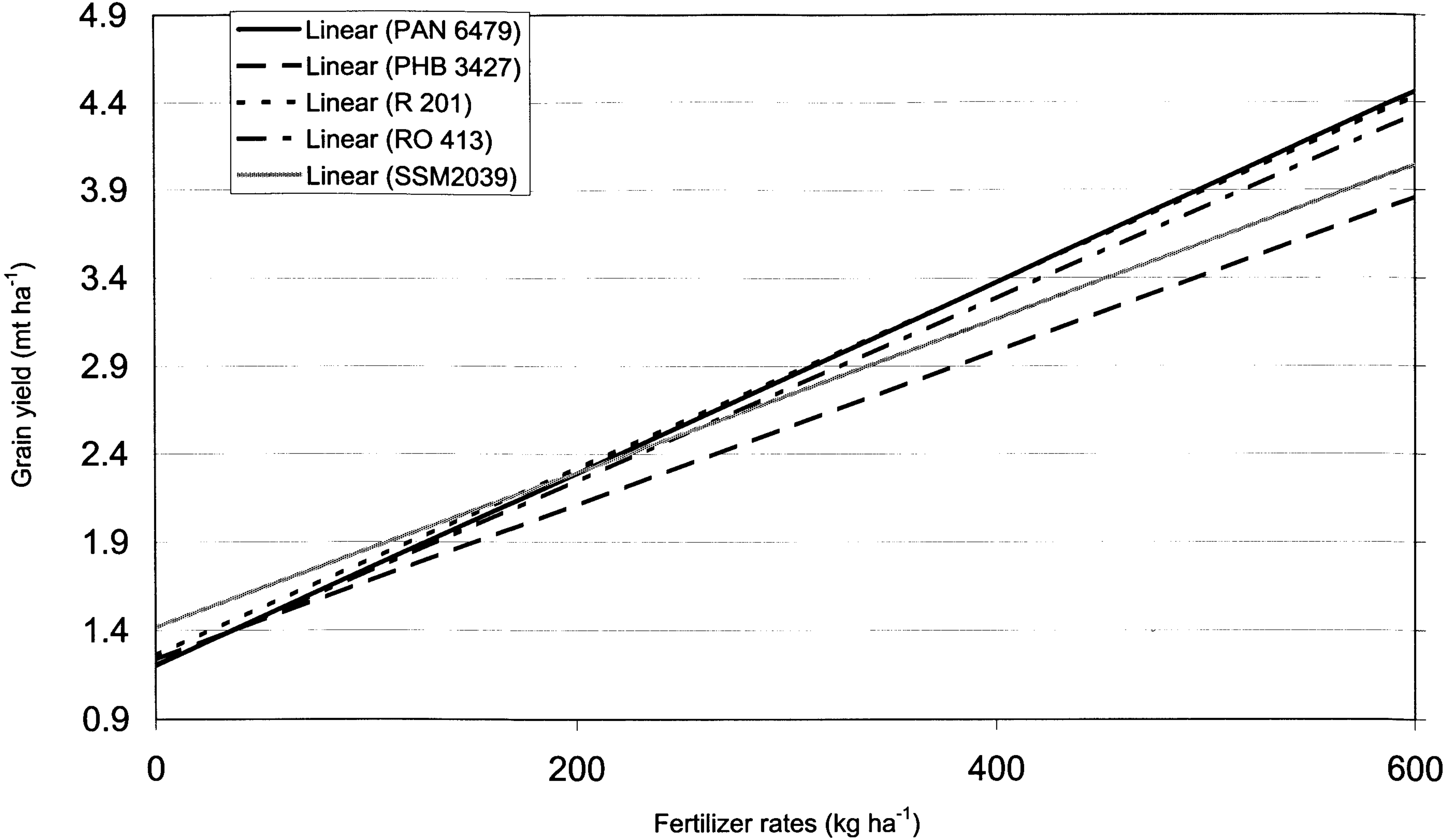

Figure 20: Regression of grain yield (mt ha^{-1}) of five maize cultivars over four fertilizer rates at Hawane

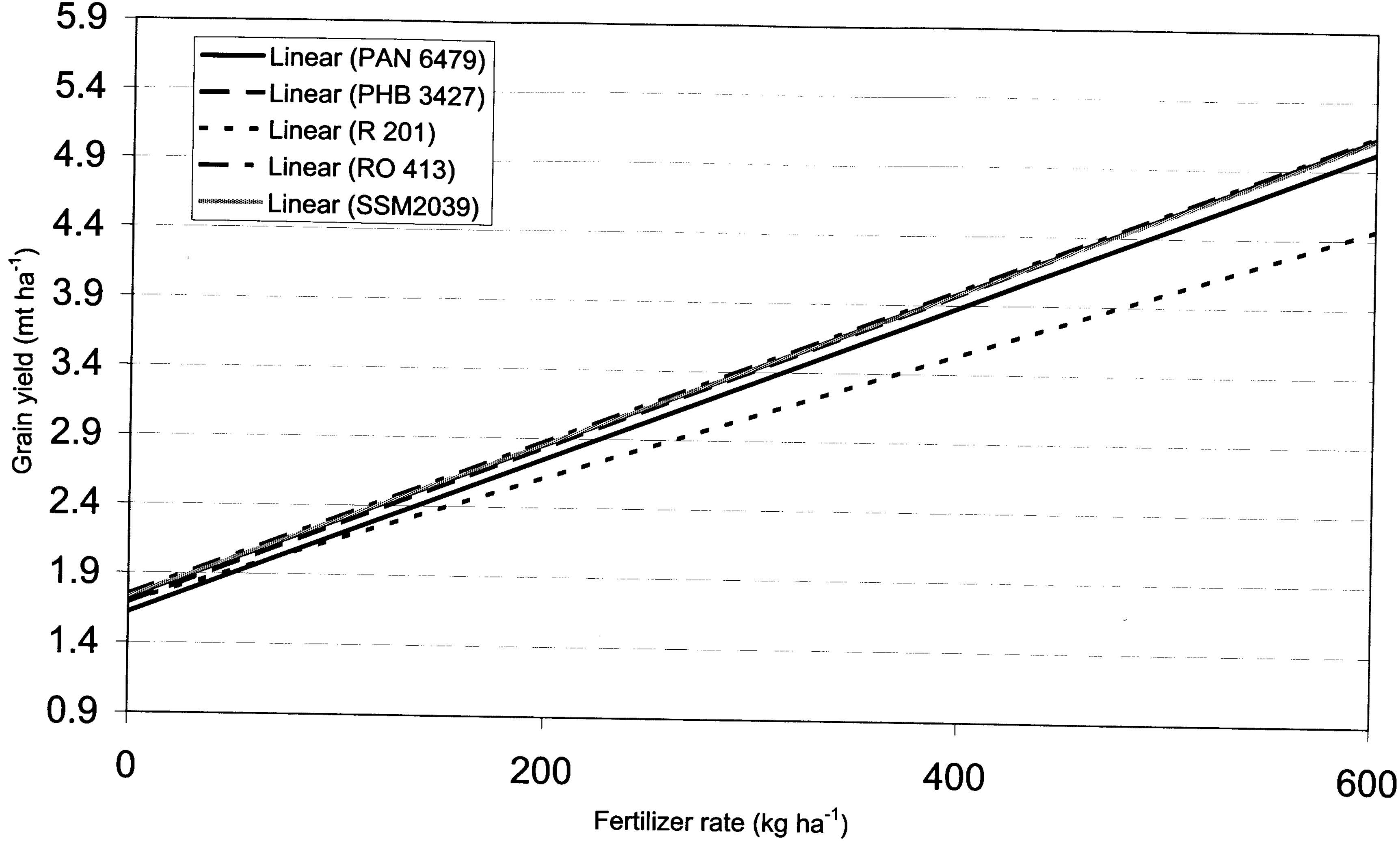

Figure 21: Regression of grain yield (mt ha^{-1}) of five maize cultivars over four fertilizer rates at Mbelebeleni

