YIELD STABILITY OF SPRING WHEAT UNDER VARYING AMBIENT TEMPERATURE REGIMES

BY

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DECLARATION

I Zanele Nxumalo declare that all the work presented in this dissertation is my work and has not been submitted for a degree at any University.

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APPROVAL

This dissertation of Zanele Nxumalo is approved as fulfilling part of the requirement for the award of the degree of Master of Science in Agronomy (Crop Science) by the University of Zambia.

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ABSTRACT

The performance of ten spring wheat varieties in respect to yield and yield components was analysed in a split-split plot design with location (Chirundu, Unza and Mpongwe representing Region I, II and III of Zambia respectively) as the main plot, planting dates (mid-April, mid-May, mid-June and mid-July) as the sub plot and variety as the sub-subplot. Five heat tolerant lines and five local varieties were used. The planting dates represented a wide range of temperature regimes. This was aimed at simulating the growing conditions of the crop when planting is delayed. The aim was to establish the extent of yield loss with delayed planting and also to determine which of the yield components are greatly affected with delayed planting and how strongly these yield components influence yield.

The varieties did not differ significantly in yield across location and planting dates. Locations had a significant influence on yield. Chirundu in the hot Zambezi valley gave the lowest average yield of the three locations. The locations and planting dates caused differences in number of spikelets/ear, number of tillers/square meter, thousand-kernel weight, plant height, leaf area index and harvest index and were lower at Chirundu compared to the other locations. The optimum planting date for Unza and Mpongwe was May while Chirundu it was April. Delayed planting resulted in low yields and low expression of yield components. The effect of delayed planting was more pronounced in Chirundu. The heat tolerant lines showed a slight edge in yield than the local varieties. The heat tolerant varieties showed superior performance in number of spikelets/ear, number of tillers/square meter and plant height.

A stepwise multiple regression analysis identified number of spikelets/ear as the most important trait explaining variation in yield and the number of tillers/square meter and harvest index showing a marginal effect. When location and planting dates combinations were taken as environments in all locations July planting gave the most negative value of the environmental index. This indicated that this location-planting date combination was the most adverse environment for wheat production.

The stability analysis using Eberhart and Russell (1966) method, considering the regression coefficient, mean square deviation from regression and mean advantage over grand mean showed the heat tolerant lines tend to be much more stable than local varieties.

The overall indication of this study was that wheat breeders could deliberately select for heat tolerance with respect to yield stability. In this process targeting number of spikelets/ear and number of tillers/square meter may result in improved yields and stability of yield performance under even harsh temperature regimes, thus ensuring that good yields are obtained even when planting is delayed. The growing of heat tolerant varieties would encourage wheat production among both the small scale and large-scale farmers in the hot areas, which are well endowed with water resources.

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1.0 INTRODUCTION

Wheat *(Triticum aestivum* L.) is an important cereal crop for both the temperate and tropical regions. In the temperate regions it is the major grain for human consumption. In the tropical regions its popularity as a food crop has increased tremendously, making it one of the most important cereals second to maize (Fischer, 1985). Wheat is classified into spring and winter type. Hartmann *et.al.* (1988), stated that the type of cultivar grown depend on the severity of the winter. If it is too cold like in Canada, spring type cultivar are planted in the spring to be harvested in late summer, but if the winters are not extreme, winter cultivars are planted in the fall for spring harvest. Winter wheat requires the chilling temperatures imposed by snow cover to promote vernalization, needed for flowering and seed set. If winter wheat is planted as spring wheat, it does not flower. In Southern Africa spring wheat cultivars are grown. Spring wheat is produced under irrigation since winter is part of the dry season. In Zambia it is grown in large scale farming operations under irrigation as a cash crop. The crop is sown from mid-April to late May when ambient temperatures are low.

There is an increasing demand for wheat and wheat products on the world market. This situation opens up opportunities for large scale wheat production even in countries like Zambia which are not traditionally wheat growing nations but have the needed weather, soils and water resources for large scale production of this important cereal crop. The grain is ground into flour, of which the chief use is for making bread. The flour for baking is obtained from hard red spring wheat varieties. Flour from soft wheat varieties is used for making cakes, biscuits and pastry products. Wheat is also used for the production of alcoholic beverages and industrial alcohol. The grain and straw may also provide valuable fodder. The straw is also used for making baskets, thatching and as a substrate for mushroom production (Poppe, 2000).

In Zambia, the optimum planting date is late April to early May (Muleoki, 1992). However, wheat is normally planted from May to late June and sometimes into July. These delays are often due to delays in harvesting of rotation crops. Wheat is normally rotated with soyabeans that require drying in the field before harvesting. This is often the case in large irrigated farms. When the crop is planted in late June to early July it has been observed that there is a progressive decline in yield than when planted in May (Woodruff, 1983). The decline in yield has been associated with increase in environmental temperature, which may affect tillering and grain filling capacity. It has also been observed that yields are generally lower in the hot river valleys such as the Zambezi river valley. Development of wheat varieties that will give consistently high yields even when the crop is sown in late June or early July would be an advantage for wheat producers in Zambia. These varieties could also give high yield performance in the hot river valleys, which are well endowed with water resources such as the Zambezi River, the Kariba Dam and the Luangwa River. However, the development of new wheat varieties requires a study that will first elucidate what effects delayed planting has on the wheat plant. This will require establishing the effects of delayed planting on the yield and yield components of wheat. Once the causes of yield reduction are established then wheat breeders would attempt to breed for stable performance of the characters that greatly influence the yield decline and thereby improve yield performance of wheat such that even if the crop is planted after the optimum planting date or grown in the hot river valleys in Zambia it will still give good yields.

The Objectives of the Study were:

1. To study the physiological components of grain yield in wheat under varying temperature regimes as determined by different location-planting date - environment combinations.

2. To examine the influence of the morpho-physiological components of grain yield on yield and how their sensitivity to environment affect crop yield and performance in the array of environments to which the crop is exposed.

Study Hypothesis: This study is based on the hypothesis that there exists variation for stability of wheat performance in an array of environments that subject the wheat to varying temperature regimes during the crop-growing season.

2.0 LITERATURE REVIEW

2.1 Significance of Wheat in Global Agriculture

Cash crop farming is one of the Agricultural activities that can improve the economy of a country. Wheat (*Triticum aestivum* L.) is grown as a cash crop under large scale farming in the United States of America, Canada, Australia and Argentina. Wheat is grown under extensive hacterages in these four countries. Whilst in other countries such as India wheat is an intensive crop grown by small-scale farmers on hacterages, which are less than 5 hectares (Fischer, 1985. A significant hectarage of land is devoted to wheat production on a global scale. It is estimated that more than thirty-five percent of the world's cultivated land is used for wheat production (Hartmann *et.al*, 1988). It is the most important food crop in terms of grain produced per year (Gooding and Davies, 1997).

Wheat provides more nourishment for the people than any other food source. It contributes more calories and more protein to the world's diet than any other food crop. Millions of people depend on the food products made from the wheat kernels. The kernels are ground into flour to make bread, cakes, cookies and other foods. The raised bread loaf is possible because wheat contains gluten, which is an elastic form of protein. Wheat is thus a predominately human food crop. Only in certain areas of developed countries, primarily in times of surplus, are some kinds of wheat used directly for animal feed. Also in highly developed countries, nearly 28% of wheat milled products; bran and shorts go into mixed feed (Gooding and Davies, 1997; Martin, 1992; Haldore et.al. 1982). Wheat is the most demanded crop in world grain trade. Its production and utilization has been intimately linked with the development of both Agriculture and civilization over the last 12,000 years (Gooding and Davies, 1997).

In the Eastern, Central and Southern African countries the total wheat importation and production stands between 2.5 to 4.8 million tonnes (CIMMYT, 1999) giving a gross turnover of over one billion United States Dollars. There is a steady increase in production although the production level still-falls short of meeting national demand for most countries in the region. In Zambia wheat ranks as the second most important cash crop after maize (Mukwavi, 1990). Since this country is well endowed with water resources and land, the country has a great potential for increasing wheat production to tap into the international markets for wheat.

2.2 Adaptation

Wheat has a broad adaptation. Few crops show such a wide distribution as wheat. It has exhibited a wide range of ecological adaptation, spreading throughout the temperate regions and extending into the tropics (Muleoki, 1992). Although wheat has such an adaptation it is poorly adapted to warm or moist climates unless there is a comparatively cool dry season that favours plant growth and retards parasitic diseases. Tropical wheat environments include most areas lying between 23°N and 40°S plus adjacent areas with tropical and subtropical climates. These areas have a mean temperature of the coolest month above 22.5°C and 17.5 to 22.5°C as very hot and below 17.5°C as warm temperature respectively (Fischer, 1985). Early growth is favoured by cool and moist conditions, with warmer drier weather towards crop maturity (Hartmann *et. al.*, 1988). Wheat can be grown on a wide variety of soils but fertile soils, with reasonable drainage and good water-holding capacity are preferred. Black cotton soils are used for unirrigated wheat in India. For optimum growth the soil pH of 5.5 to 6.5 is preferable. Wheat does not perform well in highly acidic soils (Little, 1984).

In Zambia there is a great potential for wheat production, since much of the country has been identified as being suitable for growing the crop. Although some areas of region III (which is a high rainfall area) have been found to be unsuitable for wheat production because of high soil acidity, which adversely affect wheat yield (Muleoki, 1992). High-yielding disease- resistant varieties have been released (Mukwavi *et.al.*,1990). The mean annual temperature fall within the range of 18°C to 24°C except in major river valleys e.g. Zambezi, where it maybe higher. The mean monthly minimum temperature during the coolest months, June and July ranges from 3.0°C to 12.3°C. The crop is grown under irrigation during the cool dry months when disease infestation is low. It is usually grown in rotation with soybeans. The recommended planting time is mid-April to the middle of May. Planting is usually delayed to June even into July under large-scale production.

Simmons *et.al.*, (1995) noted that yield is greatly reduced when wheat is sown after the threshold date. This is one of the major constraints in wheat production in Zambia.

2.2.1 Effects of Planting after the Threshold date

Wheat production in tropical areas is subjected to fluctuations because of numerous factors, which include, variable temperatures and sensitivity to management, especially date of planting (Fischer, 1985). Acevedo *et.al.*, (1991), stated that a planting date that causes anthesis to occur during the coolest month should be selected as this ensures a long grain filling period and hence improved yields. Baker and Verhalen (1991) gave an example of a planting date that cause anthesis to occur during the coolest month for Southern Africa. The study showed that for wheat planted early May, anthesis occurs in July and grain filling is completed mid-to-late August when the environmental temperature is still below 35°C.

Crop growth and development are greatly influenced by environment. On average delayed seeding tends to decrease yields of spring-seeded crops (Ciha and Hagmann, 1981). It also leads to increase in grain nitrogen concentration, (Briggs, 1979), decreased kernel weight (Ivins and Jessop, 1970) and a decrease in days to maturity (Briggs, 1979). Ivins and Jessop (1970) found that yields increased with delayed planting although Champlin and Black (1945) had reported that yields increased and in other studies decreased with delayed planting. Ciha and Hagmann, (1981) found that the majority of wheat cultivars used in his study showed no difference in grain yield between early and recommended planting dates, but late planting decreased yields. In the variety Capitan Miranda, maximum yield was obtained from 15 April– 15 July plantings. The yield potential was 5.6 tonnes/ha there was no decline in yield with late planting because of less radiation (Hobbs and Saunders, 1985). However, Simmons *et.al.*, (1995), reported that studies on the modelling of cereal organ development in order to predict the effects of climatic change on crop yield have shown that there is a significant decrease in wheat yields if planting is delayed after a threshold date. Aggarwal, (1999) reported that yield decreases after the optimal date at a rate dependent upon thermal regions. The reduction in yield is suspected to be that, the crop is subjected to high temperature during the reproductive and grain filling stages, which forces the crop to ripen prematurely. High temperature at the reproductive stage hastens spike development, resulting in abortion of late-forming florets and reduction in potential kernel number (Warrington *et al.*, 1977).

