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Tillage system and genotype effects on rainfed maize (*Zea mays* L.) productivity in semi-arid Zimbabwe

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Maize is the staple crop that is grown under rainfed conditions by smallholder farmers in most of Sub-Saharan Africa. A study was conducted during the 2002/3 and 2003/4 cropping seasons at a semi-arid site in South-east Zimbabwe to determine the response of five maize genotypes to four tillage systems (hand holing out, no till, inter-row furrow, tied ridge) under rainfed conditions. The trial was set up in a randomised split-plot design with tillage system as the main plot factor and maize genotype as the sub-plot factor. Grain yield, grain moisture content at harvest, total above ground biomass yield, days to flowering and maturity were highly affected ($p < 0.001$) by genotype. Tillage systems significantly affected ($p < 0.05$) number of days to physiological maturity, total above ground biomass yield and final stand count but not at harvest. The tillage furrow system significantly ($p < 0.001$) delayed emergence in the 2003/4 season compared to other tillage systems. Tillage and genotype interactions had a significant ($p < 0.05$) effect on yield, final stand count and number of cobs per plot. Hybrids had better ($p < 0.001$) biomass partitioning into grain and higher ($p < 0.001$) rainfall use efficiency than open-pollinated genotypes. The results of this study showed that maize genotypes grown on tillage systems that concentrate moisture (ridge/furrow systems) perform better than those on flat systems depending on the quality of the rainfall season. By selecting adapted genotypes grain yields can be increased without much additional investment in tillage systems.

Key words: Tillage, hybrid, open-pollinated, yield, rainfall use efficiency, cropping season.

INTRODUCTION

Agricultural research has produced innovations that enable farmers in semi-arid tropics (SATs) to increase their crop productivity. Water availability is considered a major constraint to rainfed cropping systems in SATs (Barron, 2004). The SATs are also characterised by high evaporative demand of approximately 1.5 - 10 times the average annual rainfall and low soil water holding capacity (Nonner, 1997; Rockstrom et al., 2003). Drought and frequent intra-seasonal dry spells make rainfed crop production unreliable.

Despite the climatic constraints, approximately half of the world's population live in SATs covering almost 40% of the world's land area (Rockstrom, 2003). Grain yields are low (1t/ha) and highly variable due to low external in-

puts, low and erratic rainfall and declining soil fertility (Fox, 2001). Blackie (1994) observed that due to limited water availability and low fertility, smallholder farmers in Sub-Saharan Africa have not fully benefited from advances in crop breeding which have released high yielding varieties.

Until recently, agricultural research has been focussing on improving intense crop production systems using irrigated agriculture at the expense of rainfed farming systems (Barrow, 1998; Rockstrom, 2000). Recent studies have however shown that there is limited potential to meet future food demands through expansion of irrigated agriculture (Rockstrom et al., 1999; IWMI, 2001). Therefore, food production and rural livelihoods will continue to rely on rainfed agriculture.

A lot of research work has been conducted on water management in rainfed cropping systems to improve crop yields and breeding genotypes for drier environments

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(Klajj and Vauchad, 1992; Nyamudeza et al., 1992; Chuma, 1993, Rockstrom et al., 2003; Barron, 2004). Estimates indicate that since the 1930s, crop yields have been increased by 15 - 25% due to genetic improvement (Barron, 2004). Examples of short season drought-tolerant maize genotypes bred for semi-arid environments are R201 and PNR473 in Zimbabwe, MM501, MM502, MM441, MMV400 and MM504 in Zambia, Matuba in Mozambique, Kito in Tanzania and Katumani and Makueni Composites in Kenya (Waddington et al., 1994). The drought tolerance characteristics of these genotypes were derived from their drought escaping rather than water stress tolerance at critical developmental stages. Breeding initiatives by CIMMYT and national breeding programmes in southern Africa have focused on short season, drought tolerant and open-pollinated maize varieties for the resource poor farmers.