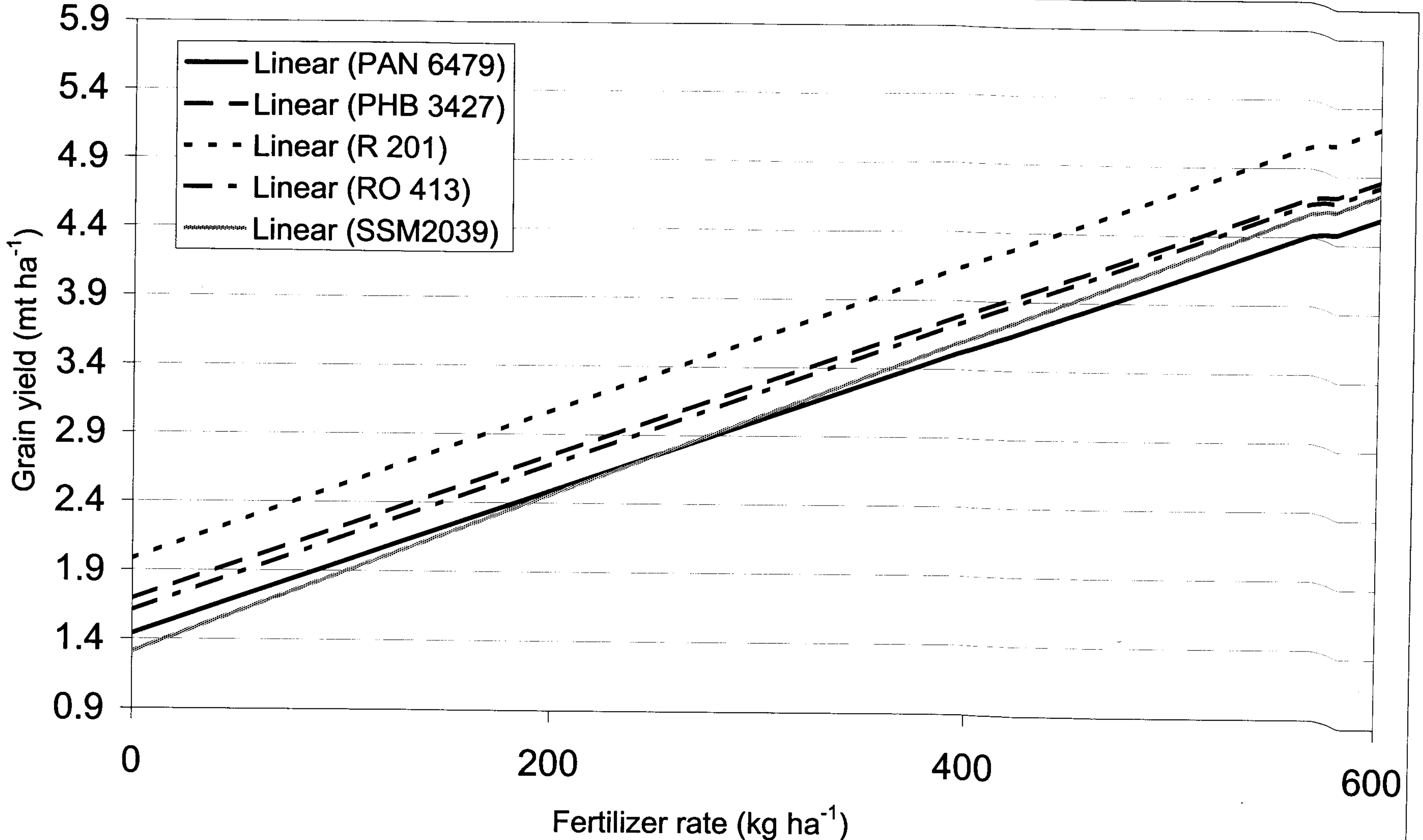

Figure 22: Regression of grain yield (mt ha-1) of five maize cultivars over four fertilizer rates at Mdayane

