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# Evaluation of Twelve Spring Wheat (*Triticum aestivum L.*) Genotypes for Water Use Efficiency under Varying Water Regimes

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## ABSTRACT

Wheat is increasingly becoming an important staple food crop in Zambia's urban and peri-urban communities where shifts in food tastes and preferences towards convenience–type wheat products, has occurred. Production and yield are however severely limited by the cost of irrigation. A study was carried out at Nanga Research Station in 2011 during the dry season to evaluate wheat genotypes for water use efficiency and identify wheat morphological traits that influence water use efficiency. The experiment was as a Split plot in a Randomised Complete Block Design with three replications. Three water regimes (100%, 75% and 50% of crop water requirement) were the main plots and twelve spring wheat genotypes were subplots. Grain yield, water use efficiency, spike length, above ground biomass, plant height, thousand kernel weight, number of grains per spike, harvest index and spikelets per spike were the parameters measured. Results revealed that there were highly significant differences among the genotypes and genotype by water regimes interactions for grain yield, morphological traits and water use efficiency. Water regimes had significant effects on most parameters measured except on number of grains per spike, spikelets per spike and thousand kernel weight. Harvest index and thousand kernel weight were identified as the most important traits that explained 60.9% of the variation in water use efficiency. These results indicated that wheat farmers could apply less water if they grow genotypes showing high water use efficiency thereby reducing water application costs. Wheat breeders could target water use efficiency as a breeding objective and deliberately select for high water use efficiency under low water supply using thousand kernel weight and harvest index as traits for selection. Sahai I and Loerie II which showed superior water use efficiency could be used as parental material for hybridisation in creation of variation in the breeding program.

**KEY WORDS:** Grain yield, Yield component, Genotypes, Water Regime, Water use efficiency

## INTRODUCTION

The major challenge of increasing wheat production in Zambia is increasing the area of land under production. In Zambia, only spring wheat is grown by commercial farmers, mainly under irrigation. ACF (2011) recently reported variable yields among commercial wheat producers based on the constraint of water supply and management as a result of decreasing ground water tables in the Central Province where the bulk of the crop is produced. The Central Province alone accounts for more than half of Zambia's wheat with bore holes now being sunk to depth of 60 to 90 m from the previous depth of 30 to 50 m. Decreasing water table in the province is attributed to drought and over exploitation of underground water for agricultural use especially during the dry season when wheat is also grown. Farmers will apply low, medium and high yield management levels, with average wheat yields ranging from 5 to 7.5 t $ha^{-1}$, while the irrigation cost can contribute as much as 44% of the variable cost of production.

Water is needed by the plant to carry out normal physiological and developmental functions. The actual water requirement is the quantity of water required to meet the demands of evapo-transpiration and metabolic activities of the plant. Mahmood and Ahmad (2005) indicated that only 1% of water requirement in wheat is used for actual metabolic activities while the balance is for evapo-transpiration. Turner (2004) and Karlberg *et al* (2008) also included drainage, surface run-off and lateral through flow as part of the water balance not used by plants.

One important way of preserving water in farming is to increase the efficiency of water use by the plant through higher water productivity (Karlberg *et al*, 2008). Crop management strategies such as water, soil and crop management have been reported to have an impact on water productivity (Turner, 2004; Karlberg *et al*, 2008; Davies *et al*, 2011). However, through classical or conventional plant breeding, a deliberate interbreeding or crossing of closely or distantly related species to produce new crops with desired traits is one of the most effective strategies in coping with limited water supply and has made strides in producing crop genotypes with some capacity to sustain yields in water – scarce environment (Turner, 2004; Bahieldin *et al*, 2005; Shamsi *et al*, 2010; Davies *et*