Water management techniques in rainfed cropping systems increase infiltration and reduce surface runoff, which can account for 10 - 25% of the total annual rainfall in SATs (Rockstrom et al., 2003). Techniques used include planting pits, infiltration pits, terracing, stone bunds and ridges/furrows (Hudson, 1987). In Zimbabwe, the most documented and recommended technique is the tied ridge/furrow system, which has been the focus of several studies (Nyamudeza, 1993; Nyakatawa et al., 1996; Nyamudeza, 1998). The effects of the system on crop yield vary considerably. Vogel (1993) observed strong yield fluctuations of between 0.9 and 5.4 t/ha in semi-arid regions which was due to ridging. Nyakatawa et al. (1996) observed a significant increase in maize yields of between 22 and 85% due to tied furrows compared to the farmers' practice of planting on the flat. The increase rose to between 35 and 115 % for maize and to between 59 and 200% sorghum on adding inorganic fertilisers. On a sandy clay loam soil, tied furrows increased sorghum yield by between 4 and 62 % in 4 out of 5 seasons compared to the farmer's practice of sowing on the flat (Nyamudeza, 1993).

Crop response to tied furrows has been affected by rainfall distribution within the season rather than total annual rainfall. In a very wet year, on vertisols and sandy loams in south eastern Zimbabwe tied furrows did not significantly affect sorghum yields in years with adequate rainfall (Nyamudeza et al., 1992; Nyamudeza, 1998). Droughts and poorly distributed rainfall resulted in negative response to both tied furrows and fertilizers, forcing farmers to revert to their old production practices. Most of the water management studies have been conducted in isolation of the achievements of breeding efforts. As such literature is scanty on the effects on water harvesting tillage systems on the yields of drought-tolerant and drought escaping maize genotypes.

This paper reports on the findings of a field study conducted over two cropping seasons in Zimbabwe to evaluate the effects of tillage systems, early maturing maize genotypes and tillage and genotype interactions on rainfed maize production at a semi-arid site.

MATERIALS AND METHODS

Experimental site characteristics

The experiment was carried out at Save Valley Experiment Station (32°21'E, 20°2'S and altitude 444 m above sea level) in the South-east Lowveld of Zimbabwe during 2002/3 and 2003/4 cropping seasons. The experiment station lies in a semi-arid region and receives a mean annual rainfall total of 500 mm calculated over 30 years, of which 95% occurs in summer (November-April; DMS, 1977). The soils at the site are predominantly fine sandy loams (11% clay, 11% silt, 78% sand) overlying fine sandy clay loams (20% clay, 12% silt, 68% sand) derived from granitic alluvium (DRSS, 1969). They are classified as alluvial siallitic sandy loams (Sabi 4U.2; Zimbabwe classification), Typic Haplustalf (US soil taxonomy) or Chromic cambisols according to FAO classification system (Nyamapfene, 1991). The soils have a weak sub-angular blocky structure at the surface and become massive in lower horizons. In addition they exhibit severe surface crusting properties. Permeability is moderately restricted for topsoil but severely restricted for subsoil (DRSS, 1969; Nyamugafata, 1994).

Experimental procedure and treatments

The trial was set up in a randomised split-plot design with four tillage systems as main plot and five maize genotypes as sub-plot factors. Each treatment factor was replicated three times. Tillage main plots were 35 m x 6 m with 1 m pathways between them. Individual subplots were 6 m x 5.4 m with 2 m bare strips between them.

The four tillage systems were as follows: (i) holing out using a hand hoe (*badza*) before opening planting stations and seed sown in manual pits made by a hand hoe (hand hoeing system- HH); (ii) direct planting into manual pits opened using a hand hoe without any other tillage operation apart from hand hoe weeding (no till system-NT); (iii) Manual ridging at about four weeks (during the first weeding) to create alternating inter-row furrows with cross-ties at 2.5 m regular intervals (furrow system- FR) and (iv) disc ploughing and ridging to create alternating ridges and furrows with cross-ties at 2.5 m regular intervals before sowing on the fringes of the furrow (tied ridge system-TR).

In both seasons five maize genotypes consisting of two hybrids (PAN413 and SC403) and three improved open-pollinated genotypes (Ops; ZM521, ZM 421 and Silver King (SK) bred for low rainfall) were tested. The characteristics of the five genotypes are as follows:

PAN 413

A three-way early maturing hybrid developed by Pannar Seeds (Pvt) Ltd for marginal areas with very good drought tolerance and prolific (multi-cobbing) characteristics. Relative days to physiological maturity are 138 and takes 72 days to 50% flowering (silking) based on an altitude of 1200 m above sea level (m.a.s.l.).