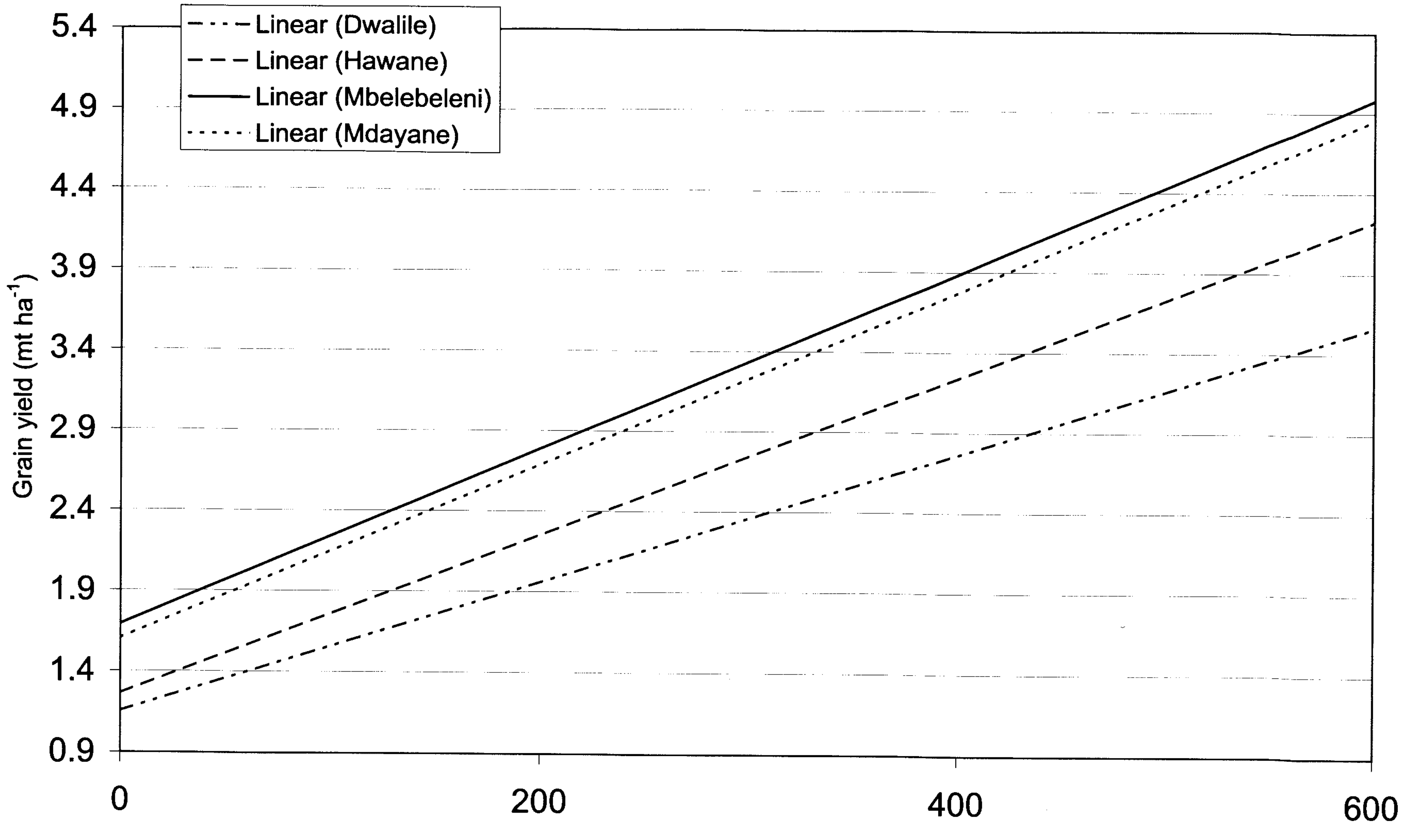

Figure 23: Regression of grain yield (mt ha^{-1}) of five maize cultivars over four fertilizer rates at four locations

Table 7: Grain yield in (mt ha^{-1}) of five maize cultivars under four fertilizer rates at Mdayane.

Fertilizer rate (kg ha^{-1})	Maize cultivars				
	PAN 6479	PHB 3427	R 201	RO 413	SSM 2039
0/0	1.37h[2]	1.34h	1.86gh	1.67h	1.26h
200/160[1]	2.71efg	3.13def	2.95ef	2.52fg	2.62efg
400/160	3.31cde	4.08abc	4.72a	3.85bcd	3.43cde
600/160	4.66ab	4.55ab	4.90a	4.81a	4.83a

[1]Figure before the slash represents the compound fertilizer rate while the figure after the slash represents the N top-dressing fertilizer rate.

[2]Means followed by the same letter are not significantly different according to Duncan Multiple Range Test.

4.9 Correlation of grain yield with HI, canopy height and canopy width

A positive correlation between yield and canopy height ($r = 0.94$) was recorded across the sites at $P \leq 0.05$. The correlation between grain yield and canopy width and between the grain yield and the harvest index were also positive with $r = 0.95$ and $r = 0.88$, respectively, at $P \leq 0.05$ across the sites. The correlation of grain yield with canopy width and canopy height indicate that the wider and taller the canopy, the more irradiance is intercepted for dry matter production through photosynthesis (Hay and Walker, 1989). This observation will hold true if other parameters such as light, temperature, soil moisture and nutrients are not restrictive. The positive correlation between the grain yield and the harvest index shows that with the fertilizer rates used, the proportion of grain yield increased as the total biological yield of the cultivars increased with increasing fertilizer rate.

CHAPTER V

DISCUSSION

The study looked into the effect of site on grain yield, canopy height, canopy width, harvest index and the nutrient concentration in the grain and leaves of five maize cultivars treated with four fertilizer levels. Soil type was the key characteristic of a site in addition to rainfall and temperature.

5.1 Canopy Height and Canopy Width

Both variables were influenced by fertilizer rate and site ($P \leq 0.01$). The variables increased as the amount of fertilizer applied was increased at each site. The responses were only significant between the control and 200/160 kg ha^{-1} rate of fertilizer and thereafter additional fertilizer did not cause a significant response in either variable. This scenario was observed at each site but the responses to the fertilizer rates differed between the sites. The canopy height and width were lower at Dwalile but higher at Hawane. At Mdayane the canopy width had the least response to fertilizer application as the control did not differ significantly from the other rates of fertilizer.

The response of the plant canopy to fertilizer application at each site must have been influenced by the soil residual fertility status. Mdayane had a higher CEC (8.80 cml (+) kg^{-1}) whereas Dwalile had the least amount (3.19 cml (+) kg^{-1}). A CEC of 8.0 cml (+) kg^{-1} is considered adequate for most soils in Swaziland (Whelan, 1969). Hawane had a CEC of 5.10 cml (+) kg^{-1} but had a higher organic matter content than Mdayane which must have resulted in the higher canopy width and height of the site. Organic matter content is a source of N which is essential for plant canopy development provided other nutrients are not limiting (Hay and Walker, 1989; Spiertz and Ellen, 1978). Soils at Hawane tested high in residual N (0.22 %) (Table 1). The site had more K (0.36 %) while Mdayane had the least (0.13%). On the other hand, Dwalile had the lowest soil pH (3.9) and CEC. It also had a low organic matter content (2.02 %) although the site tested high in P (4.97 ppm) than the other site. The availability of cations for plant uptake is adversely affected by low soil pH and thus the site had the least response to applied fertilizer and it had the lowest plant canopy under the control treatment. It also had the lowest grain yield at each fertilizer rate.

At Hawane, both the canopy height and canopy width were significantly higher than at Dwalile but the grain yield was not. The site tested higher in residual N and K content than the other sites (Table 1). It had the second highest P content (3.21 ppm) after Dwalile (4.97 ppm). The high organic matter content and CEC in addition to the applied fertilizer should have positively influenced the higher canopy height and width at this site. Although the plant canopy at Hawane (Figure 2) was conducive for higher grain yield (2.74 mt ha^{-1}), the site had the second lowest yield after Dwalile (2.36 mt ha^{-1}). This is contrary to the findings by Eik and Hanway (1966) which showed that the grain yield of some maize cultivars increased as the leaf area index increased. Stoskpf (1981) attributes low grain yield when the plant canopy is large to the shading of the ear which delays silk development. This is likely to have happened at this site due to its larger plant canopy compared to the other sites ($P \leq 0.01$).

A delay in silk development results in poor pollination due to lack of synchronization of pollen shedding and silk receptivity for fertilization. The N and K applied in addition to the higher residual contents of the elements in conjunction with a higher synthesis of gibberelic acid and indole acetic acid might have contributed to the excessive stover production at the expense of grain at Hawane, as observed by Stoskopf (1981) and Hay and Walker (1989). This is likely to have been the case although the concentration of the hormones was not determined for this study because Hawane was the only site which tested higher in residual N and K. The synthesis of these hormones is increased under high K nutrition by a cereal crop (Hay and Walker, 1989). This can only be corrected by applying the required amount of K fertilizer in the soil.

Excessive application of one element is expensive and results in the pollution of the environment and antagonism between essential nutrients is enhanced (Mengel and Kirkby, 1987).