Temperature exceeding 35°C normally has a negative effect in wheat yield and yield components. When wheat is planted after the threshold date it is exposed to high temperature due to elevation in temperature. In warm to hot environments with relatively warm winters the vegetative and reproductive phases become shorter and yields are low. There is a general decline in grain yield that corresponds with increase in prevailing temperature. A reduction in regression of 5.5% in grain number for every 1°C increase in temperature was observed (Abrol *et.al.* 1991). On the other-hand there is a reduction in grain weight for each 1°C rise in daily mean temperature. High temperature experienced prior to stem extension, hastens development of cultivars thus reducing days to maturity.

Days to maturity thus decrease with delayed planting (Wardlaw and Anderson, 1963, Hunt *et.al.*,1995, Acevedo *et. al.*,1991). In winter wheat a potential yield loss of 1.5% per day per hectare was observed for each day's delay of sowing after the optimal date (Saunder, 1988). Fischer, (1985) reported that high temperature, affect growth as well as yield components (Fischer, 1985). Elevation in temperature, accelerates plant development, while growth rate declines and there is a decline in leaf size, tillering and spike size resulting in low yield. Tillering capacity is strongly influenced by both heredity and environment. It is favoured by a temperature range of 16°C–20°C. High temperatures have a negative effect on tillering capacity. The kernel number is a function of tiller number. This implies that if few tillers bear kernels, the kernel number reduces and ultimately lower yields. The weight of the kernel is determined by the number of filled spikelets and by the size of the grains. High temperature negatively affects spikelets hence lower kernel weight and shrinked grains are received (Simmon *et.al*, 1995). Kernel growth and senescence are influenced by high temperature during grain filling (Fischer, 1985).

The development of grain yield is a complex process because of the temporal influence of ambient temperature on the expression of yield components. Temperature effects on growth efficiency of yield components appear to be due to a change in respiration rate that is coupled to a host of synthetic activities (Gerick, 1979). Wheat genotypes generally show differential yield response to varying environments, which indicates a differential effect of environment on yield component development. Although a possible reduction in yield caused by a reduction in certain components can be compensated for to a certain degree by a concurrent increase in another component, unfavourable environmental effects may still limit yield. Woodruff and Tonks, (1983) studied the environmental limitations in Thailand and concluded that a small deviation from optimal growing conditions could cause severe yield reductions. These appear to be due to the low compensation between yield components under the fast development rates caused by elevated temperature. The lack of compensation was shown by the strong correlation (r) between plant number (0.55), tiller number (0.73) and leaf area index (0.80) measured at anthesis and final grain yield.

Grain filling duration is inversely related with prevailing temperature. The optimum temperature for photosynthesis and reproductive growth is near 20°C, high temperature reduces the rate of dry matter accumulation. There is faster senescence of the foliage, poor assimilate availability, reduced translocation of photosynthates to developing grain and respiratory loses (Paulsen and Al-Khatib, 1984). The negative effect due to reduction in the grain filling period and grain- filling rate is low kernel weight. A positive correlation was reported between the rate of grain-filling and final grain weight (Hunt *et.al.*, 1995). Photosynthetic rates decline due to acceleration of senescence. The net effect that high temperature imposes on photosynthesis as well as translocation of assimilates results into a low harvest index. A positive correlation exist between grain yield and harvest index. Harvest index is merely a measure of the plant's efficiency to mobilize photosynthates and transport it to organs having economic value (Lungu, 1978). This implies that a reduction in harvest index is likely to have a negative effect on yield.

2.3 Selection for Yield using Yield Components

Plant breeders in an effort to develop superior yielding varieties have attempted the application of indirect selection criteria for improvement of yield. Generally, breeders have selected directly for yield to improve grain yield. However, Smith and Sharma (1986) reported that there has been renewed interest in selection indirectly for yield improvement. Yield components have been considered in this type of selection programme. The consideration of yield components in selection was based on the assumption that a strong association exists between yield and the yield components and that these component characters have higher heritability than yield (Lungu, 1978). A number of researchers suggested different yield components. Initially researchers suggested the use of the average number of spikes per plant, the average number of kernels per spike and the average weight of a single kernel. They then investigated the usefulness of morphological and physiological parameters as indices of single plant yield. Kernel weight was reported as a good trait to use for indirect selection for yield in wheat because it is highly heritable and favourably associated with yield (Lungu, 1978). According to Ketata (1976), overall yield components have shown to have higher heritability than grain yield.

Many other workers have found positive associations between components of yield and grain yield. They observed that only kernel number per plant was highly associated with grain yield. The number of kernels per plant showed a high positive association with plant yield. The number of kernels per plant included all yield components except kernel weight. The number of seeds was more important component to yield in grain cereals than was kernel weight in most environments as indicated by high coefficient of determination (R^2) (Hunt *et.al.*, 1995). Lungu, (1978) listed the number of spike per plant as the most important component. McNeal *et.al.* (1978) stated that kernel weight was positively correlated with grain yield. They further indicated that kernel weight and kernel number per spike were observed as dependable indicators of yield potential. Saunders et.al. (1986) later identified a negative inter component correlation between kernel weight and grain numbers. Smith and Sharma (1986) found three yield components, namely kernel weight, number of grains per spike, and number of spikes per plant to be positively and strongly correlated with grain yield.

Saunder *et.al.*, (1986) fast spike development and short duration of spike and plant growth, generally results in low grain number and low harvest index. A combination of kernels per spike and kernel weight into a selection parameter (spike weight) would be the most efficient method for increasing yields. Furthermore, combining the negative correlation between heading date and kernel weight and the positive correlation between heading date and kernels per spike into a single selection parameter, selection for heaviest spikes could provide a reliable method for increasing yield (Puri *et.al.*, 1981).

Researchers detected that yield components are greatly influenced by the environment and that negative correlations among them are common. Adams, (1967), concluded that single character selection can improve yield but long-term yield improvement requires consideration of all yield components. Grain yield in cereals can be improved either by increasing biomass yield without changing harvest index or by improving harvest index keeping biomass yield unchanged or by increasing both biomass and harvest index.

A number of researchers suggested the selection of harvest index as a way of improving grain yield in cereals (Fischer and Keitz, 1976, Bhatt, 1980). Donald (1962) defined harvest index as the ratio of grain dry weight to the total straw weight at maturity of the crop. It is the ratio of the economic yield to the biological yield. Harvest index is also a measure of the plant's efficiency to mobilize photosynthates and transport them to organs having economic value. In many instances it was observed that increasing harvest index has accounted for grain yield improvement, that is, improvement in grain yield of cereals frequently has been due to an increase in harvest index with little or no change in biological yield. Any or all combinations of morpho-physiological traits of plants that also give high harvest index and high grain yield should be considered in plant breeding programs.

Nass et.al., (1975), in a study to determine character for yield selection in spring wheat, observed a significant positive relationship between harvest index and grain yield. It was concluded that ears per plant; yield per ear and harvest index considered together in a selection program should be an effective means of selection for increased yield. Harvest index was also shown by Jain and Kulshrestha, (1982) to be positively related to grain yield. Syme, (1972) studied 49 spring wheat genotypes and found that 72% of the grain yield variability in the field could be estimated on the basis of harvest index values from single plants. Indirect selection for grain yield through harvest index in oats was 43% as efficient as direct selection (Frey and Lawrence, 1975). Harvest index in spaced plants was superior to grain yield of spaced plants for prediction of wheat grain yield in large plots (Fischer and Kertesz, 1976). Bhatt, (1976) reported that harvest index was a useful selection criterion for improving grain yield in two crosses of spring wheat and was considered more reliable at high population densities than low densities. The presence of considerable variation in harvest index and positive correlation with grain yield is important in improving harvest index genetically and thereby indirectly increasing yield.

Improved grain yield in the released genotype appears to be associated with the production of a higher biomass than with a higher partitioning efficiency to the grain sink. Improvement in grain yield was strongly associated with higher grain number/m^2. High grain number/m^2 was associated with high harvest index. Harvest index by itself may have only limited use in selecting for high grain yield. Nevertheless, harvest index is an important means of identifying physiological valuable genotypes in terms of their assimilate partitioning ability. The high positive correlation between grain yield and biomass yield suggested that biomass should be considered for indirect selection for grain yield (Nass, 1980).

2.4 Effects of Genotype x Environment Interaction in Spring Wheat

Genotype x environment interactions are of major importance to plant breeders in developing improved varieties. Genotype x Environment (G x E) interaction was first recognised by Johannsen as being important in the developmental processes (Carlson, 1980). It can occur through the environment exerting pressure on selection thus leading to change in genetic constitution of a population. Adaptation is accomplished through this change in genetic constitution. It can also be manifested through environment stimulating permanent changes in genetic materials as observed from mutation.

The regression technique as proposed by Finlay and Wilkinson (1963) has been used to study genotype x environment interactions by researchers in several crops. Finlay and Wilkinson used the regression technique for the analysis of adaptation of 277 barley varieties trials across Australian environment (Carlson, 1980). For each variety a linear regression of yield on the mean yield of all varieties in each environment was computed to measure variety adaptation. The means and regression of yields were expressed on a logarithmic scale in order to induce a high degree of linearity in the regression. The stability parameter used was the regression coefficient. A regression coefficient of one indicated average stability. Regression coefficient greater than or less than one indicate that the varieties have less than or greater than average stability. A regression coefficient of zero indicate absolute stability, in which case the variety would yield the same no matter what the environmental conditions. It was concluded that the regression method was particularly effective in emphasizing the actual trend of varietal yield responses to a range of natural environments.

Eberhart and Russell (1966) further developed the regression method to include the estimation of a second stability parameter the variance due to deviations from regression. When the linear regressions fail to remove a large proportion of the G x E interaction, the deviations from regression parameter can be used to evaluate yield stability. They added together the sum of squares for environments and G x E interactions and repartitioned them into a linear component between environments, a linear component of the G x E interaction and deviation from regression. The deviations are found separately for each of the genotype. They proposed the following linear model for the study of G x E interactions and stability:

$Y_{ij} = \mu_i + \beta_i I_j + \delta_{ij}$

Where

Y_{ij} = the variety mean of the i^{th} variety at the j^{th} environment,

μ_i = the i^{th} variety mean over all environments,

β_i = the regression coefficient that measures the response of the i^{th} variety to varying environments.

δ_i = the deviation from regression of the i^{th} variety at the j^{th} environment,

I = the environmental index.

This model defines stability parameters that may be used to describe the performance of a variety over a series of environments. A stable variety was defined as one with regression coefficient of one (b = 1.0) and with deviations from regression as small as possible (s^2d = 0). What this means is that a desirable variety would have a non-significant deviation mean square as tested by pooled error mean square, its regression coefficient would be close to unity and its varietal response would exceed the average yield of all genotypes. The regression coefficients that is also acceptable maybe greater than or less than unity (b >1.0 or b< 1.0) but the mean yield must be below average in such instances.

Testing genotypes in different locations can reduce genotype x environment interaction. The plant breeder may select stable varieties, those that show low interaction with environment but give consistently high yields.

The definition of environment is important in the study of the effect of G x E in crop improvement. If varieties, advanced lines or experimental hybrids are tested in multilocation trials, the locations can be considered environments. If this test is conducted over several years, the effect of year can be considered an environment and the location-year combinations also constitute different environmental effects (Eberhart and Russell, 1966). In this study the wheat varieties were tested over four planting dates in three locations. The location-planting date combinations were considered different environments. Even different soil types can be designated environments. Hence the definition of environment is wide and has to be specified.

3.0 MATERIALS AND METHODS

3.1 Description of Conduct of Experiment

Ten spring wheat cultivars comprising of five released varieties from the Wheat Breeding Programme of the soils and crops Research Branch of the Ministry of Agriculture and Cooperatives (MAC) and five lines selected from the 7TH Heat Tolerant Wheat Yield Trial (7TH HTWYT) of CIMMYT through the University of Zambia School of Agricultural Sciences Cereals Research Programme was planted at three sites in Zambia. The sites for the trial were chosen to represent a wide range of temperature regimes and soil types. The experiment was planted at four planting dates in order to maximize the range of temperature regimes and soil types during crop growth. The three experimental sites represent the three agro-ecological zones of the country. Table 1 represents the cultivars and their pedigrees.