SC403

A two-way hybrid developed by Seed Co. (Pvt) Ltd for semi-arid regions of Zimbabwe. It is a very early maturing genotype with an average of 132 days at an altitude of 1200 m.a.s.l. It has an excellent heat and drought resistance. Relative days to silking are about 61 at 1200 m.a.s.l.

ZM521

This is an improved open-pollinated genotype developed by

CIMMYT. Grain texture is semi-flint/semi-dent with good to very good tolerance to low fertility. It is an early maturing genotype with an average of 133 days and takes 63 days to 50% flowering based on an altitude of 1200 m.a.s.l. It has a good to very good resistance to drought, but has to be planted early in low rainfall areas.

ZM421

This is an improved open-pollinated genotype also developed by CIMMYT. Grain texture is semi-flint/semi-dent with good to very good tolerance to low fertility. It is an early maturing genotype with an average of 134 days and takes 66 days to 50% flowering based on an altitude of 1200 m.a.s.l. It has a good to very good resistance to drought and should be planted early in low rainfall areas.

Silver King (SK)

An improved open-pollinated experimental line developed by CIMMYT. It has early to medium maturity (140 days) and takes 68 days to 50% flowering based on an altitude of 1200 m.a.s.l.

Crop establishment and management

In the two cropping seasons, basal fertiliser dressings equivalent to the recommended rate of 100 kg Compound D (8: 14: 7, N: P₂O₅: K₂O)/ha were applied at each planting hole before sowing. Ammonium nitrate (34.5% N) was applied at an equivalent rate of 34.5 kgN/ha between 4 and 6 weeks after emergence. Seed was sown in moist soil on 82nd day of 2002/3 season day (20 December 2002) and 120th day of the 2003/4 season (28 January 2004) after receiving 51 and 41 mm respectively. Two seeds were planted per hole with an intra-row spacing of 30 cm and inter-row spacing of 90 cm. At two weeks after emergence, the maize plants were thinned to one plant per hole to achieve an estimated plant population of 2.8/m². Weeding was carried out manually using hand hoes twice per season. Maize stalkborer and armyworm were controlled by spraying with Fenvalerate whilst termites were controlled with Thionex.

Measurements

Rainfall during the two seasons was measured at a nearby weather station (400 m) using a standard rain gauge. The rate (%) of germination of each genotype was determined in the laboratory using germination trays. Total percent emergence and stand count at harvesting were determined for each treatment. Days to 50% flowering and 90% physiological maturity were measured. Four middle rows with two plants discarded either side were harvested for yield and yield component evaluation. Total grain weight per hectare was calculated using net plot grain weight and corrected for grain moisture content. Grain moisture content at harvesting was determined gravimetrically. The following yield components were measured: number of cobs per plot, thousand seed weight, grain yield, above ground stover weight, moisture content at harvesting and total above ground dry weight. Harvest indices were calculated according to Equation 1 as:

$$HI = 100 \cdot GY / TBY \quad \dots 1$$

Where: HI= Harvest index (%), GY= grain yield (kg/ha), TBY= total above ground biomass (kg/ha). For each season, the rainfall use efficiency (RUE) was calculated according to Equation 2 as:

$$RUE = GY / TSR \quad \dots 2$$

Where: RUE=rainfall use efficiency (kg/ha of grain per mm of rain-

fall), GY= grain yield (kg/ha), TSR= total seasonal rainfall (mm).