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*al*, 2011). Genetic diversity in a water use efficiency(WUE) trait in wheat genotypes leads to success in identifying and selecting wheat lines and cultivars having morphological and physiological characteristics suitable for higher yields and WUE (Bahieldin *et al*,2005; Shamsi *et al*, 2010; Davies *et al*, 2011; Lumpkin 2011). Plant traits such as grain yield, spike length, above ground biomass, plant height, thousand kernel weight, number of grains per spike, harvest index and number of spikelet per spike have been documented to have an effect on WUE components (Mesbah, 2009; Shamsi *et al*, 2010; Yong'an *et al*, 2010; Miranzadeh *et al*, 2011; Silva *et al*, 2012).In addition, Reynolds *et al* (2001), Bogale *et al* (2011) and Bahar *et al* (2011)also suggested the use of Stay Green duration, Canopy Temperature Depression, Membrane thermo stability, Leaf chlorophyll content, Leaf posture and rolling as better selection criterion under environmental stress which could improve WUE.

With falling water tables in Zambia's most wheat productive province, greater efforts are required in the development of alternatives for sustainable agriculture such as selection and breeding of genotypes that are efficient in WUE (Silva *et al*, 2012). WUE studies on wheat genotypes revealed high genetic variation and differences in some morphological characteristics (Alderfasi, 2000; Mahmood and Ahmad, 2005; Yousufazai, 2007; Shamsi *et al*, 2010; Miranzadeh *et al*, 2011). It is apparent from these studies that morphological characters that were used to assess WUE may be used in wheat improvement programmes. An understanding of the responses of Zambian wheat genotypes to different water regimes or application rates can lead to identification of morphological characters that can be of use in wheat breeding in order to improve wheat production among farmers.

Therefore, this study was conducted to evaluate wheat genotypes for WUE and identify wheat morphological traits that influence WUE which can be used in breeding for low water supply.

## MATERIALS AND METHODS

### Study Location

The experiment was undertaken at Nanga the National Agricultural Irrigation Research Station (Latitude $15^0$ 46'S, Longitude $27^0$ 55'E and Altitude 1044 m above sea level), in Mazabuka District of the Southern Province of Zambia in 2011 during the dry season. The soil at the research site was clay loam in texture, with a pH of 6.68, organic matter of 1.12% and total nitrogen content of 0.1%.

### Experimental Design

Field study involved twelve commercial wheat varieties comprising of two rain-fed and ten irrigated genotypes; Nduna, Sahai I, Sekuru, Shine, UNZA I,UNZA II, Coucal, Mampolyo, Nseba, Choza, Loerie II and Pungwa. Sahai I and Coucal were the rain-fed while the others were irrigated genotypes. The 100% crop water requirement recommended for Zambian wheat farmers is 450 mm – 500 mm per season which is usually calculated based on crop coefficient (kc), evapo-transpiration and weather parameters. Thus for Nanga Research Station, W 1 was 506 mm which became the reference as 100% and W 2 (75%) and W 3 (50%) was calculated from the recommended crop water supply and applied through irrigation in the season.

There were 36 treatment combinations which comprised of three water regimes as factor A (main plot) and twelve genotypes as factor B (sub-plot). The experiment was a split plot arranged in a Randomised Complete Block Design with three replications.

### Cultural Practices

Planting rows measuring 1.5 m X 0.2 m were marked in water basins and basal dressing was applied at 500 kg $ha^{-1}$ wheat basal with Avail booster (9.20 N; 21 $P_2O_5$; 16 $K_20$; 12 S; 0.8 Mg; 0.2 Cu; 0.3 Fe; 0.5 Zn; 0.2 B) thereafter covered with soil. Three rows were planted per genotype on $10^{th}$ June, 2011 at seed rate of 100 kg $ha^{-1}$. Weeding was done manually in the seventh week after planting and subsequent broad leaf weeds which emerged thereafter were pulled out to maintain healthy plants. Water was applied to each treatment using sprinkler attached to flow meter. To prevent water drift in the neighbouring water basin, a 2 m plastic sheet was raised to enclose each basin during irrigation. Top dressing using urea (46% N) was applied at eighth week after crop emergence to provide nitrogen fertiliser to total of 240 kg N $ha^{-1}$.