The locations at which the study was conducted were; Masstock Farm at Chirundu (Zambezi valley); University of Zambia field laboratory and Mpongwe Development Company Farm representing agro-ecological zones I, II and III respectively.

The planting date-location combinations were considered different environments for testing the comparative stability performance of ten cultivars.

Soil samples for analyses were collected from all the experimental sites (Table 2). Weather data during crop growth was also collected for all the three sites. However, the weather data was not complete since there was a work stoppage during the growing season and data for some months was not collected (see Table 3).

A split- split plot design with three replications was used for the study. The locations were factor A (main plot), planting dates were factor B (subplot) and cultivars factor C (sub-subplot). Four planting dates were used at four weeks intervals. The first planting date was mid-April, the second mid-May, the third mid-June and the fourth mid-July 2001. The recommended agronomic practices for wheat were used. The trial plot was ploughed and disked to prepare the seedbed for sowing. The fertilizer application rates were 500kg/ha D compound and 250kg/ha urea. The recommended seed rate of 100 kg/ha was used. Planting was done using a small wheat planter. Weeding was done as frequently as possible whenever weeds appeared using hand hoes to eliminate any possible weed competition.

Table 1. Spring Wheat Cultivars Used In The Study

CULTIVAR	SOURCE PROGRAMME	PEDIGREE
Nkanga (P7)		BUC "S"/PVN "S"
	SCRB- MACO	CM58766-18V-3M-5Y-2M-OY
Loerrie II		KAVKAZ/BUHO"S"//KALYANSONA/BLUEBIRD
	SCRB – MACO	CM33027-F-15M-500Y-OM-87B-OY
Pwele (28)		Cn079/PRL "S"
	SCRB – MACO	CM833271-2Y-8B-1Y-2B-0Y
Inw-1 # 2000		CHIL 12*STAR
(TRTII)	SCRB – MACO	CM112793-OTOPY-7M-020Y-010M-1Y-010M-2Y
Inw-2 # 2000		TJB368.25/BUC/0CI
(TRT I)	SCRB – MACO	CMSW89Y00309-3Y-11M-3Y-OB
Entry 2		BACARA T 88
	7TH HTWYT- UNZA	CM67458-4Y-1M-3Y-1M-5Y-OB-OMEX
Entry 24		KAUZ//KAUZ/STAR
	7TH HTWYT- UNZA	CMBW90M4994-OTOPY-IBM-015Y-015Y-015M-5Y-OB
Entry 28		KAUZ/STAR
	7TH HTWYT – UNZA	CMBW90Y3058-74M-015Y-015M-1Y-OB
Entry 31		ATTILA/3*BCN
	7TH HTWYT – UNZA	CMBW90Y4399-OTOPM-IY-010M-010M-01OY-8M'...
Entry 50	7TH HTWYT-UNZA	KAUZ*2/YACC/KAUZ
		CRG873-5Y-010M-OY

NOTE: MACO is an acronym for Ministry of Agriculture and Cooperative while UNZA indicates University of Zambia

Table 2 Soil Analysis.

Locations	pH $CaCl_2$	N %	P Mg/kg	K Me/100g	Sand %	Clay %	Silt %	Textural Class
Chirundu	6.13	0.13	31.43	0.9	75.4	6.2	18.4	SL
UNZA	6.92	0.05	61.01	0.21	67.60	18.20	14.20	SL
Mpongwe	7.37	0.07	25.31	0.37	44.8	32.4	22.8	SCL

NOTE: SL- Sandy loam

SCL – Sandy clay loam

Table 3.Temperature Data Of The Three Regions During The Crop Growing Period

	Region I		Region II		Region III		
Month	Minimum Temperature (°C)	Maximum Temperature (°C)	Minimum Temperature (°C)	Maximum Temperature (°C	Minimum Temperature (°C)	Maximum Temperature (°C)	Valid days
April	14.8	28.9	15.7	27.0	14.8	29.0	27
May	10.3	27.0	13.4	24.7	11.2	27.9	29
June	7.5	25.2	-	-	-	-	
July	6.3	24.9	-	-	8.6	25.9	
August	-	-	12.8	27.6	10.7	29.6	26
September	14.6	33.1	15.2	30.3	13.3	32.4	29
October	16.9	33.7	17.2	31.0	16.8	32.3	29
November	19.4	31.3	17.1	30.3	18.0	30.5	30

3.2 Field Data Collected

Routine field data such as seedling emergence, data of ears or spike emergence and crop maturity dates were recorded. Seedling emergence was recorded as the date when seedlings completely emerged from the soil on 50% of the plot, spike emergence was recorded as the date when the spike completely emerged from the flag-leaf sheath on 50% of the plants and physiological maturity was recorded as the date when all the green colour was lost on 50% of the plants. Moisture concentration of plot samples was recorded and used to adjust yield at 13% moisture. Data on yield components and other yield related morpho-physiological components were also measured. These were based on ten randomly selected plants per replication. The yield components measured were 1000-kernel weight, spikelets per ear, number of tillers per square meter obtained by meter square quadrant and counting the number of tillers within a randomly selected quadrant per replication. The morpho-physiological traits measured were, plant height, leaf area index and harvest index. Days to anthesis, Days to maturity and Grain yield were also determined.

3.3 Statistical Analysis

A split-split plot analysis of variance using a GENSTAT Statistical Package was conducted to determine the effect of location, planting date and variety on yield and yield components of spring wheat. The interaction effects on yield and yield components were also determined. A stepwise multiple regression analysis identified variables that contributed significantly to variation in yield. The coefficient of multiple determination (R^2) was used as selection parameter.

To identify varieties among the ten involved in the study with stable performance in the various location-planting date combinations, a stability test was conducted using the Eberhart and Russell (1966) method. The location and planting dates were considered as environments hence there were 12 environments.

The following model was used:

$Y_{ij} = \mu_i + \beta_i I_j + \delta_{ij}$

Where:

Y_{ij} = the variety mean of the i^{th} variety at the j^{th} environment,

μ_i = the i^{th} variety mean over all environments,

β_i = the regression coefficient that measures the response of the i^{th} variety to varying environments.

δ_i = the deviation from regression of the i^{th} variety at the j^{th} environment.

I = the environmental index.

4.0 RESULTS

4.1 Variety effect on Grain yield and Yield Components

The analysis of variance (Table 4) shows that there was no significant differences among the ten varieties in yield performance. These varieties appeared to generally have the same yield potential.

Table 4, however shows that although the varieties involved in the study were similar in yield performance, they significantly differed in yield components. The varieties showed significant differences for number of spikelets per head, number of tillers per square meter, one thousand-kernel weight, plant height and leaf area index (LAI). They however did not differ in harvest index (HI).

4.2 Effect of Location on Yield and Yield Components

The locations used for the study had significant influence on yield and all the yield components as shown in Table 4. There was also a significant variety x location interaction indicating that the varieties performed differently in different locations. The overall location effect on yield showed Chirundu in the hot Zambezi valley representing

Region I to be the adverse environment for wheat production. Yield was lowest at the Chirundu site with an average site of 3.9 tons per hectare. The site yield for Unza, which is Region II of the agro-ecological zones of Zambia, gave an average of 6.0 tons per hectare. The highest yield was recorded at Mpongwe representing Region III, which averaged at 7.5 tons per hectare.

Table 5 shows the effect of location on yields of the ten spring wheat varieties used in the study. Results show that all varieties performed poorly for yield at Chirundu compared to Unza and Mpongwe. This could be attributed to the ambient temperature that prevail in Chirundu, which is the hot river valley. The Mpongwe and Unza the varieties performed similarly. This implies that for high yield potential these two sites are the most desirable ones for the grown varieties. It should be noted that this does rule out Chirundu because of the endowed water resources, which are required for irrigation. Table 6 shows the effect of location on yield components. The Chirundu site showed reduced expression of number of spikelets per ear, number of tillers per square meter and plant height. This effect was further accelerated with delayed planting.

4.3 Effect of Planting Date on Yield and Yield Components

Table 4 shows that the factor planting date has a significant influence on yield and all the other characters studied. The effect of planting date as shown in table 7 clearly shows the depressing effect of delayed planting on yield of wheat. At Chirundu, the April planting date gave the best average yield of 6.6 tons/ha with yields declining to 1.9 tons/ha for the July planting. The Unza and Mpongwe sites however, showed that May planting date was the best. At both of these sites the yields for April were lower than those for May planting. However, after the peak yields in May there was a significant decline in yields in the June and July planting. It is important to note that yield reduction was not as severe at the Mpongwe site. This could be attributed to the better productivity of the Mpongwe soils.

The effect of planting date on yield components is presented in table 6. The yield components, number of spikelets per ear and number of tillers per square meter were the most sensitive to delayed planting. Plant height has an effect on biological yield or the total photosynthesising surface of the plant and hence has an effect on yield. Spikelets were negatively affected by planting date. In April and May an average of 20 spikelets/tiller, were obtained. There was a reduction in June to an average of 19 spikelets/tiller and in July to 18 spikelets/tiller. The spikelets were significantly higher in April and May in all the locations (figure 2).

Mpongwe attained the highest number of tillers/square meter of an average of 437 tillers/m^2 followed by Unza with an average 333 tillers/m^2 and the lowest tillering capacity was at Chirundu 241 tillers/m^2. In April-planting an average of 381 tillers/m^2 was obtained and in May an average of 391 tillers/m^2 was obtained. June and July planting resulted in lower tillers/m^2 (figure 3).

Table 4 A Split-Split Plot Analysis of Variance for Yield and Yield Components across Location Planting Date.

		Yield		Spikelets		Tillers		1000 kernel weight		Plant height		Leaf Area Index		H.I.	
Source of variation	**Df**	**Ms**	**F**	**Ms**	**F**	**Ms**	**F**	**Ms**	**F**	**Ms**	**F**	**Ms**	**F**	**Ms**	**F**
Replication	2	24.12	5.74	1.141	0.18	5736	0.22	0.85	0.5	0.005	0.51	0.25		0.0095	15
Location	2	364.4	86.7**	62.67	9.73**	115177	43.8**	0.19	105**	2.84	275**	25.7	65**	1.922	752.6
Error	4	4.204		6.438		26279		0.18		0.01		0.56		0.0026	
Planting date	3	267.1	35.6**	50.74	29.0**	303109	34.1**	0.725	89.5**	0.51	74.7**	8.59	12**	0.11	6.92**
Loc.x Pd	6	26.95	3.59**	25.82	14.8**	107196	12.1**	0.115	14.2**	0.118	17.4**	17.8	25**	0.097	6.2**
Residual	18	7.508		1.34		8891		0.81		0.007		0.71		0.02	
Varieties	9	2.068	1.54	6.54	5.02**	16899	5.41**	0.235	34.2**	0.012	6.2**	1.89	2.7**	0.006	1.34
Loc. X var	18	2.467	1.83**	2.332	1.79*	7992	2.68*	0.832	12.1**	0.005	2.7**	0.35	0.5	0.003	0.72
Pd x Var	27	0.95	0.7	2.49	1.91**	6170	1.98**	0.178	2.6**	0.002	1.29	1.0	1.4*	0.005	1.09
L x V x Pd	54	1.52	1.13	1.619	1.24	3962	1.2	0.206	3.0**	0.002	1.15	0.87	1.2	0.005	1.15**
Residual	216	1.35		1.303		3122		0.686		0.002		0.7		0.005	
Cv%		20		6.0		16.6		6.8		5.5		18.7		13.1	

****- significant at p ≤ 0.01** **H.I. – Harvest index**

Table 5 Mean Yields Of Ten Spring Wheat Varieties Grown In Three Locations.