Statistical analysis

The data were subjected to analysis of variance procedure as a split-plot design with tillage systems as a main plot factor and maize genotype as a sub-plot factor using GENSTAT statistical program (Rothamsted Experiment Station, 1995). The following model (Equation 3) was used for ANOVA:

$$Y_{ijk} = \mu + T_i + G_j + (TxG)_{ij} + \dots 3$$

Where: Y_{ijk} = Response of the jth maize genotype under the ith tillage system in the kth replication

μ = overall mean (constant), T_i = fixed effect of the ith tillage system, i = 1, 2, 3, 4. G_j = fixed effect of the jth genotype, j = 1, 2, 3, 4, 5. k = replication index, k = 1, 2, 3. ijk = random residual error associated with observation, ijk ~ N(0, σ²)

When necessary the least significance differences (l.s.d) were used to separate means at P= 0.05, 0.01 and 0.001. A simple regression analysis was conducted to determine linear relationships between two yield variables. A two-sample t-test was used to compare mean yields of two tillage (ridge/furrow versus flat) and two genotype (hybrid versus open-pollinated) strata.

RESULTS

Rainfall characteristics during the cropping seasons

Figure 1 and 2 shows the rainfall distribution during the 2002/3 and 2003/4 cropping seasons. The totals for the seasons (October – April) were 516 in 2002/3 and 469 mm in 2003/4. In the 2002/3 season 147 mm of rainfall were received over 3 days. Both seasons were characterized by frequent occurrence of dry spells exceeding 5 days. In 2002/3 season, no rainfall was received soon after planting while in 2003/4 more than 50 mm were received a day after planting.

Days to emergence, final rates (%) of emergence and stand counts at harvest

Table 1 shows the effects of tillage and genotype on days to emergence, per cent emergence and stand counts at harvest for the 2002/3 and 2003/4 cropping seasons. In the 2002/3 season genotype had a highly significant (p < 0.001) effect on percent emergence. Both tillage and genotype main effects had no significant effect on stand count at harvest in 2003/4 season (Table 1).

In both seasons tillage main effects significantly (p < 0.05) affected emergence. In 2002/3 season the ridge/furrow tillage systems (FR and TR) improved emergence by 11 % relative to the flat tillage systems (HH and NT). In 2003/4 season, the trend was reversed, resulting in lower emergence in the two ridge/furrow tillage systems. The TF system had significantly delayed (p < 0.05) and reduced (p < 0.001) emergence than the other three tillage systems. With the exception of 2003/4 season when tillage and genotype interactions significantly (p < 0.05) affected percent emergence, interactions had no