In Zambia, the practice of compound fertilizer application is based on the most abundant key nutrient element in the soil type. It was found that the response to K by some maize genotypes planted in Kalahari sands and in some soils of the North Western Province was not significant (Mwale, 1988). Then the recommended technology for K abundant soils was a compound fertilizer that was low or had no K depending on observed responses. Compound R has no K while compound X has less K than compound D and each was recommended accordingly. This practice conforms to part of the notion that the amount of fertilizer to apply should be based on the amount of N, P and K as well as key trace elements already in the soil, the maize cultivar being used, the length of the growing season and the target optimum yield (Mwale, 1988).

5.2 **Harvest Index**

The HI of the cultivars differed significantly ($P \leq 0.01$) between the sites, fertilizer rates and the cultivars. The influence of these factors was also noticed with canopy width and height. The HI increased significantly with the addition of 200/160 kg ha-1 rates of fertilizer than when the rates were increased thereafter. At Mbelebeleni the grain to stover proportion remained the same as fertilizer rate was increased. This implies that the added nutrients resulted in a proportional increase to both the grain and the stover. At Dwalile, Hawane and Mdayane the addition of the 200/160 kg ha^{-1} of fertilizer resulted in a relatively more grain being formed compared to the stover but this could not be significantly maintained as the rate was increased. The greatest increase was realized at Hawane between this rate (200/160 kg ha^{-1}) and the control which showed that the added fertilizer increased the availability of some nutrients (N, P and K) for plant uptake and synthesis. Overall, the HI increased as fertilizer application was increased and this increase differed between sites.

This general increase in HI with increasing fertility was also observed by Spiertz and Ellen (1978 but at variance with those of Pearman (1978) and Downes (1988). The decrease in HI as fertility increases is attributable to an increase in biomass at the expense of the grain. This phenomenon is common where nitrogen is involved (Stoskopf, 1981). A high N nutrition in excess of other nutrients encourages the production of stover at the expense of grain in cereals thus the HI is reduced. At Dwalile and Mbelebeleni the addition of 600/160 kg ha^{-1} of fertilizer did not increase the HI but an increase was observed at the other sites.

Although Hawane had the largest canopy across the fertilizer rates, it had the lowest HI. The lower grain proportion compared to stover could have been caused by poor pollination resulting from delayed silk development due to shading caused by the large plant canopy (Stoskopf, 1981). On the other hand, Dwalile had the highest HI although the site had the lowest yield, canopy height and canopy width. At this site, more photosynthates were used in grain development relative to the stover. This could have been a result of a stressful environment arising from the low soil pH (3.9), low CEC and organic matter (Table 1) or some soil characteristics which need further investigation when the soil pH has been corrected (assuming similar results are obtained during subsequent seasons). Some researchers have found that environment affects the HI. Snyder and Carlson (1984) found that the environment has a significant effect on HI as it affects the partitioning and accumulation of dry matter.

A cultivar with a high HI accompanied by a high biological yield is said to be efficient in partitioning more of its dry matter produced into economic yield under a given environment (Nass, 1973; Tesar, 1988). The nutrients available to the crop plant are optimized by cultivars with a high HI (Wallace *et al.* 1972; Snyder and Carlson, 1984). In this study, PHB 3427 and R 201 had higher HIs than the other cultivars (Figure 4). These cultivars had significantly higher HI at Mbelebeleni and Mdayane (Figure 4) and across the sites (47.9% and 49.0%, respectively).

Both cultivars tended to have higher overall canopy heights and widths (Figures 1 and 3). The cultivar R 201 had the highest yield at Mdayane and across the sites while PHB 3427 had the second highest yield at Mbelebeleni and Mdayane (Figure 18).

5.3 Grain and Leaf Concentration of N, P and K

The concentration of N, P and K in both the grain and the leaves generally increased as the fertilizer rate was increased at each site as it was observed by Hanway (1962b; 1962c), Voss *et al.* (1970) and Walker and Peck (1975). This followed the trend of grain yield. The concentration of the elements differed significantly ($P \leq 0.01$) between sites (Figures 5, 7, 9, 11, 13, 14 and 16). These differences can be attributed to the soil types and their residual fertility. The results indicate that fertilizer application rates should take soil type and its residual fertility into account. The leaf concentrations of the elements were generally below the optimum values of 2.8%, 0.28% and 1.7% for N, P and K, respectively (Manson *et al.*1997).

At Mbelebeleni the soil texture was more sandy and the concentration of the elements in the grain and leaves showed a great increase as the fertilizer rate was increased compared to Mdayane or Hawane (Figures 6, 8, and 13). The site also tested low in the soil content of N, P, total CEC and organic matter content (Table 1) and thus the response to additional fertilizer was higher compared to Mdayane or Hawane. Sandy soils are prone to leaching and are low in residual N and K relative to other soil types (Mallett,1988; Chancey and Kamprath, 1982). The soil found at Mbelebeleni may require a specific fertilizer recommendation compared to Hawane and Mdayane. Cooke (1982) found that the response to added nutrient elements depended on the residual content of each element as well as the soil condition.

The leaf and grain [N], [P] and [K] showed a great variation between the sites ($P \leq 0.01$). The grain [N] was relatively higher at Dwalile and Hawane while lower at Mbelebeleni and

Mdayane (Figure 5, 6). Dwalile and Hawane had lower grain yields than the other sites, which shows that there were either few or small grains at these sites and the nutrient was not adequately utilized. The lower soil pH for these sites could have affected the uptake of other elements like P and Ca to enhance the optimum development of potential biomass of the grains. Since at Mbelebeleni and Mdayane the yields were higher the grain [N] was diluted by more biomass per grain indicating a more efficient use of the element. The [P] concentration in the grain was highest at Mbelebeleni. This could have been enhanced by the higher soil pH (4.9) compared to the other sites. Secondly, the [P] was greatest at the 400/160 and 600/160 kg ha^{-1} rates of fertilizer whereas at the lower rates it was the lowest. This shows that the uptake of P was enhanced by the addition of fertilizer to the soil as the residual P (1.86 ppm) of the soil was lower than the other sites. Sandy soil colloidal particles have a small surface area compared to clay soils which increases the amount of soluble P in the soil which in turn improves its uptake. The [P] (0.37%) at the 600/160 kg ha^{-1} was within the expected range of 0.2 - 0.6% P (Jones, 1973).

Hawane had a higher grain [K] than the other sites. It also had a higher residual soil K (0.36%) and the addition of fertilizer increased K availability in the soil. The grain [K] exceeded the normal expected range (0.2 - 0.4%) at all the fertilizer rates. At Mdayane the grain [K] was above the optimum range at the 600/160 kg ha^{-1} rate of fertilizer whereas at Mbelebeleni the concentration exceeded the expected range at both the 400/160 and 600/160 kg ha^{-1} rates. This suggests that K containing fertilizer recommendations should be modified accordingly.

From these results, it is evident that the sites differed in the availability of the tested nutrients. The differences confirm the results obtained under canopy height, canopy width and the harvest index which showed significant differences between the sites. The use of tissue analysis results to augment soil test results in making fertilizer recommendations have been emphasized by Ross *et al* (1970); Walker and Peck (1974 and 1975) and Dumenil (1961). The advantage of tissue analysis is that it relates availability of nutrients in the soil solution to the uptake of such nutrients by the plants.