	Entry 2	Entry 24	Entry 28	Entry 31	Entry 50	Inw 1	Inw 2	Loerie	Nkanga	Pwele
Chirundu	4.6 c	3.9 b	3.6 b	4.2 c	3.9 c	4.2c	3.7c	3.6 c	3.8 c	4.0 c
Unza	6.4 b	6.1 a	6.5 a	6.3 b	6.1 b	5.9b	6.2b	5.4 b	5.8 b	5.7 b
Mpongwe	8.4 a	6.4 a	7.5 a	8.1 a	7.6 a	7.3a	7.7a	7.9 a	7.1 a	6.5 a

Lsd = 1.1

Lsd significant at $p \leq 0.01$

Means of same alphabet indicate that the means are not significantly different from each other.

Table 6. Average Expressions Of Yield Components Of Spring Wheat In Different Locations And Planting Dates.

.	Spikelets	Tillers	Kernel Weight (grams)	Leaf Area Index	Plant Height (cm)	Harvest Index (%)
Mpongwe April	19.9 a	442 a	40.0 a	5.8	100 a	60 a
Mpongwe May	20.9 b	477 a	40.0 a	5.2	100 a	60 a
Mpongwe June	19.4 a	441 a	40.0 a	4.8	90 b	60 a
Mpongwe July	18.8 ac	388 b	40.0 a	4.2	90 b	60 a
Unza April	18.6 c	399 b	40.0 a	5.2	80 c	60 a
Unza May	20.4 b	461 a	40.0 a	4.7	90 b	60 a
Unza June	18.5 c	254 c	40.0 a	4.4	80 c	60 a
Unza July	17.4 d	217 c	40.0 a	3.4	70 d	50 a
Chirundu April	19.4 a	309 c	40.0 a	4.7	70 d	50 b
Chirundu May	19.2 a	235 d	30.0 b	4.6	80 c	40 c
Chirundu June	17.7 d	226 d	30.0 b	3.7	60 e	30 d
Chirundu July	17.3 d	194 d	30.0 b	3.3	50 f	30 d
Lsd	0.9	64	2.0	0.4	5.0	6.0

Lsd Significant at $p \leq 0.01$

Table 7 Means Of Grain Yields For Ten Varieties Of Spring Wheat Grown In Different Environments In Zambia 2001.

LOCATION	MASSTOCK Region 1				UNZA Region 2				MPONGWE Region 3			
Planting date	April	May	June	July	April	May	June	July	April	May	June	July
ENTRY 2	7.2	5.9	2.9	2.4	7.1	7.7	6.9	3.9	9.4	9.5	8.3	6.3
ENTRY 24	6.5	4.7	2.9	1.7	6.7	8.7	6.2	2.6	7.2	7.3	6.2	4.8
ENTRY 28	6.0	4.0	2.3	2.0	6.7	9.1	6.2	4.1	8.126	9.0	7.1	5.6
ENTRY 31	6.4	5.6	2.8	2.1	7.1	8.2	5.8	3.9	8.259	10.2	7.2	6.8
ENTRY 50	6.3	5.1	2.5	2.0	6.2	8.1	6.3	3.6	8.170	8.5	6.8	6.8
INW 1#2000	8.5	4.1	2.1	1.9	5.5	8.9	6.3	3.0	8.237	8.6	7.1	5.2
INW 2#2000	6.4	4.0	2.4	2.0	6.3	8.1	6.1	4.0	9.315	8.5	7.0	5.8
LOERIE II	5.9	5.1	2.0	1.3	5.7	7.2	5.6	3.0	8.569	10.8	7.0	5.1
NKANGA(P7)	5.9	5.0	2.3	2.0	5.7	8.2	5.1	4.0	8.973	8.0	6.6	4.8
PWELE (28)	7.0	6.0	1.6	1.4	6.4	7.5	6.2	2.7	7.590	6.9	6.1	5.3
Average	**6.6**	**4.9**	**2.4**	**1.9**	**6.4**	**8.20**	**6.2**	**3.5**	**8.46**	**8.8**	**6.9**	**5.70**
		3.9				**6.0**				**7.5**		

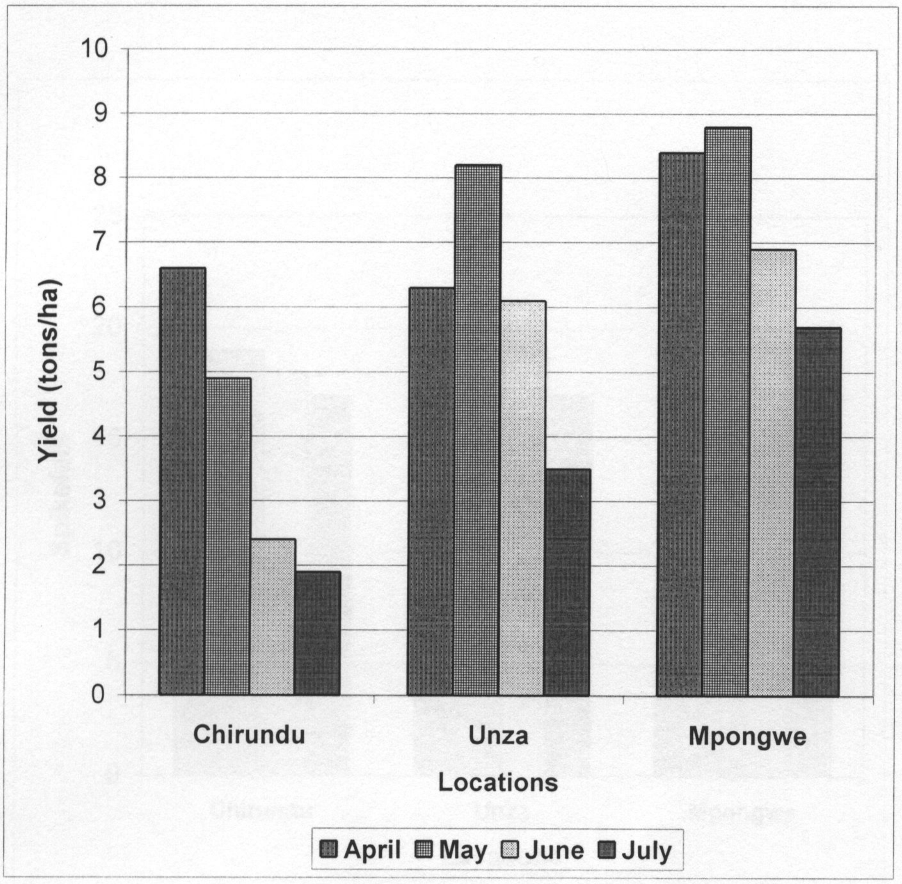


Figure 1 Grain Yield From Three Locations in different Planting Dates.

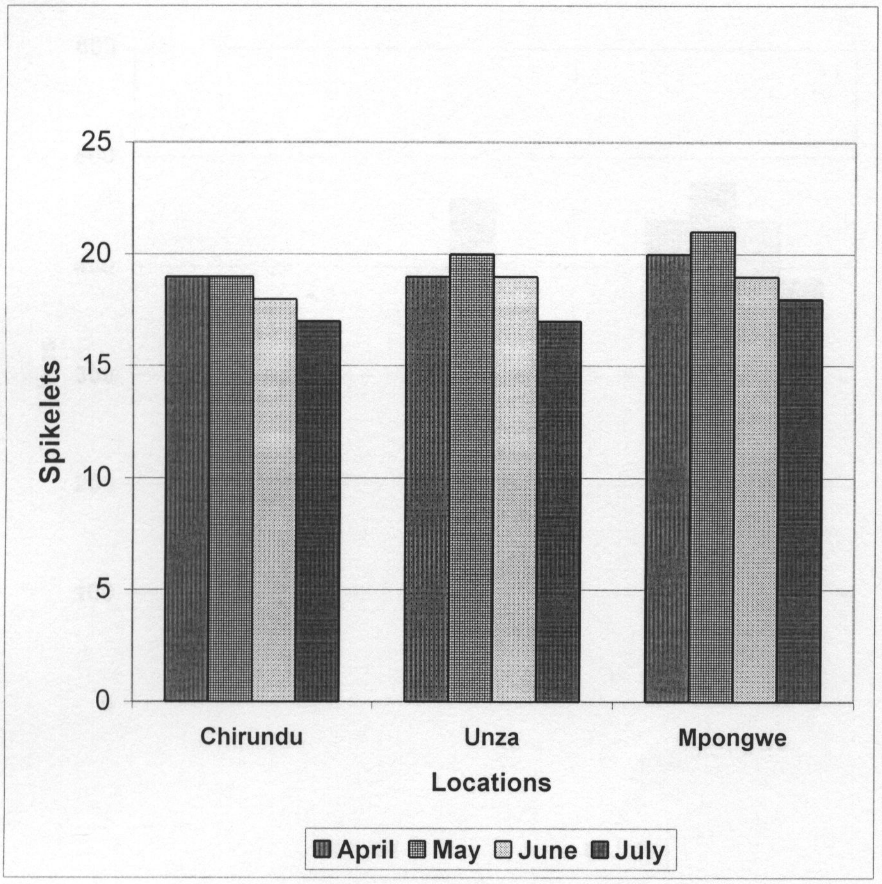


Figure 2 Comparison of Spikelet number in the Different Locations and Planting Date

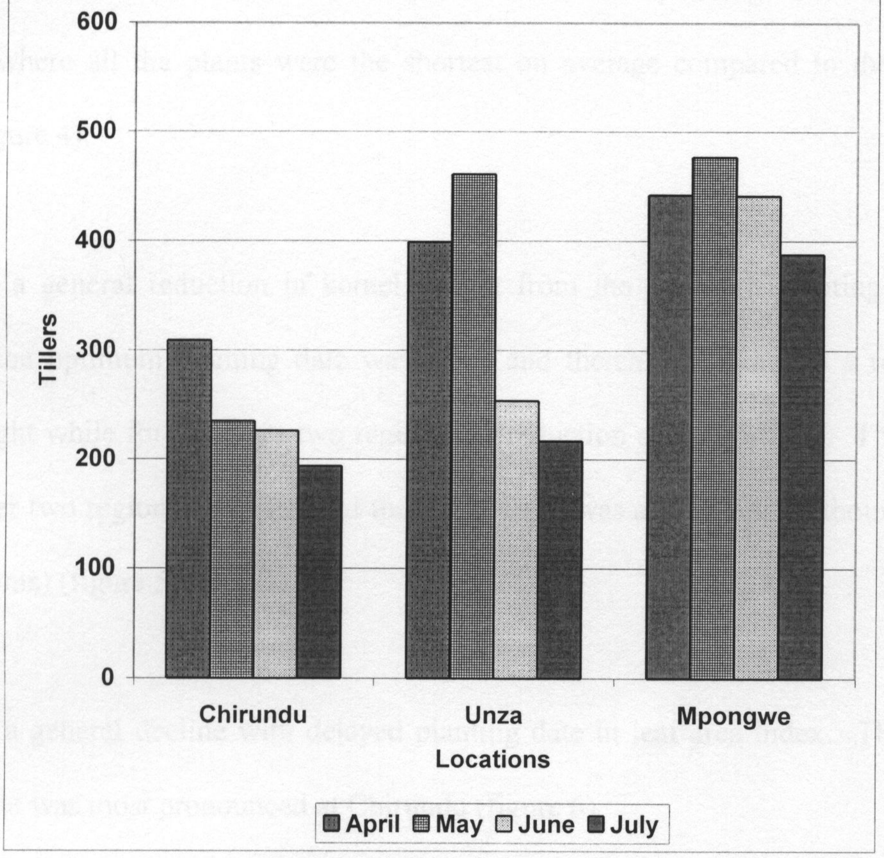


Figure 3 Comparison of number of Tillers across Locations and Planting Dates.

Plant height was highly significant at Unza and Mpongwe. At Unza an average height of 77.0cm was obtained, at Mpongwe an average of 96.0 cm was obtained and at Chirundu an average of 65.0cm. The tallest plants were obtained in May planting 88.0cm and the shortest plants were obtained in July 72.0cm. The effect of planting date was greatest at Chirundu where all the plants were the shortest on average compared to the other two regions (figure 4).