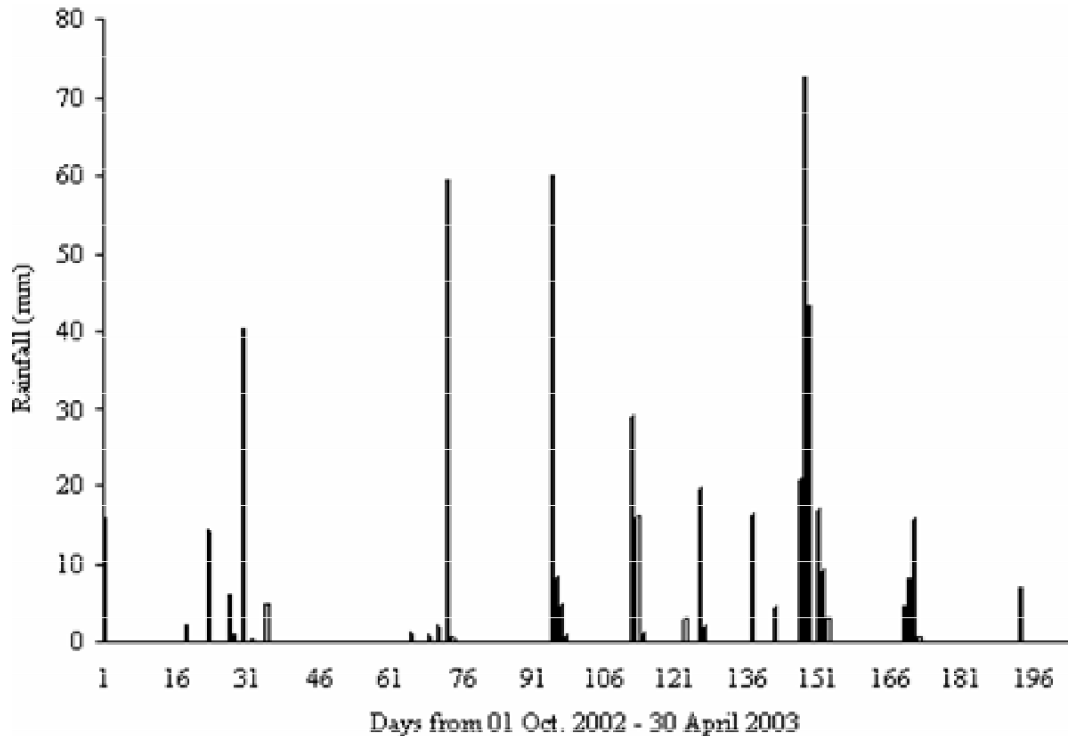


Figure 1. Daily rainfall distribution at Save Valley Experiment Station in 2002/3 cropping season.

Table 1. Effect of tillage systems and maize genotype on days to emergence and stand counts after thinning and at harvest.

	Days to emergence		Emergence rate (%)		Stand count at harvest	
	2002/3	2003/4	2002/3	2003/4	2002/3	2003/4
Genotype (G)						
PAN413		6.0	82.2	76.4	53.0	42.3
SC403		6.0	58.2	78.6	39.0	47.6
ZM521		6.0	79.4	80.0	43.0	45.8
ZM421		6.0	82.7	76.0	46.0	45.1
SILVER KING		5.8	81.7	82.0	44.0	46.8
Mean		6.0	76.8	78.6	45.0	45.5
Sig.		N.S	***	N.S	*	N.S
Tillage (T)						
HH		5	71.0	84.3	43	49.9
NT		6	71.0	83.3	44	46.3
FR		6	83.0	79.7	53	47.1
TF		6.8	80.0	67.6	42	38.9
Mean		6.0	77.0	78.0	45	45.5
Sig.		***	*	*	N.S	N.S
T x G		N.S	N.S	*	N.S	N.S
C.V. (%)		6.5	4.3	13.1	12.9	17

C.V.: Coefficient of variation, T x G: Tillage x genotype interaction, Sig.: Statistical significance of differences at probability, P < 0.05 (*), P < 0.01 (**), and P < 0.001 (***).

significant effect on days to emergence, emergence and stand counts at harvest in all season

Table 2. Effect of tillage systems on days to silking, days to physiological maturity and moisture content at harvest of five maize genotypes.

	Silking		Physiological maturity		Grain moisture content at harvest (%)	
	2002/3	2003/4	2002/3	2003/4	2002/3	2003/4
Genotype (G)						
PAN413	70	56.9	119	103.1		13.4
SC403	67	53.3	113	97.7		11.6
ZM521	66	54.4	113	94.7		10.9
ZM421	69	55	114	93.6		10.8
SILVER KING	69	55.1	115	100.0		12.0
Mean	68	54.9	115	97.8		11.7
Sig.	***	***	***	***		***
Tillage (T)						
HH	68	54.7	117	96.8		11.6
NT	70	54.9	118	97.9		12.1
FR	66	55.3	112	96.7		11.5
TF	67	54.9	114	99.8		11.9
Mean	68	55	115	97.8		11.8
Sig.	N.S	N.S	***	*		N.S
T x G	N.S	N.S	*	N.S		N.S
C.V. (%)	2.2	2.0	0.7	4.4		9.4

C.V.: Coefficient of variation, T x G: Tillage x genotype interaction, Sig.: Statistical significance of differences at probability, $p < 0.05$ (*), $P < 0.01$ (**) and $P < 0.001$ (***).

Grain moisture content at harvest, days to silking and physiological maturity

Table 2 shows days to silking and to physiological maturity and grain moisture content at harvest. Factors such as grain moisture content at harvest, days to silking and to physiological maturities in both seasons are highly ($p < 0.001$) reflected in the genotypes. In the 2003/4 season PAN413 had significantly ($p < 0.001$) longer days to silking than the other genotypes whilst SC403 had significantly ($P < 0.001$) shorter days. In 2002/3 season there was no consistent trend although PAN413, Silver King and ZM421 had longer days (about 70) to silking than SC403 and ZM521. In the same season PAN413 had significantly ($p < 0.001$) delayed maturity compared to the other genotypes. Results of grain moisture content at harvest showed that PAN413 had less moisture than the other genotypes. Both ZM421 and ZM521 had comparable moisture content (10.8 and 10.9% which was less than Silver King (12.0%) and PAN413 (13.4%).