5.4 **Grain yield**

The differences in grain yields between the sites, as found in the study, are a reflection of the significant variations in some key factors that affect plant growth and development and subsequently yield. These include, among others, rainfall, temperature, soil physical and chemical properties, prevalence of pest and diseases and location (Russell, 1973; Manson, 1988). The results reported herein, showed that the grain yield of maize averaged over cultivars, was lowest at Dwalile (2.36 mt ha^{-1}) followed by Hawane (2.74 mt ha^{-1}) Mdayane (3.23 mt ha^{-1}) and Mbelebeleni (3.34 mt ha^{-1}) (Figure 17). In terms of significance, the grain yield from Dwalile was significantly lower than at the other sites. The differences in grain yield between the sites can be attributed to the different soil chemical and physical properties since the treatments were not varied. Soil texture is one factor that can affect plant development and yield. Sandy soils found at Mbelebeleni could have limited grain yield due to moisture stress if soil moisture supply is limiting even though nutrient supply can be optimum. When both soil moisture and nutrients are not limiting, they are easily taken up by the roots in sandy soils than in clayey soils due to low adhesive forces and thus yields are increased (Manson, 1988; Hamblin, 1985; Russell, 1973, Mengel and Barber, 1974). The increasing grain [P] and [K] with increasing fertilizer rate at Mbelebeleni indicate that the uptake of the elements by the maize plants was easier than at the other sites which had more clay relative to sand. This will hold true if soil moisture is not excessive to enhance the leaching of nutrients out off the rooting zone.

Soils which are high in clay (more than 35%) as found at Hawane and Mdayane have a tendency to hold more water and nutrients due to the high surface area of their colloidal particles. They *are not easily penetrated by roots as a result of their high bulk density. Roots have to spend more* energy to traverse the soil profile to take up moisture and nutrients (Hamblin, 1985; Warncke and Barber, 1972; Veen et al., 1992). Under optimum soil moisture conditions as it was the case at Hawane and Mdayane these disadvantages of clayey soils are less prevalent than as might happen under soil moisture limiting conditions (Manson, 1988). When nutrients are adequately supplied as shown at Hawane and Mdayane, uptake of the nutrients is enhanced due to a rather high reservoir and buffering ability of the soils. Schenk and Barber (1979) found that soils with a high buffering ability ensure a prolonged supply of nutrients during plant development since leaching is reduced. The effect of the soil particles on nutrient supply are a challenge to the development of fertilizer recommendations and need further study in Swaziland. The study has not established a correlation between the grain yield and the soil particle composition but does indicate a possible effect as the grain yield differed between the sites in addition to the differences observed from the other parameters studied. The differences in grain yield between sites were also obtained by Hanway (1962a and 1962b); Robertson et al. (1965); Voss *et al.* (1970); Tsai *et al.* (1984; Zambezi *et al.* (1995, Hikwa *et al.* 1997). Some of these researchers attributed the differences to factors such as the residual soil fertility, previous management practices, soil properties and season. For this study, climate may also have had an effect in that the sites with lower yields are in the Highveld while those with higher grain yields are in the Middleveld. Previous management practices of the sites differed slightly. Dwalile had not received any addition of kraal manure than the other sites. This may have contributed to its low organic matter content and low residual N. Its soil texture may have been relatively poorer which restricted soil moisture content and root penetration in addition to the effects of low pH. Adequate organic matter content improves the porosity and moisture retaining capacity of a soil which in turn improves the uptake of nutrients and water by a crop (Russell, 1973)..

The maize grain yield increased with the rate of fertilizer across the sites, i.e., 1.36, 2.46, 3.50

and 4.32 mt ha^{-1} with the 0/0, 200/160, 400/160 and 600/160 kg ha^{-1} rates of fertilizer, respectively. This implies that in general, the fertility level of the soils was significantly improved by the application of nutrients. Similar results were reported by Zambezi *et al.* (1995) and Hikwa *et al.* (1997) in Malawi and Zimbabwe, respectively. Tsai *et al.* (1984) and Hanway (1962a; 1962b) also obtained similar results. Most of these researchers concur that the response to applied fertilizer depends on the soil condition and its residual fertility status in addition to the effects of cultivar, climate and season. The general response of grain yield to increasing fertilizer rate for this study was irrespective of site. Zambezi *et al.* (1995) and Voss *et al.* (1970) obtained similar results from their experiments, which they conducted in Malawi at different sites where soil chemical and physical differences were at play. For this study, it has been noted that the magnitude of the yield response to increasing nutrient application was not the same across the sites. The study also showed that the yield response between some fertilizer rates was not significantly different, indicating that the higher rate may not be necessary. At Dwalile, Mbelebeleni and Mdayane, the optimum yields were obtained with the 400/160 kg ha^{-1} rate, while at Hawane, the optimum response was achieved at the 600/160 kg ha^{-1} rate of fertilizer. This is in spite of the fact that this site had the highest total N, organic matter content and K; the second highest P, Ca and CEC, with a pH of 4.5 (Table 1). The grain yield at Dwalile was the lowest at each fertilizer rate as it was true for the plant canopy. This is attributable to low soil pH (3.9) plus the other soil properties already mentioned above. This view is also shared by Russell (1973) and Tisdale *et al.* (1985) reported in their literature review on nutrient uptake under acid soil conditions.

The individual cultivar yield performances averaged across the four sites were similar. This is supported by the absence of individual site cultivar effect on grain yield except at Mdayane, where the cultivar effect was significant ($P \leq 0.05$). Zambezi *et al.* (1995) obtained similar results in one of the sites used for their study in Malawi. On the other hand, some sites had better conditions for the cultivars to express their yield potential (Figure 18). The cultivar R 201 had a significantly higher yield at Mdayane relative to the other sites ($P \leq 0.05$). This finding is in partial agreement with the present practice in the country of recommending cultivars according to agro-ecological zones and planting date. Early maturing cultivars are recommended for late planting. Further research is required to investigate the responses of the cultivars to increasing rates of fertilizer based on the residual fertility and physical properties of a soil per site and the time of planting, as some cultivars may consistently yield higher over different dates of planting provided that the fertility of the soil is adequate. Late maturing cultivars should yield lower than early maturing types if planting is done late (Mallett, 1988). The cultivar R 201 should have yielded higher than the other varieties since it is early maturing but it yielded higher at Mdayane only. It should have yielded higher at Dwalile and Hawane since the sites have higher altitudes where cool temperatures set in earlier than at Mdayane. This was most likely to occur because the experiment was planted later than October which is the suitable month for planting maize in the country (Pali-Shikhulu and Ndlangamandla, 1995).

The differences in grain yield between the sites were also revealed by regressing the site mean grain yield per fertilizer rate against the four fertilizer (Figure 23). This showed that the grain yield response of the maize cultivars differed between sites over the same fertilizer rates.

5.5 **Correlation**

The correlation of the grain yield with canopy height, canopy width and the harvest index was positive across the sites. This observation was also made by DeLoughery and Crookston (1979) with the exception of plant canopy width. This positive correlation between these yield components with grain yield shows that they may be equally affected as the yield in an environment (Synder and Carlson, 1984). Eik and Hanway (1966) noted that the maize grain yield tended to be linearly related to the leaf area index (LAI).