### Data Collection

Data for plant height, harvest index, above ground biomass, number of grains per spike, spike length and spikelet per spike at physiological maturity stage were obtained from twelve tagged plants in the middle of each treatment plot. Grain yield per hectare at harvest was obtained by weighing harvested grains and converted to kg $ha^{-1}$ at 12% grain moisture content. Thousand kernel weight was obtained randomly by drawing some seeds from each grain yield sample and after counting the seeds were weighed. Water use efficiency was calculated as ratio of the grain yield to total water applied in mm (Waraich *et al*, 2007; Shamsi *et al*, 2010; Miranzadeh *et al*, 2011).

**Data Analysis and Interpretation**

The data on yield and yield components were analysed using the GENSTAT 13$^{th}$Edition. Means were separated using Fisher's Least Significant Difference (LSD). Stepwise multiple regression analyses were done to identify parameters explaining most of the variation in the response variable water use efficiency using SPSS version 16.0.

## RESULTS AND DISCUSSION

The Analysis of Variance as presented in Table 1 showed that there were significant differences among genotypes for grain yield, water use efficiency and yield components ($p< 0.001$).Water regimes had significant effect on most parameter measured except for number of grains per spike, number of spikelet per spike and thousand kernel weight. There were significant water regimes by genotype interactions forall parameters measured.

**Effect of Genotype on Grain Yield**

Grain yield differences were observed across crop water requirements for all genotypes (Table 2). The highest mean grain yield was obtained from Mampolyo (5, 838 kg ha$^{-1}$) and Sahai I (5,669 kg ha$^{-1}$) whereas the lowest mean grain yield was observed for Choza (4, 049 kg ha$^{-1}$), Nduna (4, 155 kg ha$^{-1}$) and UNZA I (4, 212 kg ha$^{-1}$). Decreasing water supply from 100% to 50% crop water requirements led to different grain yield responses among genotypes (Table 4). The general tendency was a decrease in grain yield for most genotypes with reduced water application. However, some genotypes like Sekuru, UNZA II and Loerie II, grain yield statistically remained stable with reduction in application of crop water requirements across all water regimes while UNZA I, Mampolyo and Nseba in two water regimes. Mampolyo produced the highest grain yield of 7, 346 kg ha$^{-1}$ in 100% crop water requirement while in 50% crop water requirement, Sahai I gave the highest yield of 6, 086 kg ha$^{-1}$ followed by Loerie II with a yield of 5,351 kg ha$^{-1}$). Although, Sekuru, UNZA II and Loerie II statistically maintained their grain yield in all water regimes, Loerie II recorded higher grain yield compared to UNZA II and Sekuru. The results also showed that UNZA I, Mampolyo and Nseba statistically remained stable in grain yield when water supply decreased from 75% to 50% of crop water requirement while Sahai I maintained a high and same grain yield of above 6, 000 kg ha$^{-1}$ in both 100% and 50% crop water requirement.

Maximum grain yields observed from high yielding genotypes might be attributed to the improvements in their yield components. Most high yielding genotypes recorded high WUE, above ground biomass, harvest index, number of spikelet per spike and number of grains per spike. The lowest grain yielding genotypes also tended to have lower WUE, harvest index, number of spikelet per spike and either had the lowest above ground biomass, number of grains per spike or thousand kernel weight. The differences in grain yield was genotypic dependence while the maintenance of same mean grain yields of some genotypes as crop water requirements reduced from 100% to 50% could be associated to their ability to double their WUE a trait linked to adaptability of genotypes to drought conditions. The findings in this study are supported by research findings of Tas and Tas (2007), Gholamin *et al* (2010), Yong'an *et al* (2010), Miranzadeh *et al* (2011) and Khamssi and Najaphy (2012).