Tillage had no significant effect on days to silking and grain moisture content in both seasons. However, tillage systems significantly affected days to physiological maturity in both 2002/3 ($p < 0.001$) and 2003/4 ($p < 0.05$) seasons while the ridge/furrow tillage systems (FR and TR) significantly ($p < 0.001$) hastening maturity in 2002/3 season relative to flat systems. In the 2003/4 there was no particular trend but TR and NT significantly ($p < 0.001$) de-layed maturity than HH and FR. In both seasons tillage and genotype interaction effects on grain moisture

content at harvest, days to silking and maturity were not significant except in 2002/3. It was however, observed that interactions significantly ($p < 0.05$) affected days to maturity.

Yield components and grain yield

The effects of genotype and tillage system on yield components, that is cobs/plot and cobs/plant and weight of 1000 seeds, are shown in Table 3. Genotype significantly affected 1000 seed weight in 2002/3 ($p < 0.05$) and 2003/4 ($p < 0.001$) seasons but had no effect on number of cobs per plot and per plant in 2003/4 and 2002/3, respectively. In 2002/3 season, PAN413 genotype had a significantly ($p < 0.001$) higher number of cobs per plot than the other genotypes. Corresponding cobs per plant were similar (close to unit) during the same season, but significantly ($P < 0.01$) varied among genotypes in 2003/4 where Silver king had a significantly ($p < 0.05$) lower number of cobs per plant than the other genotypes. In both seasons significant genotype effects on 1000 seed weight were observed. The hybrids and Silver king had the heaviest seeds although ZM521 was significantly ($p < 0.05$) the lightest seed. The two hybrids (PAN413 and SC403) and Silver King (OP) had significantly ($p < 0.001$) heavier seeds than ZM521 and ZM421 in 2003/4 season while ZM421 produced the lightest seeds. The differences in seed weight were later reflected in the grain yields shown in Table 4.

Table 3. Effect of tillage systems and genotype on yield components of maize.

	Cobs/plot		Cobs/plant		1000 seed weight (g)	
	2002/3	2003/4	2002/3	2003/4	2002/3	2003/4
Genotype (G)						
PAN413	54	42.3	1.0	1.0	262	241.3
SC403	40	45.6	1.0	1.0	279	248.8
ZM521	43	42.3	1.0	0.9	235	203.0
ZM421	46	40.7	1.0	0.9	249	179.4
SILVER KING	44	38.3	1.0	0.8	258	239.7
Mean	45	41.8	1.0	0.9	257	222.4
Sig.	***	N.S	N.S	*	*	***
Tillage (T)						
HH	39	45.9	0.9	0.9	241	220.4
NT	48	39.5	1.1	0.9	248	210.9
FR	37	44.8	0.7	1.0	272	232.4
TF	39	37.1	0.9	1.0	266	226.0
Mean	41	41.8	0.9	1.0	257	222.4
Sig.	N.S	N.S	N.S	N.S	N.S	N.S
T x G	N.S	*	*	N.S	N.S	N.S
C.V. (%)	20.8	16.2	9.3	13.2	8.2	10.3

C.V: Coefficient of variation, T x G: Tillage x genotype interaction, Sig.: Statistical significance of differences at probability, $P < 0.05$ (*).

The number of cobs per plot, cobs per plant and 1000 seed weight were not significantly affected by tillage system. However, in both seasons the ridge/furrow tillage systems seem to produce heavier seeds than the flat tillage systems although differences were not significantly different. For the other yield components there seems to be no particular tillage effect trends on cobs per plot and cobs per plant. A significant ($p < 0.05$) tillage and genotype interaction effect on number of cobs per plant and cobs per plot was observed in 2002/3 and 2003/4 seasons respectively.