CONCLUSION AND RECOMMENDATIONS

The results of the study show that the optimum maize grain yield can be achieved with 400 kg ha^{-1} of the compound fertilizer 2:3:2 (22) and a top-dressing of 160 kgN ha^{-1} (L.A.N (28)) irrespective of cultivar. The grain yields were different between the sites, showing that some sites had better conditions of fertility than others although none of the cultivars gave a superior yield at any of the sites except R 201 at Mdayane. The differences in the productivity of the sites were further proven by the statistically different canopy widths and heights as well as the harvest indices, the grain and leaf [N], [P] and [K] of the maize cultivars. The maize grain yield response can be improved if the current fertilizer recommendations are reviewed so that individual nutrient elements are applied according to their soil residual contents so that the crop's nutrient requirements are adequately addressed. These conclusions are tentative and need to be proven through further research.

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APPENDICES

Appendix 1: Combined site analysis of variance for grain yield

K Value	Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob
1	Location	3	36.834	12.278	8.3033**	0.0006
3	R(L)	8	15.873	1.984	1.3418	0.2712
4	Factor A	3	297.277	99.092	67.0141**	0.0000
5	LA	9	6.668	0.741	0.5011ns	
-7	Error	24	35.488	1.479		
8	Factor B	4	0.185	0.046	0.2326ns	
9	LB	12	4.521	0.377	1.8902*	0.0413
12	AB	12	2.115	0.176	0.8842ns	
13	LAB	36	7.221	0.201	1.0064ns	0.4706
-15	Error	128	25.512	0.199		
	Total	239	431.694			

Coefficient of Variation: 15.31%
ns : not significant
* : significant at 5% probability level.
** : significant at 1% probability level.

Appendix 2: Recommended maize cultivars according to agro- ecological zone in Swaziland.

Main Agro-ecological Zones and Recommended Maize Cultivars			
Highveld	Middleveld	Lubombo Plateau	Lowveld
SR 52	SR 52	TX 379	CG 4141
SNK 2665	SNK 2665	PAN 473	R 201
PAN 6479	SNK 2147	SSM 2039	
SNK 2147	PAN 6479	PHB 3435	
PAN 6549	PAN 6549	RO 413	
PHB 3427	PHB 3427	CG 4141	
PHB 3253	PHB 3253	R 201	
PAN 95	PAN 95		
RO 413	RO 413		
TX 379	TX 379		
PAN 473	SSM 2039		
SSM 2039	PAN 473		
PHB 3435	PHB 3435		
CG 4141	CG 4141		
R 201	R 201		

Source: Ministry of Agriculture and Cooperatives, Mbabane, Swaziland (1995).

Appendix 3: Rainfall (mm) Data for Hawane, 1996/97 cropping season.

Date	Months						
	Oct	Nov	Dec	Jan	Feb	Mar	Apri
1				60.0		2.0	3.0
2				8.0	5.0	5.0	5.0
3			20.0		5.6	5.5	6.0
4				15.0		20.0	0.5
5			11.0	6.0	7.0	21.0	22.0
6		2.0				2.0	
7		0.5	6.5			4.0	1.0
8					10.0	5.5	
9					5.0	22.0	
10				7.0	40.0	25.0	
11				10.0	0.5	1.0	
12	10.0			30.0		22.0	0.5
13				13.0	2.0	3.5	
14		50.0	20.0	9.0		2.0	
15	0.5			17.0		3.0	0.5
16	2.5	4.0	17.0	27.0		3.3	2.0
17	2.0	12.0		5.0	3.0		20.0
18		4.0	5.0				
19	10.0		10.0				
20							10.0
21						24.0	
22	80.0						
23	40.0	2.0	30.0				2.0
24	30.0				5.0	2.0	
25	1.0				4.0	55.0	
26	2.0	10.0		1.0		5.0	
27		5.0		0.5	40.0	20.0	
28		30.0		5.0	3.0		
29		13.0		4.0		2.0	
30	50.0						
31						5.0	
Total	228.0	132.5	119.5	217.5	130.1	259.8	72.5
*Mean	137.0	197 0	217.0	254.0	221.0	157.0	85.0

*Mean : Longterm monthly average rainfall for the Mbabane meteorological station in the Highveld.

Source: Motshane/Siphocosini Rural Development Areas (Project Centre), 1997.

Appendix 4: Rainfall (mm) Data for Mbelebeleni, 1996\97 Cropping Season.

Date	Months						
	Oct	Nov	Dec	Jan	Feb	Mar	Apri
1			9.0			12.0	
2				18.0	95.0		2.1
3	1.8						
4						1.1	
5			9.0	2.8		85.0	
6		2.8				5.8	
7			47.0			2.0	3.5
8		0.8			10.0	6.8	
9			17.0				31.0
10				36.0	48.0	46.0	
11				5.9			
12				46.0		15.0	
13	5.9				4.5	6.0	
14		22.0					
15		3.6		8.0			
16		8.0	18.0	1.1			
17		12.0		4.5			1.2
18							
19							
20				42.0			28.0
21	1.9	6.0				24.0	
22		1.2					
23	53.0		6.0				
24	68.0		9.0		3.0	3.4	
25	28.0					60.0	
26		2.3					
27		6.8			3.3	4.5	
28		1.0			5.4		
29		1.1					
30	6.0					30.0	
31	9.8						
Total		67.6	115.0	164.3	169.2	247.6	90.6
*Mean	102.0	130.0	121.0	138.0	132.0	105.0	60.9

*Mean : Longterm monthly average rainfall for the Matsapha meteorological station in the Middleveld.

Source: Mliba/Bhekinkosi Rural Development Areas (Project centre), 1997..

Appendix 5: Rainfall (mm) Data for Mdayane, 1996\97 cropping Season.

Date	Months						
	Oct	Nov	Dec	Jan	Feb	Mar	Apri
1				49.0		11.0	
2					86.0		
3	1.0	2.0			26.0		18.0
4						2.0	
5			15.0	2.5		62.0	
6		1.5				5.0	
7			9.0				1.5
8				1.0			
9			3.0		15.0	42.0	
10	1.0			17.0		9 0	26.0
11				19.0			
12				22.0		19.0	
13				4.0	5.0	9.0	
14	3.0	22.0					
15		7.5		4.5			
16			16.0				
17				6.0			
18		11.0		7.0			
19			10.0				
20		2.0					
21		9.0				20.0	15.0
22						9.0	
23	54.0			26.5			
24	48.0	35.0		3.0	3.5		
25						15.0	
26		30.0					
27		24.0			2.5	4.0	
28							
29	9.0						
30		5.0					
31	5.0					20.0	
Total	121.0	149.0	53.0	161.5	138.0	227.0	60.5
*Mean	102.0	130.0	121.0	138.0	132.0	105.0	60.9

*Mean: Longterm monthly average rainfall for the Matsapha meteorological station in the Middleveld.

Source: Mliba/Bhekinkosi Rural Development Areas (Project Centre), 1997

Appendix 6: Maximum Temperatures (°C) for Hawane, 1996\97 cropping Season.