There was a general reduction in kernel weight from the optimum planting date. For Chirundu the optimum planting date was April and thereafter there was a reduction in kernel weight while for the other two regions the reduction started in June. The optimum for the other two regions was May and thereafter there was a reduction in thousand-kernel weight (grams) (figure 5).

There was a general decline with delayed planting date in leaf area index. The effect of planting date was most pronounced at Chirundu (figure 6).

Planting date had a marginal effect on harvest index at Unza and Mpongwe while at Chirundu there was a drastic reduction in harvest index with later plantings after the optimum planting date, which was April (figure 7).

There was a significant variety x planting date interaction for yield components spikelets per ear, tillering capacity, thousand-kernel weight and harvest index. This indicates that the varieties used in the study performed differently in different planting dates for these traits.

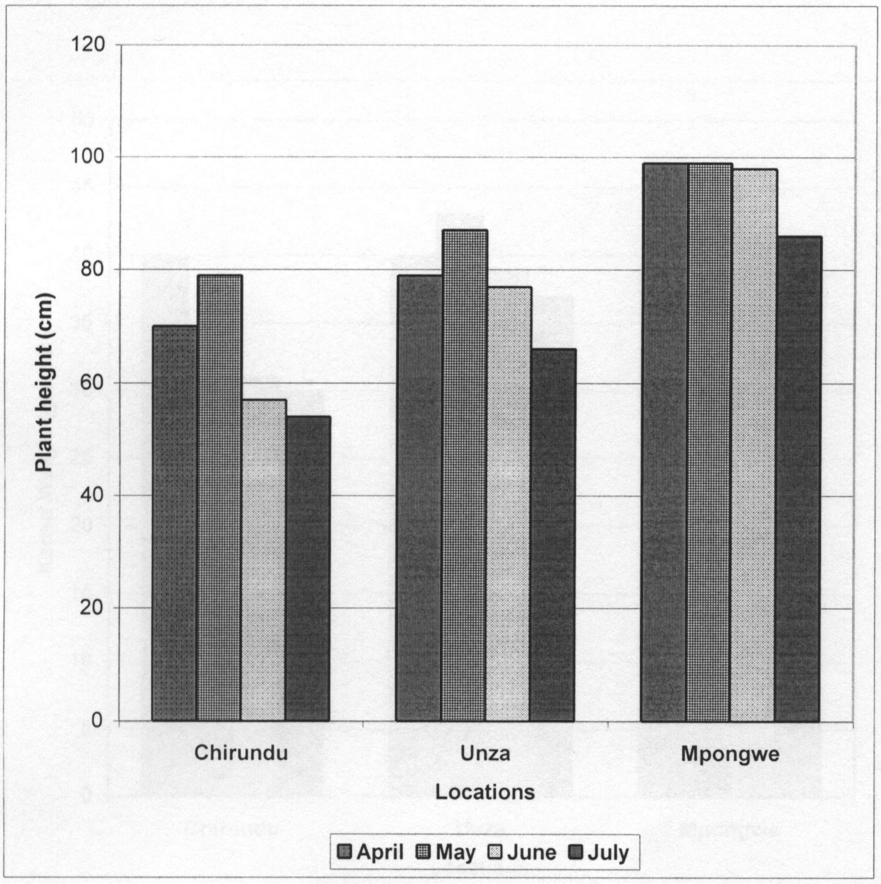


Figure 4 Comparisons of Plant Heights in Different Dates of Planting in three Locations

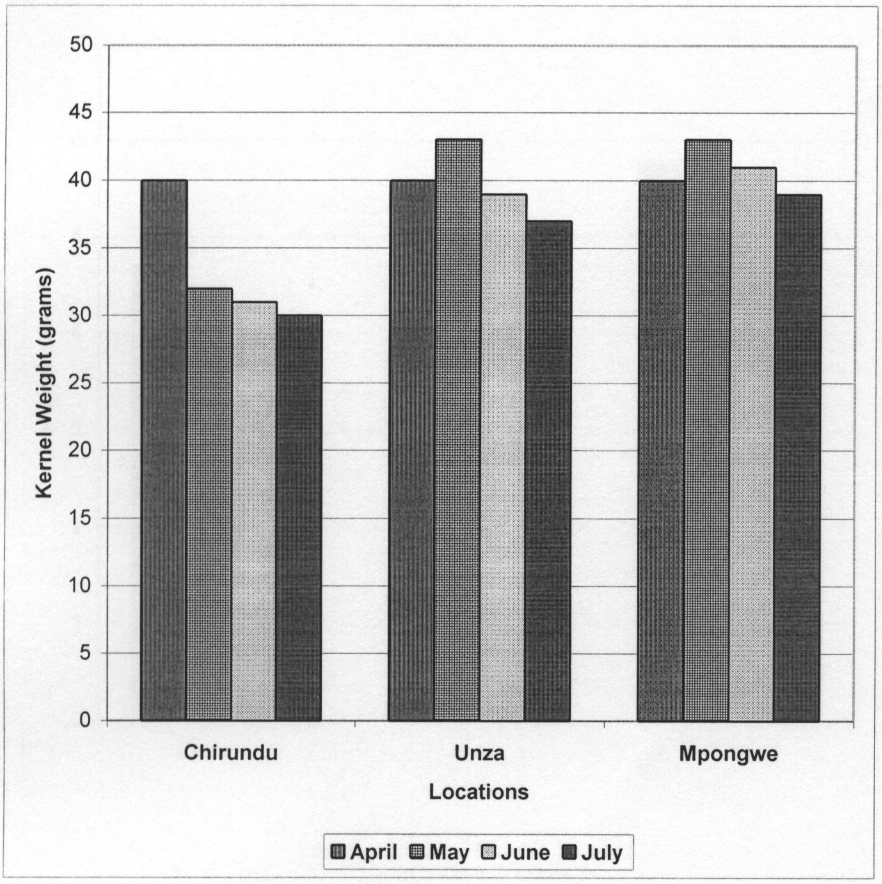


Figure 5 Comparison of Kernel Weight in Different Locations and Planting Dates

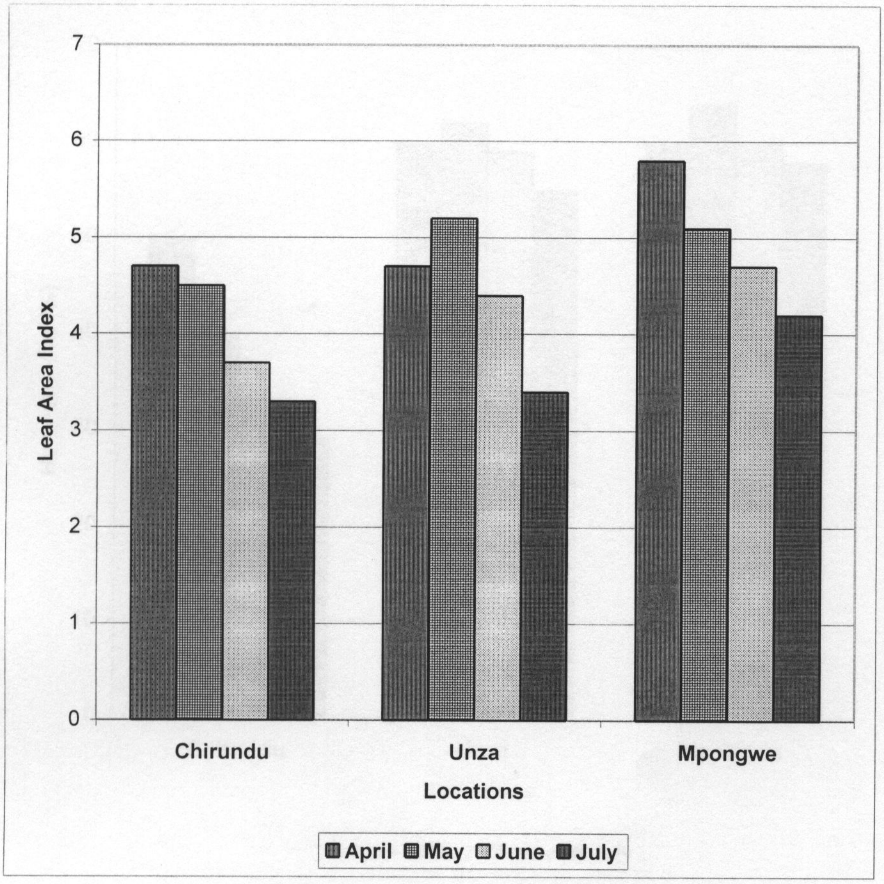


Figure 6 Comparison of Leaf Area Index in Different Locations and Planting Dates

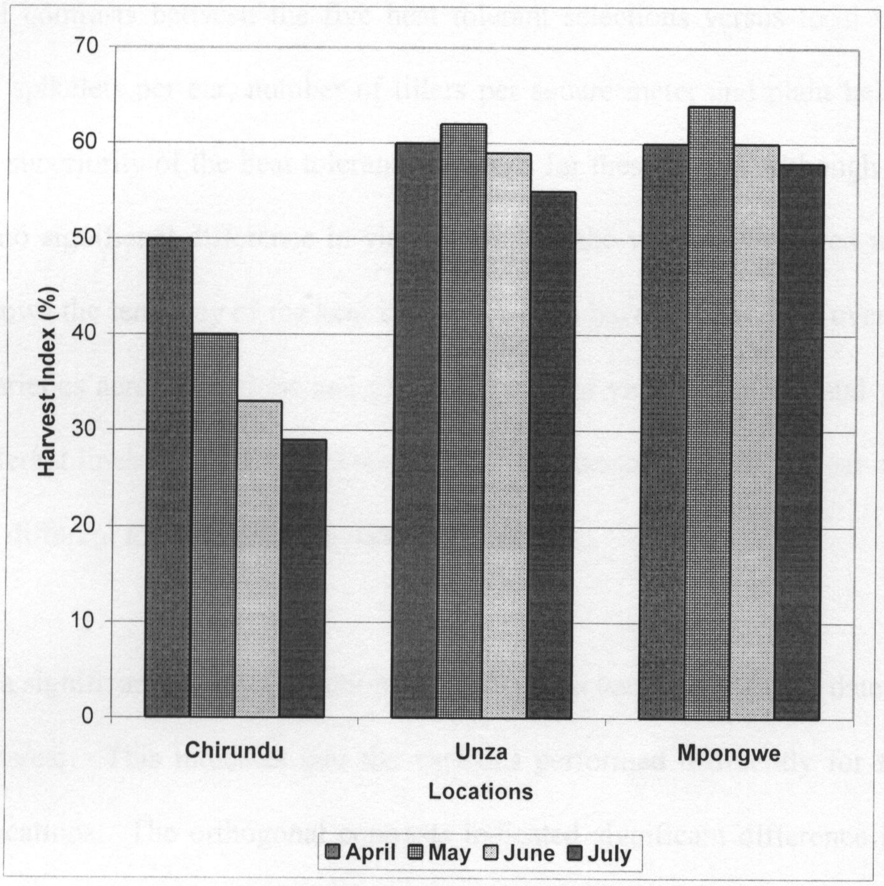


Figure 7 Differences in Harvest Index in the Different Locations and Planting Dates

4.4 Comparative Performance of Heat Tolerant Selection versus Local Varieties for Yield Components.

Orthogonal contrasts between the five heat tolerant selections versus local varieties for number of spikelets per ear, number of tillers per square meter and plant height showed significant superiority of the heat tolerant selections for these traits. Although statistically there was no significant difference in yield among all the varieties involved in the study, figure 8 shows the tendency of the heat tolerant lines to have a slight edge over the locally released varieties across locations and planting dates for yield. Figure 9 and 10 compare the heat tolerant lines versus the local varieties for number of spikelets per ear and tillering capacity in different location planting date combinations.