Grain yield was highly dependent ($p < 0.001$) on genotype in both seasons (Table 4). In 2002/3 season, the grain yields of ZM521 and SC403 were comparable but PAN413 significantly out yielded all the other genotypes, while Silver King produced significantly lower ($p < 0.001$) yield than the other four genotypes. In 2003/4 season, ZM521 and ZM421 had similar yields while the two hybrids significantly ($p < 0.001$) gave higher yields than the OPs. Tillage system had a significant ($p < 0.05$) effect on grain yield in 2002/3 season with ridge/furrow tillage systems having significantly ($P < 0.05$) higher yields than flat systems. Tillage and genotype interaction effect was only significant ($p < 0.05$) in 2003/4 season.

Total above ground dry biomass, harvest index and rainfall use efficiency

Table 4 shows the effects of tillage and genotype on grain yield, total above ground dry biomass, harvest in-

dex and rainfall use efficiency (RUE) . In 2003/4 season the genotype effect was significant on total above ground biomass yield ($p < 0.01$), harvest index ($p < 0.01$) and rainfall use efficiency ($p < 0.001$). Tillage system had no significant effect on the three parameters although tillage and genotype interaction effects were significant ($p < 0.01$) on total above ground biomass and rainfall use efficiency in 2003/4 season.

DISCUSSION

Rainfall characteristics during the cropping seasons

Rainfall during the two seasons (Oct – April) was comparable to the long-term (30 year) average of 477 mm for the same period reported by LRS (unpublished) . In 2002/3 season considerably higher rainfall than that of 2003/4 and long-term average value of 147 mm was received in three days, a situation that was attributed to a severe storm. The two seasons were typical of semi-arid regions with rainfall distribution being poor and characterised by frequent occurrence of dry spells. Similar rainfall trends were reported in North-east Zimbabwe, where the dry spells adversely reduced crop yields if they occur at critical stages of crop development such as flowering and grain filling (Chiduzo, 1995; Nyamudeza, 1998; Rockstrom, 2003). However, rainfall distribution and onset during the 2002/3 cropping season was better than the 2003/4 season. The season received effective rainfall that was adequate for planting earlier (82 days into the

Table 4. Effects of tillage systems and maize genotype on grain yield, total above ground biomass, harvest index and RUE.

	^a Grain yield (kg/ha)		Total above ground biomass (kg/ha)		Harvest index (%)		^b RUE (kg ha ⁻¹ mm ⁻¹)	
	2002/3	2003/4	2002/3	2003/4	2002/3	2003/4	2002/3	2003/4
Genotype (G)								
PAN413	708	999.0	5230	5160	13.5	19.4	1.4	2.1
SC403	553	1115.0	3672	5177	15.1	21.5	1.1	2.4
ZM521	542	775	2926	4428	18.5	17.5	1.1	1.7
ZM421	405	639	3282	4129	12.3	15.5	0.8	1.4
Silver King	281	789	3517	5330	8.0	14.8	0.5	1.7
Mean	498	863.4	3726	4845	13.4	17.8	1.0	1.8
Sig.	***	***	***	**	*	**	*	***
Tillage (T)								
HH	322	882	3066	5612	10.5	15.7	0.6	1.9
NT	255	660	3463	4273	7.4	15.4	0.5	1.4
FR	659	959	4076	5285	16.2	18.1	1.3	2.0
TF	755	953	4321	4209	17.5	22.6	1.5	2.0
Mean	498	863.5	3731	4845	13.3	18.0	1.0	1.8
Sig.	*	N.S	**	N.S	**	N.S	**	N.S
T x G	N.S	*	*	*	*	N.S	N.S	N.S
C.V. (%)	24.0	20.7	18.5	19.0	23.7	27.9	21.3	20.7

^aGrain yield at 12.5% moisture content, ^bRUE: Total grain yield (kg/ha)/total rainfall for the season (mm). C.V: Coefficient of variation, T x G: Tillage x genotype interaction, Sig.: Statistical significance of differences at probability, p < 0.05 (*), P < 0.01 (**) and P < 0.001 (***), N.S: not significant at p = 0.05.

season; Figure 1) than the 2003/4 season (120 days; Figure 2).