**Effects of Water Regimes on Grain Yield and Yield Components**

The variations in grain yield and yield components performance across all genotypes (Table 3) were influenced by decreasing the application of crop water requirements in the study. Contradicting research findings have been reported on number of grains per spike with water stress. Waraich *et al* (2007), Gull *et al* (2012) and Karamanos *et al* (2012) reported a decrease in on number of grains per spike when water application rate was reduced while Khamssi and Najaphy (2012), Savic *et al* (2012) and Guendouz *et al* (2012) did not find any difference. Reduction of number of spikelet per spike and thousand kernel weight with increased water stress is well documented by other researchers (Waraich *et al*, 2007; Sial *et al*, 2009; Mushtaq *et al*, 2011; Gull *et al*, 2012; Guendouz *et al*, 2012). However, in this study, number of spikelet per spike, thousand kernel weight and number of grains per spike were not statistically reduced by decreasing water application rate. The differences in the findings from this study with those of other researchers could be attributed to different climatic and soil conditions, different methods of exercising water treatments and differences in the genotypes used in different experiments.

Apart from above ground biomass which recorded highest yield of 61.60 g per plant in 75% water requirement, plant height, spike length, harvest index and grain yield were highest in 100% crop water requirement. Water stress up to 50% of the crop water requirement reduced plant height by 16%, grain yield and harvest index by 25% each and above ground biomass by 12%. Spike length remained the same in both 100% and 50% crop water requirement but recorded the shortest length of 6.30 cm in 75% water regime. The decreases in yield components could have led to a concomitant reduction of 25% in both harvest index and grain yield in the study. The equal reduction in percentage in harvest index and grain yield explains the dependence of grain yield on availability of assimilates and ability to partition it into economic grain yield. Other researchers (Waraich *et al*, 2007; Mushtaq *et al*, 2011; Guendouz *et al*, 2012) also reported decreased grain yield as a result of reduction in yield components such as above ground biomass, plant height, harvest index and spike length when water supply was reduced.

**Effect of Water Regime by Genotype Interaction on Yield Components**

The interaction of genotypes with water regimes (Table 4) showed significant effects on all traits assessed. Maintenance or improvements in yield components in wheat genotypes in different water regimes have been cited by researchers for the pivotal role they play in wheat production or use as selection traits in improvement programme (Sial *et al*, 2009; Gholamin *et al*, 2010; Yong'an *et al*, 2010; Bogale *et al*, 2011; Guendouz *et al*, 2012; Karamanos *et al*, 2012). This is because different genotypes possess different inherent potential or introgressed genes for controlling physiological mechanisms that enable them sustain water stress. In this study, different genotypic responses to increased water stress were observed in yield components as crop water requirements was reduced from 100% to 50%. More wheat genotypes statistically maintained their number of grains per spike, spike length, harvest index, thousand kernel weight and number of spikelets per spike both in 100% and 50% water supply which did not contribute to their tolerance in terms of improvement in mean grain yield. However, Nseba, Sahai I and Sekuru increased thousand kernel weight when crop water requirement was reduced from 100% to 50%. The above ground biomass for most genotypes drastically reduced with increased water stress with the exception of Coucal, Mampolyo and Sekuru. Coucal doubled above ground biomass when water supply was reduced from 100% to 75% while Sekuru and Mampolyo increased from 68.66 g to 76.61 g and 47.61 g to 73.27 g, respectively when water supply was reduced from 100% to 50%. Increased above ground biomass and thousand kernel weight when crop water requirement was decreased could have contributed to the ability of these genotypes to maintain stable mean grain yields in two water regimes.

**Water Use Efficiency**

There were highly significant differences ($p \leq 0.001$) in WUE among genotypes (Table 1 and Table 2). Results showed that WUE ranged from 10.84 kg/ha $mm^{-1}$ for Choza to 16.26 kg/ha $mm^{-1}$ for Sahai I. The WUE for three genotypes (Choza, Nduna and UNZA I) were statistically placed the lowest and same while Sahai I was the highest. Although Mampolyo had the same WUE as Loerie II, it was also statistically placed together with Sahai I. Genotypes that recorded high WUE were observed to have improvements in their yield components such as thousand kernel weight, spikelet per spike, above ground biomass and harvest index, resulting into higher grain yield. The high WUE exhibited by Sahai I, Loerie II and Mampolyo could also be due to introgressed genes. In addition, Loerie II which is the oldest irrigated wheat genotype in the country and Sahai I breed for rain-fed conditions associated with seasonal variation in amount of rainfall could have acquired resistance to drought resulting to high WUE observed. These results agree with findings of other researchers (Yousufzai, 2007; Yong'an *et al*, 2010; Shamsi *et al*, 2010; Miranzadeh *et al*, 2011).