There was a significant variety x location interaction and variety x planting date interaction for spikelets/ear. This indicates that the varieties performed differently for this trait in different locations. The orthogonal contrasts indicated significant difference in this trait when compare heat tolerant selection and local varieties Table 8 further illustrates the superiority of heat tolerant lines over the local varieties for number of spikelets/ear.

With regards to number of tillers/m^2 there was a significant difference between heat tolerant selection and local varieties. Heat tolerant selection had significantly high average number of tillers/m^2 (figure 10).

Figure 11 illustrates the effect of location and planting date on plant heights of the heat tolerant lines versus the local varieties. Heat tolerant lines were on average taller than the local varieties.

Table 8 Orthogonal Comparisons of Heat Tolerant Lines versus Local Varieties

		Spikelets		Tillers		Kernel Wt.		Plant height		LAI	
Source of Variation	**Df**	**Ms**	**F-cal**	**Ms**	**F-cal**	**Ms**	**F-cal**	**Ms**	**F-cal**	**Ms**	**F-cal**
Varieties	9	6.5	5.02**	16899	5.4**	23.5	34.2	1.2	6.18**	1.89	2.69**
Heat Tol. Vs Local	1	6.3	4.8*	15609	5.0*	21	30.6	1.1	5.79*	1.63	2.33**
Residual	216	1.3		3122		6.8		0.1		0.7	

** Significant at $p \leq 0.01$

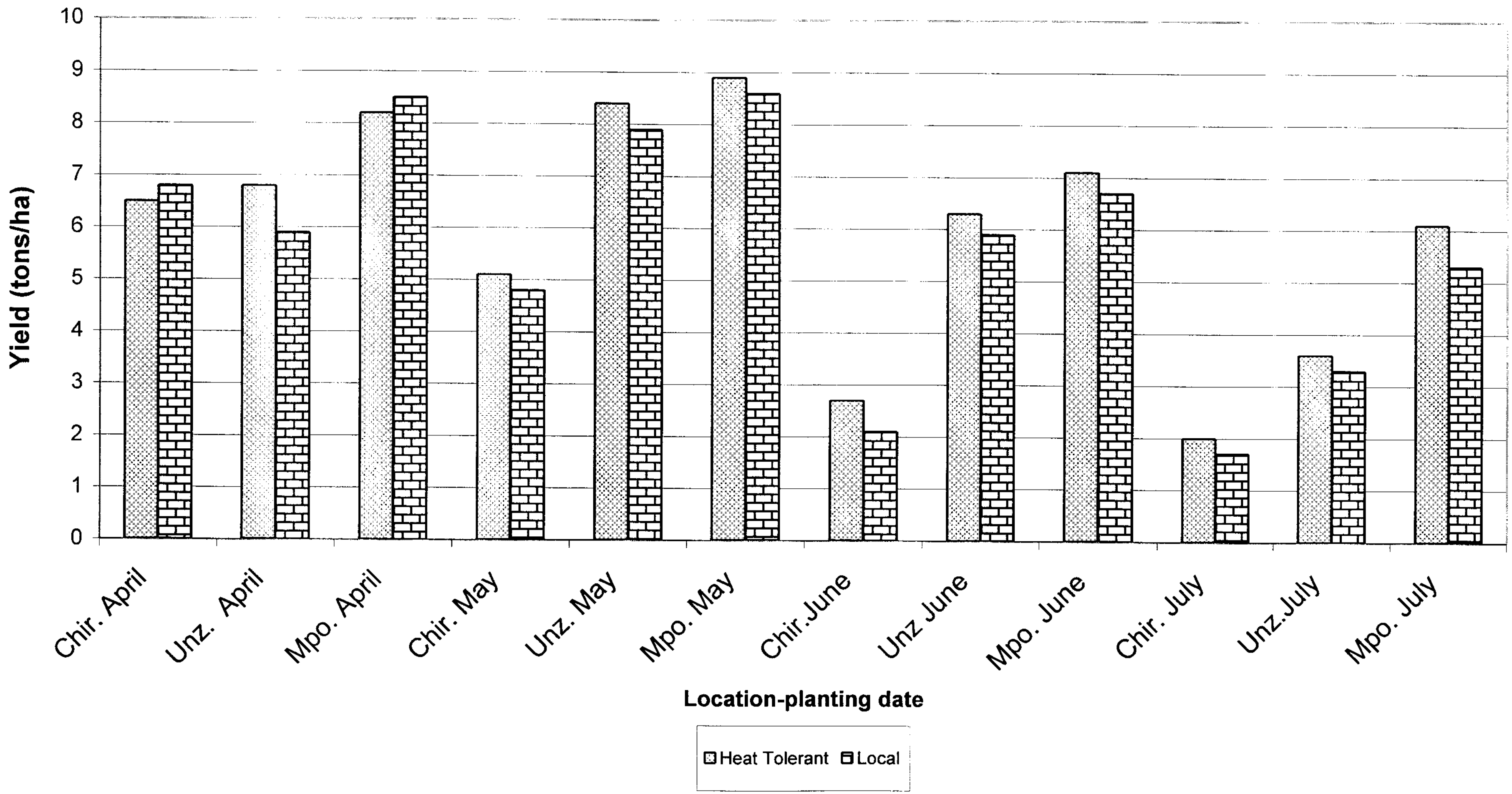


Figure 8 Comparison of heat tolerant lines and local varieties in yield

Figure 9 Comparison of number of spikelet/ear between heat tolerant lines and local varieties in different environments

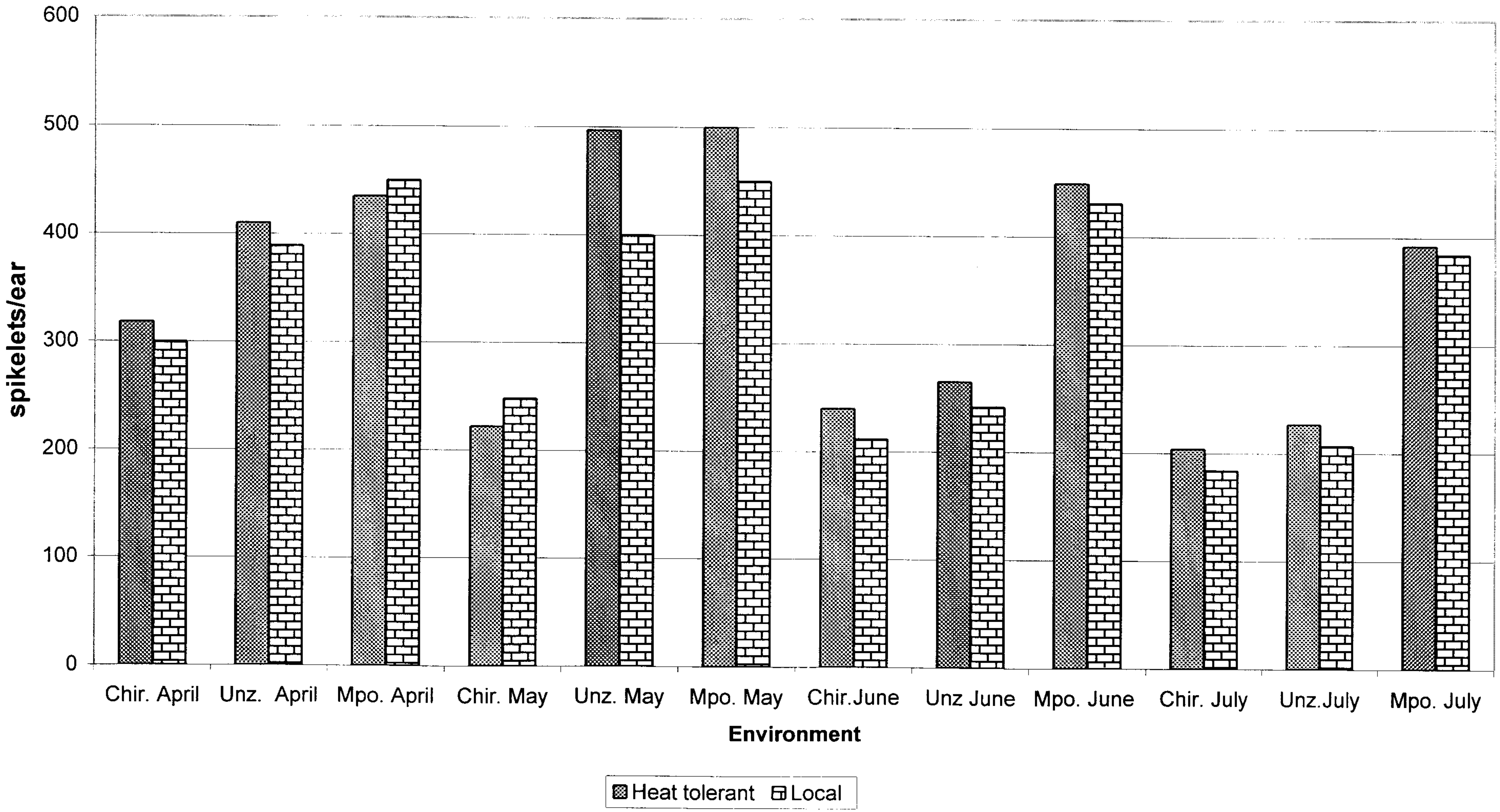


Figure 10 Effect of number of tillers in the different environment between heat tolerant lines and local varieties