Date	Month							
	Oct	Nov	Dec	Jan	Feb	Mar	Apri	May
1	33.3	27.7	26.8	28.0	m	m	16.6	24.2
2	24.3	29.4	31.4	19.2	25.1	25.8	21.0	25.7
3	24.2	27.4	15.9	24.3	23.0	30.9	22.3	m
4	28.4	31.7	20.0	22.4	26.0	28.8	m	26.0
5	27.6	27.	21.7	22.0	25.9	23.4	26.0	25.8
6	27.3	21.3	26.1	2.1	25.9	25.1	25.8	21.6
7	30.3	26.0	25.0	27.0	27.3	24.4	21.6	19.8
8	30.4	m	21.2	29.5	23.4	23.0	19.8	20.6
9	22.9	m	24.2	31.7	23.0	20.2	20.6	19.0
10	18.2	27.1	24.3	17.8	25.0	26.0	19.0	m
11	28.2	29.2	28.2	17.0	26.6	28.4	m	m
12	29.9	31.2	24.0	15.6	17.0	15.5	m	22.2
13	25.1	29.4	25.0	21.8	18.0	17.7	22.2	21.9
14	25.9	12.1	20.5	20.4	m	m	21.9	26.3
15	20.2	m	24.5	23.8	m	20.6	26.3	22.4
16	15.2	m	25.8	26.2	27.0	22.0	22.4	25.0
17	19.6	23.6	30.1	m	21.9	22.6	25.0	26.5
18	26.4	27.0	29.0	20.4	27.5	22.0	2.5	m
19	27.5	25.9	15.8	24.8	26.6	26.0	m	23.9
20	31.9	28.3	m	26.0	26.8	25.8	23.9	22.5
21	14.8	25.8	m	26.1	28.3	20.7	22.5	21.0
22	18.5	m	28.7	28.1	m	m	21.0	22.4
23	16.8	24.0	24.4	21.5	16.0	23.9	19.2	19.5
24	27.5	26.4	26.9	24.0	16.8	25.0	20.0	m
25	19.7	29.2	28.8	m	25.5	22.	m	21.5
26	21.0	20.2	29.1	26.3	25.0	19.3	24.3	18.6
27	25.3	14.1	28.4	24.6	18.8	17.1	22.5	16.2
28	2.1	19.9	28.1	24.0	m	m	22.2	11.5
29	20.4	28.2	2.7	25.3		25.8	16.5	7.5
30	21.4	23.0	28.2	27.0		22.0	21.4	m
31	27.4		26.4	27.3		22.0		m
*Mean	22.9	23.1	24.4	24.9	24.0	24.0	22.5	21.3

m = missing data
*Mean = longterm monthly daily mixinum temperatures
Source: Mbabane Meteorological Station, 1997.

Appendix 7: Minimum Temperatures (°C) for Hawane, 1996/97 cropping season.

Date	Months							
	Oct	Nov	Dec	Jan	Feb	Mar	Apri	May
1	17.6	12.1	15.3	17.5	16.1	m	13.5	8.0
2	12.8	14.5	17.1	16.0	m	m	15.0	12.0
3	13.8	15.5	13.6	15.1	16.1	16.5	18.1	9.4
4	12.4	17.1	14.1	15.8	15.0	16.5	12.5	m
5	14.6	17.8	13.1	15.4	18.5	18.0	m	12.0
6	15.4	14.0	16.4	15.2	17.0	18.5	11.8	10.0
7	14.9	13.8	15.1	17.4	17.6	18.2	7.8	6.6
8	13.4	16.0	16 0	17.0	16.5	18.0	6.6	m
9	15.7	m	12.0	18.5	16.2	m	7.0	9.5
10	9.9	m	13.3	15.9	15.1	18.5	11.5	m
11	9.8	12.0	14.6	15.3	18.5	19.5	9.0	m
12	19.3	17.0	17.0	14.7	17.0	12.5	m	4.6
13	13.2	19.6	15.1	13.1	17.0	13.5	m	7.5
14	13.7	10.8	15.0	12.0	11.5	13.0	14.0	8.0
15	18.6	9.8	16.5	16.1	m	m	13.8	5.0
16	8.5	m	12.5	16.0	m	13.4	11.0	11.0
17	8.0	m	14.2	17.5	12.6	14.2	11.5	8.2
18	9.9	17.9	17.1	m	16.9	12.5	15.0	m
19	11.0	15.5	12.0	14.0	17.0	14.6	16.5	7.5
20	18.3	16.8	12.2	16.1	18.2	17.5	m	9.5
21	11 0	17.2	m	17.9	17.0	16.0	13.5	8.2
22	11.1	13.2	m	17.5	15.4	12.5	9.9	12.0
23	12.8	m	14.5	17.6	m	m	10.9	11.5
24	13.4	18.1	17.2	17.0	13.5	12.5	7.5	12.0
25	14.5	15.2	17.9	m	14.5	13.5	10.7	m
26	13.0	16.4	17.5	m	16.0	15.5	m	12.5
27	13.5	10.2	17.3	15.8	13.5	12.5	10.2	6.5
28	15.0	11.0	16.3	16.5	14.5	13.2	15.0	3.6
29	15.5	14.4	17.5	16.5		13.2	7.5	1.6
30	13.8	17.0	15.4	14.4		17.0	4.8	3.5
31	14.2		18.6	16.4		10.8		m
*Mean	11.2	12.7	14.1	14.8	14.5	13.3	10.8	7.8

m : missing data
*Mean : longterm monthly daily minimum temperature
Source: Mbabane Meteorological Station, 1997.

Appendix 8: Maximum Temperature (°C) for Mdayane, 1996\97 cropping season.

Date	Months							
	Oct	Nov	Dec	Jan	Feb	Mar	Apri	May
1	35.1	30.5	25.6	32.1	29.9	27.0	24.5	24.2
2	26.6	31.5	35.6	24.5	28.2	29.4	24.0	25.7
3	27.0	29.4	21.5	29.0	28.0	33.8	24.9	m
4	30.5	35.1	25.0	28.4	29.4	33.4	25.9	19.7
5	31.0	31.5	24.7	26.5	30.4	27.1	27.7	19.3
6	31.0	27.0	30.0	30.2	30.5	28.7	28.5	16.4
7	33.8	25.5	26.4	32.5	31.4	26.5	24.0	m
8	33 2	29.6	25.0	33.4	28.5	31.6	23.	21.0
9	26.0	30.1	27.9	37.4	27.0	24.5	24.2	m
10	22 2	27.8	28.0	20.6	29.5	28.9	21.5	m
11	31.0	33 1	31.5	19.5	30.5	31.3	25 2	18.6
12	31.3	34 2	28.6	20.0	31.0	20.0	21.0	18.9
13	27.0	34.1	28.6	25.6	20.7	22.0	23.6	18 5
14	29 6	16.2	28.5	25.0	23.4	24.2	44 9	20.0
15	24.0	21.5	28.2	28.6	21.9	24.3	26.0	19.2
16	21.0	25.0	31.9	30.5	30.5	26 1	24.7	22.6
17	23.2	27.6	31.9	25.5	23.4	25.2	29.4	m
18	28.2	28.5	31.0	22.2	29.2	26.3	29.0	24.6
19	30.6	28.5	21.2	28.7	30.0	29.4	28.8	23.8
20	34.2	30.8	25.5	30.4	29.4	28.5	25.5	25 3
21	20.9	29.0	32.0	30.0	27.0	24 0	25.4	22.0
22	20.5	29.5	25.6	31.6	34.5	22.6	22.8	23.4
23	18.9	26.0	27.3	26.2	21.9	27.4	21.0	19.5
24	26.1	27.5	30.5	29.0	22.5	27 5	23.6	m
25	24.2	31.8	33.3	30.0	29.2	25.5	22 6	21.5
26	24.7	23.2	32.0	31.5	29.8	24.7	27.0	18.6
27	24.9	18.5	32.4	30.9	20.0	19.9	24.9	16.2
28	27 1	23.8	32.5	31.1	26.1	19.6	24.0	11.5
29	25.0	31.2	31.1	30.4	m	28.4	20.0	7.5
30	26.0	28.0	33.0	31 6		24 7	22.0	m
31	m		31.4	30 7		25.4		m
*Mean	25.7	26.4	28.1	28.5	28.0	27.2	25.7	24.3