Decreasing crop water requirements from 100% to 50% in this study increased WUE by 49.32% from 11.07 kg/ha $mm^{-1}$(Table 3). Similar findings were observed by Mesbah (2009) who found an increase in water use efficiency when the quantity of irrigation water was decreased from 1,850 $m^3$ to 1,350 $m^3$ in the growing season. Comparison means in Table 4 show the influence of genotypes and water regimes interaction on WUE. Choza, Nduna and UNZA I statistically maintained lowest WUE in all crop water requirements while Loerie II and Sahai I doubled as water supply decreased from 100% to 50%. Sekuru and Pungwa were increasing WUE with increased water stress. Mampolyo recorded the highest WUE in 100% crop water requirement while Sahai I followed by Loerie II and Mampolyo were highest under 50% crop water requirement. Alderfasi (2000) and Miranzadeh *et al* (2011) also reported differences in WUE among different four wheat genotypes under different water stress. In this study, the differences in behaviour of wheat genotypes under water stress appear to be due to inherent potential to sustain water stress conditions that may be attributed to their variable genetic make-up and different impairments of physiological mechanisms. Genotypes with high WUE would be preferable to farmers due to ability to produce stable high grain yields both in high and low water supply. Thus, they would reduce cost of water application in production and help reduce the rate of underground water table depletion especially in areas where water supply is through boreholes.

WUE is not only a component of crop drought resistance and adaptation but also considered as an important trait in determining crop yields (Blum, 2009; Silva *et al*, 2012). Parry and Hawkesford (2012) revealed that WUE is a complex physiological trait which is affected and explained by the plants' root and canopy traits and environmental conditions. In this study, the stepwise multiple regression of canopy traits using WUE as dependent variable under low water application rate identified harvest index and thousand kernel weight (Table 5). These traits accounted for 60.9% of variation in WUE and would be potential indirect selection criteria for WUE under water stressed wheat breeding programmes. These results are supported by findings of other researchers who observed that improvements of harvest index and thousand kernel weight in wheat would lead to enhanced WUE (Mahmood and Ahmad, 2005; Shamsi *et al*, 2010; Hwary and Yagoub, 2011).

**Table 1: Summary of ANOVA for grain yield , WUE and yield components across spring wheat genotypes under three water regimes**

| Source of Variation | DF | GY | TKW | BM | SPS | PHT | GS | SL | HI | WUE |
|---|---|---|---|---|---|---|---|---|---|---|
| Genotype (G) | 11 | ** | ** | * | ** | ** | ** | ** | ** | ** |
| Water Regime (W) | 2 | ** | NS | ** | NS | ** | NS | * | ** | ** |
| W X G | 22 | ** | ** | ** | ** | ** | ** | ** | ** | ** |

** = Significance at P < 0.01 * = Significance at P < 0.05 NS = Non -significant

GY: Grain Yield, TKW: Thousand Kernel Weight, SPS: Number of Spikelet per Spike, BM: Above Ground Biomass, SL: Spike length, GS: Number of grains per spike, HI: Harvest index, PHT: Plant height and WUE: Water use efficiency.