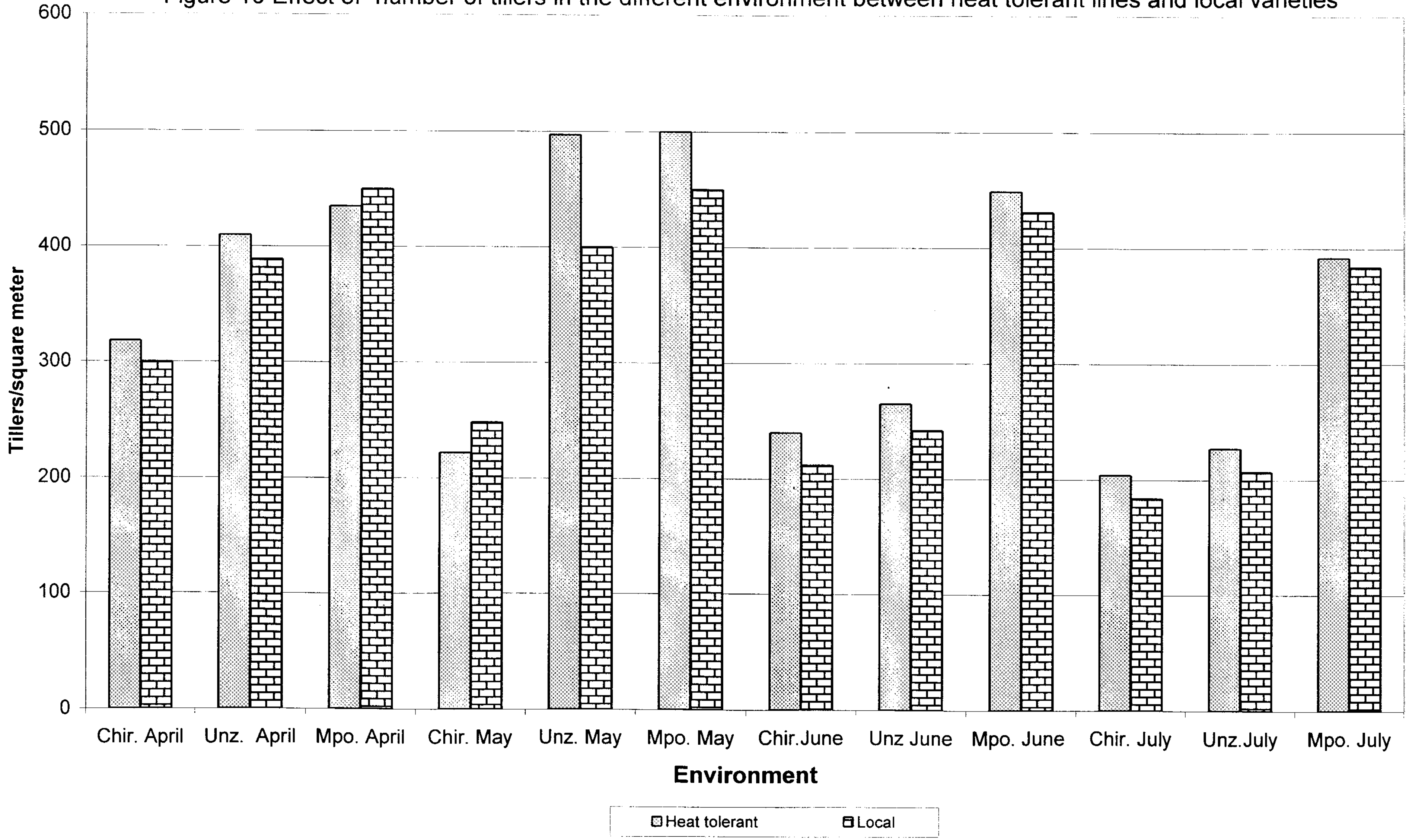
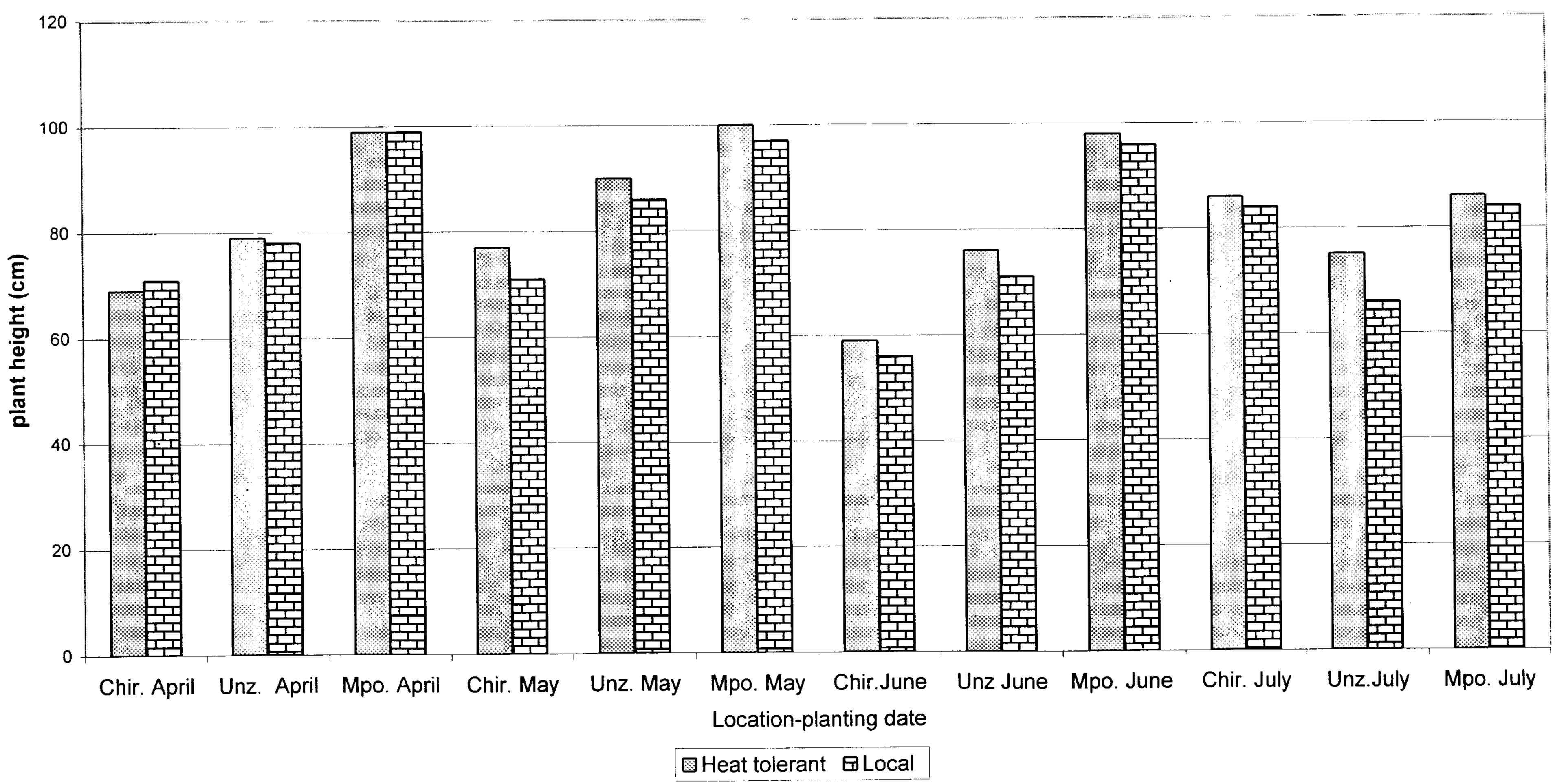


Figure 11 Comparison of plant height between heat tolerant lines and local varieties in different environments



4.5 Relationship of Yield and Morpho-Physiological Yield Components

A stepwise multiple regression analysis was conducted using yields as the dependent variable and yield components as independent variables. The purpose for this analysis was to identify the components that explained most of the variation in yield. Once these components are identified they could be used as indirect selection criteria for improving performance of wheat under varying ambient temperature regimes.

The stepwise multiple regression analysis identified the components that explained most of the variation in yield. The yield components spikelets/ear, number of tillers/m^2 and harvest index as shown (table 9) explained most of the variation in yield. The number of spikelets/ear explained most of the variation. It indicated a multiple coefficient of determination R^2 = 77.1%. The number of tillers/m^2 combined with spikelets contributed to 79.8% of the variation in yield. When harvest index is considered as a third parameter they contributed to 82.3% of the variation in yield. The number of tillers/square meter explained about 2.7% of the variation in yield while harvest index explained another 2.5% of the variation. These three traits together explained 82.3% of the variation in yield. Tillering capacity and harvest index have also been reported to have a significant positive relationship with yield. Plant height and kernel weight contributed to a smaller variation in yield.

Table 9 Coefficient of Determination of the physiological yield components

Component							Coefficient of Determination R^2 %
Spikelets	Spikelets	-	-	-	-	-	77.1
Tillers (m^2)	Spikelets	Tillers (m^2)	-	-	-	-	79.8
Harvest Index	Spikelets	Tillers (m^2)	Harvest Index	-	-	-	82.3
Kernel Weight (KW)	Spikelets	Tillers (m^2)	Harvest Index	KW	-	-	83.5
Plant Height	Spikelets	Tillers (m^2)	Harvest Index	KW	Plant Height	-	84.2
Leaf Area Index (LAI)	Spikelets	Tillers (m^2)	Harvest Index	KW	Plant Height	LAI	84.4

4.6 Stability Performance of the Spring Wheat Varieties in the Twelve Planting Date-Location Combination.

A stability analysis as per Eberhart and Russell method was carried out to identify which of the ten lines was more stable compared to the others. The location planting date combinations were used as environments in order to sample the array of temperature regimes to which the wheat crop was subjected during growth. Table 10 gives the twelve different location-planting date environments on which the individual yield of the varieties were regressed. The table clearly shows that Chirundu June and July environments were the adverse environment with an environmental index June –3.4 and July –3.8. The negative environmental index reflects an increase in ambient temperature with delayed planting dates. Across all the locations at Unza and Mpongwe the July location environment was the adverse environment since in all locations the environmental index was negative.

The regression analysis table 11 shows a significant regression, genotype x environment interaction and also a significant pooled deviation linear.

4.61 Yield Stability

In assessing stability the main parameters are mean square deviation from regression and regression coefficient. However, also the mean yields of the varieties are considered in determining stability. The productivity of the variety, which is above grand mean, is taken into account in assessing the variety stability. According to Carlson (1980) a regression coefficient (b= 1) indicate average stability, regression coefficient (b>1) a variety shows less than average stability and when b<1, a variety has a higher than average stability under adverse conditions Lungu, (1978) indicated the parameters of a stable variety. A stable variety was defined as one with regression coefficient of one (b = 1.0) and with mean square deviation from regression as small as possible ($s^2d = 0$), its regression coefficient would be close to unity and its varietal response would exceed the average yield of all genotypes. The regression coefficients that is also acceptable maybe greater than or less than unity (b >1.0 or b< 1.0) but the mean yield must be below average in such instances.

The grand mean yield for the ten spring wheat varieties used in the study was 5.8 tons/hectare (Table 12). Varieties with such mean yield are desirable in the Tropics, since they have a high yield potential. The heat tolerant lines Entry 2 gave an average yield of 6.4 tons/ha that was above the grand mean of 5.8 tons/ha, Entry 28 gave mean yield of 5.9 tons/ha, Entry 31 gave a mean yield of 6.2 tons/ha and Entry 50 indicated a mean yield of 5.9 tons/ha. The heat tolerant lines, gave an average mean yield above the grand mean thus when considering mean yield as a stability parameter four varieties can be considered stable. Inw 1 and Inw 2 of the local varieties indicated an average yield above the grand mean. These varieties gave a mean yield of 5.8 and 5.8 tons/ha respectively.

When the regression coefficient is considered as a stability parameter. The heat tolerant varieties Entry 2, Entry 24, Entry 28 and Entry 50 indicated regression coefficient of 1.06, 0.93, 1.02 and 0.96 respectively. Among the local varieties Inw 1, Inw 2 Nkanga and Pwele indicated regression coefficients of 1.06, 0.95, 0.87 and 0.92 respectively. These varieties are considered stable because of the regression coefficient values close to 1. Nkanga proved to be more stable than the other varieties because of the low regression coefficient value.

The mean square deviation from regression identified four of the heat tolerant lines as stable varieties and two of the local varieties. Entry 2, Entry 28, Entry 31 and Entry 50 of the heat tolerant lines indicated mean square regression values of 0.39, 0.29, 0.40, and 0.29 respectively. Among the local varieties Inw 2 and Nkanga indicated mean square regression coefficient values of 0.10 and 0.32 respectively. The varieties indicated mean square regression coefficient values close to one hence could be considered as stable varieties.

The heat tolerant selection appear to be more stable than the local varieties although Nkanga appear to be more stable although it gave lower yields (figure 12).

Table 10 Divisions Of The Location-Planting Date And Their Environmental Index.