m = missing data

*Mean = Longterm monthly daily maximum temperature

Source: Matsapha Meteorological Station, 1997.

Appendix 8: Maximum Temperature (°C) for Mdayane, 1996\97 cropping season.

Date	Months							
	Oct	Nov	Dec	Jan	Feb	Mar	Apri	May
1	35.1	30.5	25.6	32.1	29.9	27.0	24.5	24.2
2	26.6	31.5	35.6	24.5	28.2	29.4	24.0	25.7
3	27.0	29.4	21.5	29.0	28.0	33.8	24.9	m
4	30.5	35.1	25.0	28.4	29.4	33.4	25.9	19.7
5	31.0	31.5	24.7	26.5	30.4	27.1	27.7	19.3
6	31.0	27.0	30.0	30.2	30.5	28.7	28.5	16.4
7	33.8	25.5	26.4	32.5	31.4	26.5	24.0	m
8	33 2	29.6	25.0	33.4	28.5	31.6	23.	21.0
9	26.0	30.1	27.9	37.4	27.0	24.5	24.2	m
10	22 2	27.8	28.0	20.6	29.5	28.9	21.5	m
11	31.0	33 1	31.5	19.5	30.5	31.3	25 2	18.6
12	31.3	34 2	28.6	20.0	31.0	20.0	21.0	18.9
13	27.0	34.1	28.6	25.6	20.7	22.0	23.6	18 5
14	29 6	16.2	28.5	25.0	23.4	24.2	44 9	20.0
15	24.0	21.5	28.2	28.6	21.9	24.3	26.0	19.2
16	21.0	25.0	31.9	30.5	30.5	26 1	24.7	22.6
17	23.2	27.6	31.9	25.5	23.4	25.2	29.4	m
18	28.2	28.5	31.0	22.2	29.2	26.3	29.0	24.6
19	30.6	28.5	21.2	28.7	30.0	29.4	28.8	23.8
20	34.2	30.8	25.5	30.4	29.4	28.5	25.5	25 3
21	20.9	29.0	32.0	30.0	27.0	24 0	25.4	22.0
22	20.5	29.5	25.6	31.6	34.5	22.6	22.8	23.4
23	18.9	26.0	27.3	26.2	21.9	27.4	21.0	19.5
24	26.1	27.5	30.5	29.0	22.5	27 5	23.6	m
25	24.2	31.8	33.3	30.0	29.2	25.5	22 6	21.5
26	24.7	23.2	32.0	31.5	29.8	24.7	27.0	18.6
27	24.9	18.5	32.4	30.9	20.0	19.9	24.9	16.2
28	27 1	23.8	32.5	31.1	26.1	19.6	24.0	11.5
29	25.0	31.2	31.1	30.4	m	28.4	20.0	7.5
30	26.0	28.0	33.0	31 6		24 7	22.0	m
31	m		31.4	30 7		25.4		m
*Mean	25.7	26.4	28.1	28.5	28.0	27.2	25.7	24.3

m = missing data

*Mean = Longterm monthly daily maximum temperature

Source: Matsapha Meteorological Station, 1997.

Appendix 9: Minimum Temperature (°C) for Mdayane, 1996\97 Cropping Season.

Date	Months							
	Oct	Nov	Dec	Jan	Feb	Mar	Apri	May
1	17.6	15.6	18.4	15.5	20.1	19.0	16.0	8.0
2	15.48	17.0	18.1	17.9	18.4	18.5	17.9	12.0
3	16.0	18.4	16.9	19.0	19.1	20.7	18.0	9.4
4	15.5	19.0	16.8	18.4	19.5	19.5	16.1	m
5	16.5	19.9	16.4	18.0	17.9	20 0	15.1	12.0
6	18.5	17.9	18.9	19.4	20.5	21.2	17.9	10.0
7	17.9	17.0	16.4	20.5	20.5	21.0	10.4	6.6
8	16.9	19.9	18.0	20.	19.6	21.5	10.2	m
9	18.4	20.5	15.0	21.0	19.0	22.0	10.9	9.5
10	13.8	16.3	16 9	19.0	19.4	21.5	13.8	m
11	12.7	18.8	17.7	13.0	21.0	21.1	11.5	m
12	18.5	18.8	20.0	12.5	21.5	16.1	12.6	4.6
13	16.5	20.2	18.5	16.0	19.6	16.4	15.0	7.5
14	17.4	14.2	18.8	16.0	15.5	16.4	13.0	8.0
15	20.8	12.3	19.4	18.2	16.0	16.0	16.0	5.0
16	13.8	16.4	16.0.....	19.5	16.8	17.4	14.0	11.0
17	12.4	17.8	18.2	21.5	19.2	17.5	13.4	8.2
18	16.6	16.1	21.2	17.0	19.5	16.0	16.4	m
19	13.5	19.0	14.6	18 5	20.1	18.1	17.5	7.5
20	15.5	19.4	16.0	19.8	20.5	19.6	18.0	9.5
21	13.9	19.5	16.5	20.8	20.0	19.0	16.5	8.2
22	14.9	16.2	18.4	21.5	19.9	16.0	12.8	12.0
23	15.1	15.4	19.5	20.5	19.8	16.5	14.2	11.5
24	16.0	15.5	19.2	20.1	16.2	18.0	11.5	12.0
25	17.6	17.5	21.0	20.5	17.0	16.0	13.6	m
26	15.2	18.5	20.9	19 8	18.1	19.4	10.6	12.5
27	15.5	14.9	20.9	22 0	17.5	16.5	13.2	6.5
28	17.5	14.0	20.1	21.0	17.5	16.0	13.3	3.6
29	17.6	16.0	21.2	20.5	m	18.4	11.5	1.6
30	17.4	18.6	19.5	18.0		18 3	7.9	3.5
31	16.5		20.5	18 1		15.7		m
*Mean	14.8	16.2	17.8	18.5	18.5	17.6	15.0	11.9

m : missing data

*Mean : Longterm monthly daily minimum temperature

Source: Matsapha Meteorological Station, 1997.