**Table 2: The mean grain yields, WUE and yield components of genotypes across water regimes**

| GENOTYPE | GY (Kg/ha) | TKW (g) | SPS | BM (g) | S L (cm) | GS | HI (%) | PHT (cm) | WUE (Kg/ha /mm) |
|---|---|---|---|---|---|---|---|---|---|
| Choza | 4,049d | 50.21bc | 12.64ab | 59.13b | 6.76c | 19.30cd | 20.00d | 73.00e | 10.84e |
| Coucal | 4,804c | 50.79bc | 12.97ab | 66.84ab | 6.16d | 25.32a | 17.07e | 85.31a | 13.12cd |
| Loerie II | 5,229b | 48.35c | 12.86ab | 62.73b | 7.03bc | 22.92b | 28.20b | 77.89c | 15.05b |
| Mampolyo | 5,838a | 55.35a | 13.46a | 64.06b | 7.00bc | 24.12ab | 32.50a | 74.27e | 15.95ab |
| Nduna | 4,155d | 40.71e | 11.52bc | 43.93d | 6.80c | 21.08bc | 24.64c | 72.50e | 11.06e |
| Nseba | 4,643c | 49.48c | 12.25b | 65.18ab | 6.63c | 22.45bc | 25.83bc | 74.13e | 12.80d |
| Pungwa | 4,918bc | 42.24de | 11.84b | 46.69cd | 6.55c | 19.48c | 26.41bc | 75.38de | 13.46cd |
| Sahai I | 5,669a | 52.45b | 13.10ab | 68.81ab | 7.22b | 22.42bc | 26.17bc | 81.53b | 16.26a |
| Sekuru | 4,924bc | 50.50bc | 13.33a | 69.68a | 7.63a | 22.75b | 23.11cd | 75.50de | 13.89c |
| Shine | 4,751c | 51.46bc | 11.57b | 59.92b | 5.90d | 20.34c | 24.53c | 69.27f | 12.95cd |
| UNZA I | 4,212d | 44.14d | 10.61c | 40.92d | 6.77c | 17.08d | 26.78b | 68.31f | 11.27e |
| UNZA II | 4,794c | 48.64c | 11.67b | 49.14e | 6.81c | 13.90e | 21.92d | 67.31f | 13.48cd |
| Mean | 4,832 | 48.69 | 12.32 | 58.09 | 6.77 | 20.93 | 24.76 | 74.53 | 13.34 |
| LSD (5%) | 355 | 2.86 | 0.94 | 4.96 | 0.36 | 2.35 | 2.56 | 2.12 | 0.98 |
| CV (%) | 8 | 6.2 | 8.1 | 9.1 | 5.6 | 11.9 | 11.00 | 3 | 7.8 |

Mean of the same category followed by different letters are significantly different (P<0.05) using LSD test.
GY: Grain yield, TKW: Thousand kernel weight, SPS: Number of spikelet per spike, BM: Above ground biomass, SL: Spike length, GS: Number of grains per spike, HI: Harvest index, PHT: Plant height and WUE: Water use efficiency.

**Table 3 : Effect of water regime on grain yield, yield components and water use efficiency across genotypes**

| Water Regime | GY | TKW | SPS | BM | SL | GS | HI | PHT | WUE |
|---|---|---|---|---|---|---|---|---|---|
| W 1 (100%) | 5,601a | 47.18 | 13.05 | 59.90a | 7.29a | 22.51 | 28.27a | 81.48a | 11.07b |
| W 2 (75%) | 4,714b | 48.74 | 11.99 | 61.60a | 6.30b | 21.47 | 24.93b | 73.46b | 12.44b |
| W 3 (50%) | 4,182c | 50.15 | 11.92 | 52.76b | 6.72a | 18.8 | 21.09c | 68.67c | 16.53a |
| Change (%) | 25.33 | - | - | 11.92 | 7.82 | - | 25.40 | 15.72 | 49.32 |
| LSD (5 %) | 433 | NS | NS | 5.20 | 0.57 | NS | 1.37 | 3.00 | 1.56 |

Mean of the same category followed by different letters are significantly different(P<0.05) using LSD test.
GY: Grain yield, TKW: Thousand kernel weight, SPS: Number of spikelet per spike, BM: Above ground biomass, SL: Spike length, GS: Number of grains per spike, HI: Harvest index, PHT: Plant height and WUE: Water use efficiency.