Planting date	Locations	Agro-ecological zone	Environmental Index
April	Chirundu	I	0.8
May	Chirundu	I	-0.9
June	Chirundu	I	-3.4
July	Chirundu	I	-3.8
April	Unza	II	0.5
May	Unza	II	2.4
June	Unza	II	0.3
July	Unza	II	-2.4
April	Mpongwe	III	2.6
May	Mpongwe	III	2.9
June	Mpongwe	III	0.9
July	Mpongwe	III	-0.1

Table 11 Analysis of Variance of grain yield on ten spring wheat varieties grown in twelve environments

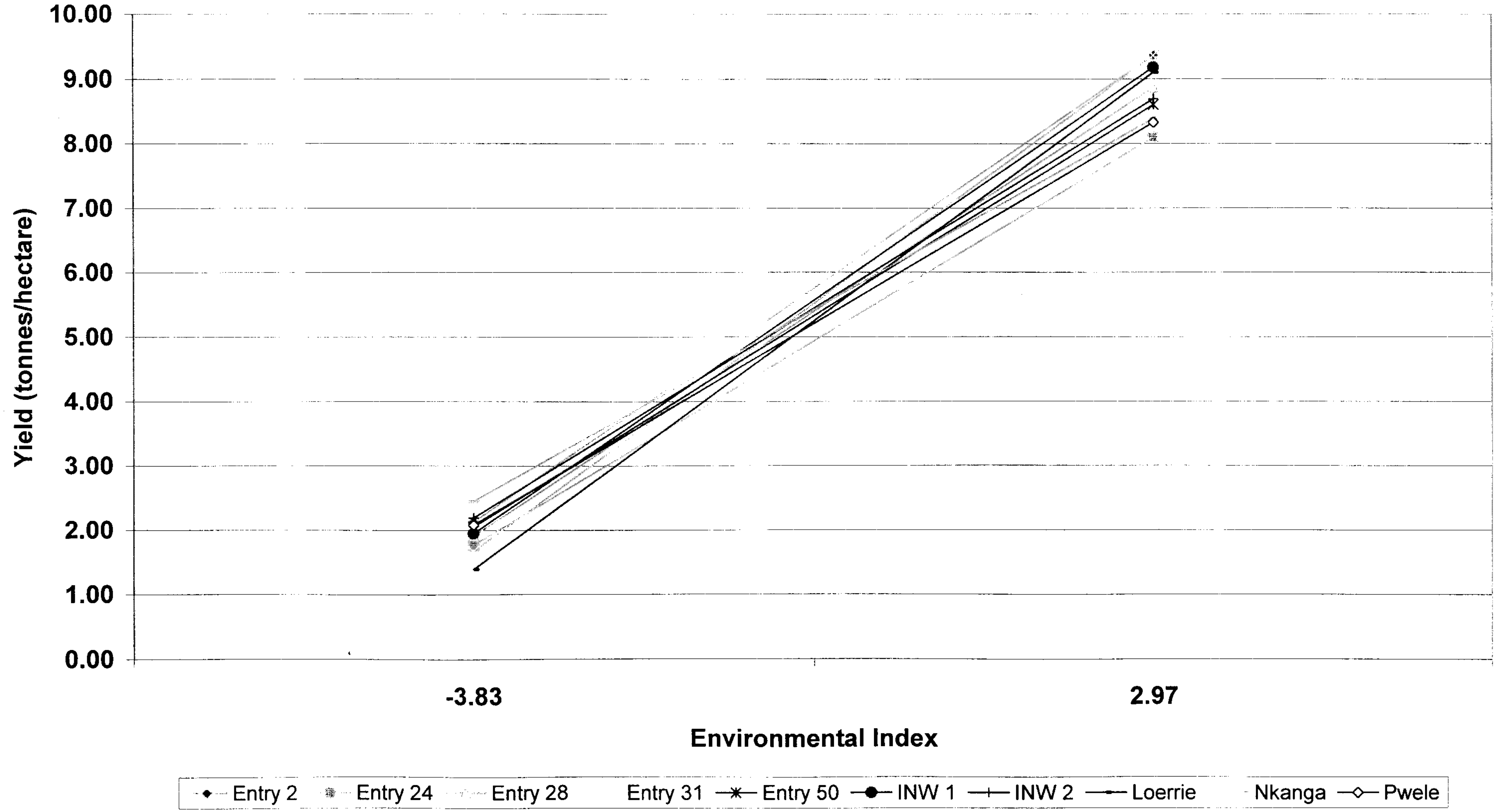
Source of Variation	Df	SS	MS
Varieties	9		
Environments			
G x E	11		
Environment (linear)	1	563.9062	563.9**
G x E (linear)	9	50.79	5.634*
Pooled deviation	100	463.49	4.6349**
Error	240	163.6	0.6817

**significant at $p \leq 0.01$

Table 12 Stability parameters of yield for ten spring wheat varieties tested in twelve environments

Varieties	Mean yield tons/hectare	Regression	
		Coefficient	Deviation Ms (s^2d)
Entry 2	6.40	1.06	0.39
Entry 24	5.5	0.93	0.56
Entry 28	5.9	1.02	0.29
Entry 31	6.2	1.13	0.40
Entry 50	5.9	0.9	0.29
Inw- 1	5.8	1.06	0.63
Inw-2	5.8	0.95	0.10
Loerrie II	5.6	1.13	0.66
Nkanga (P7)	5.5	0.87	0.32
Pwele (28)	5.4	0.92	0.97
Average	**5.8**		

Figure 12 Stability of ten varieties across twelve environments



5.0 DISCUSSION

The results showed that the ten spring wheat varieties used in the study generally have the same yield potential. The varieties were all of high yield potential since according to Little (1988) varieties with yield of 6 tons per hectare could be said to have a high yield. The varieties showed significant differences for number of spikelets per ear, number of tillers per square meter, one thousand-kernel weight, plant height and leaf area index. They however did not differ in harvest index.

The varieties performed differently in different locations. These results tally with Woodruff and Tonks (1983) findings that indicated that genotypes show differences in yield response to varying environments. Chirundu in the hot Zambezi valley-representing Region I showed to be the adverse environment for wheat production. The Chirundu site showed reduced expression of number of spikelets per ear, number of tillers per square meter and plant height. Peak yield were obtained in April in Chirundu and in Mpongwe and Unza they occurred in May. The reduction in yields in June and July planting could be associated with elevation of ambient temperatures has been said to have a negative effect on yield and yield components (Hunt *et.al*, 1995). The yield reduction in Mpongwe was not severe and this could be associated with the better productivity of the Mpongwe soils. According to Aggarwal (1999) yield reduction after the optimal date highly depend upon thermal region. This explains the greater reduction in yield with delayed planting in

Chirundu that is in the hot valley area. This is supportive of Ciha and Hagmann (1981) results that the majority of wheat cultivars showed no difference in grain yield between early and recommended planting date, but late planting decrease yields. Although Ivins and Jessop (1970) found that yields increased with delayed planting. The yield components number of spikelets per ear and number of tillers per square meter were the most sensitive to delayed planting. These results indicate that the expression of yield components highly depend on location and date of planting. Planting after the threshold date especially in July the yield components so a seriously reduction in their expression. This tends to have a negative effect on grain yield. These findings concur with the researchers reports that yield components are greatly influenced by the environment.

A number of researchers have reported that wheat genotypes generally show differential yield response to varying environment, which indicates a differential effect of environment on yield component development. Heredity and environment was noted to have a strong influence on tillering capacity (Fischer, 1985, Saunder, 1988 and Simmons *et.al.*,1995). The orthogonal contrasts between the five heat tolerant selections versus local varieties for number of spikelets per ear, number of tillers per square meter and plant height showed significant superiority of the heat tolerant selections for these traits. This explains the slight edge of the heat tolerant lines over the locally released varieties across the locations and planting dates for yield. The heat tolerant selection had significantly higher average number of tillers/square meter. This indicates that the heat tolerant lines have a higher performance than the local varieties in the morpho-physiological yield components tillers per square meter and spikelets. This implied that the heat tolerant lines have a higher tillering capacity than the local varieties in all the locations and planting date.

The stepwise multiple regression analysis identified the components that explained most of the variation in yield. The yield components spikelets/ear, number of tillers/square meter and harvest index explained most of the variation in yield. The number of spikelets/per ear explained most of the variation. It indicated a high multiple coefficient of determination R^2 of 77.1%. These results are in line with the findings of Austin and Jones (1976). These workers identified average number of spikes per plant as the most important component of yield. Hsu and Walton (1971) reported findings consistent with these findings. They studied the relationship between yield components in wheat grown under field and greenhouse conditions. They found that the number of spikes per plant were the most important component in determining grain yield. High tillering capacity is likely to result in more tillers bearing kernels thus improving grain yield. Although, Donald, (1968) stated that highest harvest index maybe achieved with fewest tillers. There is a need for sufficient tillering to ensure plant survival and compensation for effects variation in number of plants per unit area. Moreover, Simpson (1968) stated that high yield in short cultivars is due to greater capacity for tillering. High number of tillers per square metre can be achieved in spaced plants. Low population density is likely to result to high number of tillers (Austin and Jones, 1976).

Improvement of harvest index is likely to have a positive effect on yield. Frey, (1975) stated that crops where harvest index already exceeds 0.8 it might not be possible to increase the index much more. Since the harvest index values for the spring wheat varieties used still fall within the range of 0.5-0.6 increases is still possible. The efficiency of selection for a yield component depends on the heritability of the trait. Borrell *et.al.*, (1991) estimated heritability data from hills for number of spikes, kernels per spike and kernel weight and found that number of spikes and kernels per spike were highly heritable than kernel weight. Lungu, (1978) highlighted that overall yield components were inherited highly than grain yield per se.

Plant height and kernel weight contributed to a smaller variation in yield. The two traits indicated a positive relationship with yield. The small variation accounted for by these parameters indicated that selection for these traits cannot significantly increase yield. However selecting for dwarf types if dwarfiness reduces plant lodging has been known to increase yield. This was infact the basis for the much-reported green revolution where research work at CIMMYT in Mexico developed dwarf varieties of wheat, which could withstand heavy fertilization under irrigation and gave impressive yields without lodging. McNeal *et.al.* (1978) stated that a single trait character can improve yield but long-range improvements probably results from concomitant improvement in all yield components. This implied that spikelet improvement is likely to improve yield significantly but consideration of spikelets/ear, tillers/square meter and harvest index in yield improvement programme can be of additional advantage. Characters that affect yield components expression should be considered simultaneously.

The heat tolerant selection appears to be more stable than the local varieties. Although Nkanga gave a low yield it appears to be more stable since Carlson, (1980) stated that a stable variety its mean square deviation from regression would be as small as possible, its regression coefficient would be close to unity The heat tolerant varieties gave an average mean yield above the grand mean thus when considering mean yield as a stability parameter four of these varieties can be considered stable. These varieties also indicated regression coefficient values close to one and mean square deviation close to 1, which are characters for a stable variety. The results indicate that plant breeders need to deliberately select for heat tolerance and this would lead to development of varieties that would give a stable performance even under high ambient temperatures.

6.0 CONCLUSION

The study showed that the varieties did not differ significantly in yield across location and all planting dates. However, the study showed that there was a significant influence on locations. Chirundu location in the hot Zambezi valley gave the lowest average yield of the three locations. This can be attributed to the relatively high ambient temperatures that were obtaining during crop growth. The effect of location was also significant even with yield components. Number of spikelets/ear, tillers/square meter, harvest index, thousand kernel weight, plant height, leaf area index and harvest index were all lower at Chirundu compared to the other locations.

With regards to planting date the study established the optimum planting date for Unza and Mpongwe as being May and Chirundu April. Furthermore, the study clearly established that delayed planting result to reduction in grain yield. At Mpongwe the yield ranged from 8.4 tons/hectare in April to 5.7tons/hectare in July. Unza the yield ranged from 8.2 tons/ha to 3.5 tons/ha. Whilst in Chirundu the yield ranged from 6.6 tons/ha to 1.9 tons/ha. In all cases the reduction in yield could be attributed to the elevation in environmental temperature thus tillering capacity was occurring when ambient temperature was still high and also the grain filling period occurred when ambient temperature was accelerating. Despite the general reduction in yield for all the varieties the heat tolerant lines tended to have a slight edge in yield. For the yield components the heat tolerant lines showed a superior performance in number of spikelets/ear, number of tillers/square meter and plant height.

A stepwise multiple regression analysis identified number of spikelets/ear as being the most important trait explaining variation in yield and two other components which had a marginal effect were number of tillers/square meter and harvest index. These three traits accounted for 82.3% of the variation in yield using coefficient of multiple determination R^2 as a selection criteria. This analysis identified these three components as potential indirect selection criteria for yield and yield stability under hot ambient temperatures. If breeders can select for more spikelets/ear and stability of this expression even under hot ambient temperatures not only yield will increase but also there will be stable performance under hot temperature. This goes for selection for high tillering capacity under hot ambient temperature will also lead to high yield performance under these conditions. These two will naturally lead to an improvement in harvest index.

Analysing the comparative stability performance of heat tolerant selection and local varieties showed that the heat tolerant lines tend to be much more stable than local varieties when consider the regression coefficient, mean square deviation from regression and mean advantage over grand mean. This study then indicates that deliberate selection for heat tolerant for yield and targeting the characters that most affect yield such as number of spikelet/ear and number of tillers/square meter lead to greater yield stability performance under even harsh temperature regimes. This will ensure the farmer in Zambia to still get good yield even if they delay planting. The heat tolerant varieties would encourage wheat production among both the small scale and large-scale farmers in the hot valley areas, which are well endowed with water resources.

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