| Table 4 : Effect of Water Regimes and Genotype Interaction on Grain Yield, WUE and Yield Components | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Genotype** | **Water** | **GY** | **TKW** | **BM** | **GS** | **SL** | **HI** | **PHT** | **SPS** | **WUE** |
| **Choza** | W 1 | 5,203cd | 58.49bc | 78.39c | 21.31cd | 7.02bc | 23.94de | 79.48de | 13.86ab | 10.28f |
| | W 2 | 3,959e | 42.76de | 51.77ef | 20.19cd | 6.63bc | 21.16e | 70.27fg | 12.06bc | 10.45f |
| | W 3 | 2,985f | 49.39cd | 47.24f | 16.40de | 6.62bc | 14.91f | 69.24fg | 12.00bc | 11.80ef |
| **Coucal** | W 1 | 5,300cd | 41.75e | 50.36ef | 21.74cd | 7.06bc | 20.30ef | 98.46a | 13.31ab | 10.47f |
| | W 2 | 5,435c | 64.16a | 102.06a | 33.05a | 5.80cd | 18.21ef | 85.12c | 13.79ab | 14.34de |
| | W 3 | 3,678ef | 46.45de | 48.10ef | 21.18cd | 5.61d | 12.72f | 72.35ef | 11.82bc | 14.54de |
| **Loerie II** | W 1 | 4,936cd | 43.61de | 66.30d | 27.93b | 7.67ab | 34.22bc | 80.85d | 13.75ab | 9.76f |
| | W 2 | 5,399c | 51.96cd | 69.96cd | 21.44cd | 6.59bc | 24.15de | 79.06de | 13.36ab | 14.24de |
| | W 3 | 5,351cd | 49.48cd | 51.92ef | 19.39cd | 6.82bc | 26.23cd | 73.75ef | 11.46bc | 21.15b |
| **Mampolyo** | W 1 | 7,346a | 59.89ab | 47.61f | 22.66cd | 7.37ab | 34.68b | 80.56de | 14.75a | 14.52de |
| | W 2 | 5,212cd | 48.22cd | 71.32cd | 22.69cd | 6.05cd | 29.96c | 68.90fg | 11.71bc | 13.75de |
| | W 3 | 4,957cd | 57.93bc | 73.27cd | 27.02bc | 7.56ab | 32.87bc | 73.35ef | 13.92ab | 19.59bc |
| **Nduna** | W 1 | 5,453c | 43.47de | 49.91ef | 27.96b | 8.00ab | 34.91b | 81.06cd | 11.29bc | 10.78f |
| | W 2 | 4,038e | 40.52e | 42.47fg | 16.33de | 5.85cd | 23.22de | 69.94fg | 11.42bc | 10.65f |
| | W 3 | 2,973f | 38.15e | 39.40fg | 18.95cd | 6.55bc | 15.78f | 66.50g | 11.86bc | 11.75ef |
| **Nseba** | W 1 | 5,608b | 45.23de | 87.77b | 28.82ab | 7.27b | 26.00cd | 82.73cd | 13.22ab | 11.08f |
| | W 2 | 4,234de | 44.27de | 56.02ef | 20.01cd | 6.01cd | 27.65cd | 73.46ef | 11.01bc | 11.17f |
| | W 3 | 4,087de | 58.94b | 51.76ef | 18.52cd | 6.60bc | 23.85de | 66.21g | 12.53b | 16.15cd |
| **Pungwa** | W 1 | 5,679b | 37.80e | 59.79de | 18.75cd | 6.61bc | 23.46de | 79.14de | 13.03ab | 11.22f |
| | W 2 | 5,109cd | 43.39de | 53.04ef | 23.07c | 6.30cd | 30.22c | 76.38e | 11.42bc | 13.48e |
| | W 3 | 3,965e | 45.54de | 47.23f | 16.63de | 6.75bc | 25.54d | 70.64fg | 11.08bc | 15.67d |
| **Sahai I** | W 1 | 6,195b | 45.12de | 67.64d | 21.22cd | 7.47ab | 27.54cd | 90.72b | 14.25ab | 12.24ef |
| | W 2 | 4,726de | 50.83cd | 81.94bc | 27.72b | 7.32ab | 23.70de | 82.56cd | 13.11ab | 12.47ef |
| | W 3 | 6,086b | 61.40ab | 56.85e | 18.30d | 6.85bc | 27.27cd | 71.31f | 11.94bc | 24.06a |
| **Sekuru** | W 1 | 4,996cd | 47.01d | 68.66d | 21.47cd | 8.02a | 20.24ef | 84.44cd | 14.83a | 9.87f |
| | W 2 | 5,212cd | 53.37c | 63.77de | 20.00cd | 7.66ab | 26.50cd | 69.04fg | 13.18ab | 13.75de |
| | W 3 | 4,565de | 51.13cd | 76.61cd | 26.77bc | 7.20b | 22.59de | 73.02ef | 11.98bc | 18.04c |
| **Shine** | W 1 | 5,658b | 43.16de | 56.11ef | 22.34cd | 6.05cd | 28.80cd | 76.01e | 11.88bc | 11.18f |
| | W 2 | 4,795cd | 55.21bc | 60.15de | 23.71bc | 5.66d | 28.30cd | 67.05g | 11.51bc | 12.65ef |
| | W 3 | 3,801ef | 56.01bc | 63.52de | 14.96de | 5.98cd | 16.50f | 64.76g | 11.32bc | 15.02de |
| **UNZA I** | W 1 | 5,629b | 44.55de | 45.22f | 24.03bc | 6.89bc | 41.58a | 76.15e | 10.58c | 11.12f |
| | W 2 | 3,801ef | 45.36de | 42.11fg | 11.84e | 5.79d | 22.50de | 64.94g | 9.40c | 10.03f |
| | W 3 | 3,205f | 42.50de | 35.42g | 15.36de | 7.65ab | 16.25f | 63.86g | 11.84bc | 12.67ef |
| **UNZA II** | W 1 | 5,212cd | 56.14bc | 61.08de | 11.95e | 8.02a | 23.63de | 68.15fg | 11.90bc | 10.30f |
| | W 2 | 4,644de | 44.86de | 44.60f | 17.63de | 5.98cd | 23.56de | 74.77ef | 11.90bc | 12.25ef |
| | W 3 | 4,525de | 44.93de | 41.75fg | 12.12e | 6.45c | 18.58ef | 59.01h | 11.24bc | 17.89c |
| | | | | | | | | | | |
| **LSD(5 %)** | | 672 | 5.18 | 9.07 | 4.60 | 0.74 | 4.35 | 4.18 | 1.90 | 2.03 |

Mean of the same category followed by different letters are significantly different($P<0.05$) using LSD test.
GY: Grain yield, TKW: Thousand kernel weight, SPS: Number of spikelet per spike, BM: Above ground biomass, SL: Spike length, GS: Number of grains per spike, HI: Harvest index, PHT: Plant height and WUE: Water use efficiency.

| Table 5: Stepwise multiple regression of wheat WUE on the components across all genotypes at W 3 (50 %) | | | | |
|---|---|---|---|---|
| **Variable** | **Partial Square** | **R-Model Square** | **R - F- Value** | **Pr > F** |
| **Harvest index** | 0.533 | 0.533 | 38.828 | 0.000 |
| **Thousand kernel weight** | 0.076 | 0.609 | 6.447 | 0.016 |

## CONCLUSION

The results of this study has shown that Sahai I a rain-fed genotype and Loerie II an irrigated genotype had the highest yield stability and highest WUE than the others as they maintained their yield in all water regimes. This suggests that deliberate selection using these two genotypes as parents in hybridisation to create variation for selection for WUE while targeting thousand kernel weight and harvest index which explained most of the variations, could lead to development of appropriate varieties which could give higher grain yields in reduced water application rates. Adoption of these genotypes with potential to produce stable high yields at low water supply by more farmers would reduce production costs and contribute to overall increased wheat production in Zambia.

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