Days to emergence, final per cent emergence and stand count at harvest

Significant differences in total rate (%) of emergence and stand count at harvest were observed among genotypes in 2002/3 season but not in 2003/4. In 2002/3 season SC403 had significantly lower rate (%) of emergence than the other four genotypes. This was attributed to low seed viability as confirmed by laboratory germination tests. A significant linear relationship between field emergence rate (%) and laboratory germination rate (%) was established for the 2002/3 season according to Equation 4 as:

$$E = 1.02G - 3.03 \quad (r^2 = 0.6; p < 0.01) \quad \dots 4$$

Where: E = field emergence rate (%) and G = laboratory germination rate (%)

Consequently, stand count at harvest for SC403 was significantly (p < 0.05) lower than the other genotypes. The significantly higher stand count at harvest for PAN 413 in 2002/3 season suggests a higher ability to withstand lodging since the severe (windy, high intensity and

prolonged) storm experienced subjected the maize crop to lodging stress. In 2003/4 season all genotypes had laboratory germination rates greater than 90%, thus genotype had no significant effect on both days to emergence and rate of emergence (%).

In both seasons, tillage systems significantly affected final emergence rate. In 2002/3 season higher emergence for ridge/furrow tillage systems was attributed to improved soil moisture (Nyamudeza and Jones, 1993). It was not clear why HH significantly (p < 0.001) hastened emergence during 2003/4 season but could be attributed to effective soil surface de-crusting. In 2002/3, when seed was sown after receiving 51 mm of rainfall TR and FR significantly increased final percent emergence due to improved soil moisture conditions (results not shown).

The trend was reversed in 2003/4 season when seed was sown after receiving 41 mm of rainfall, followed by 55 mm of rainfall two days later. The lower and delayed emergence under TR in 2003/4 season was probably caused by seed rot from water logging following about 55 mm of rainfall recorded. In very wet seasons water logging has been observed by Nyamudeza (1993) and Hudson (1987) under tied furrows leading to anaerobic conditions in the root zone. In 2003/4 a significant (p < 0.05) tillage and genotype interaction effect on emergence was observed. This implies that the genotypes were able to adapt to various soil moisture regimes created by the tillage systems during emergence.

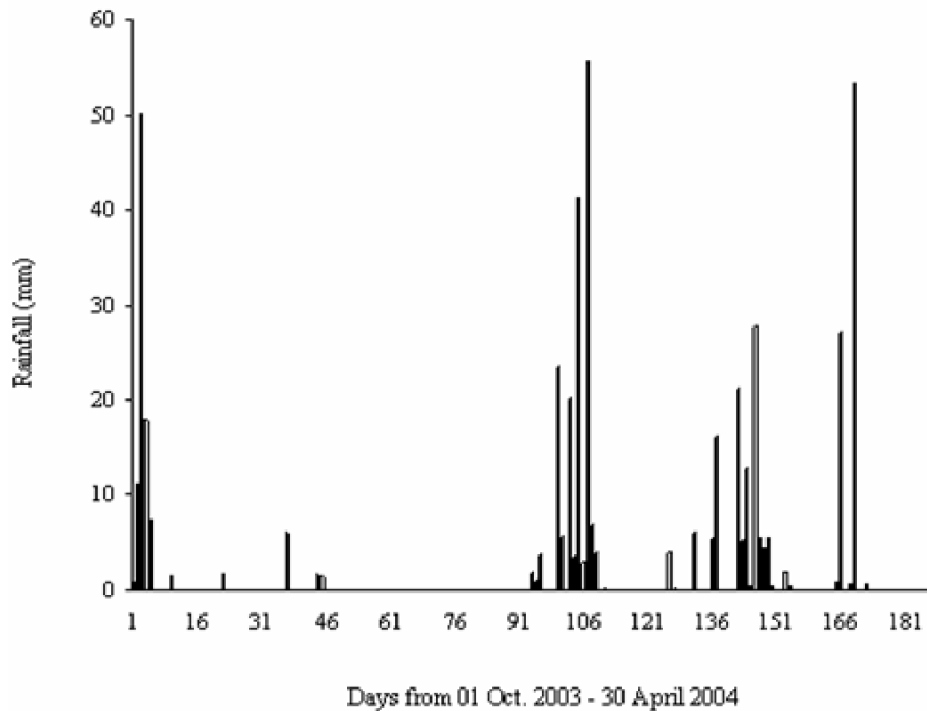


Figure 2. Daily rainfall distribution at Save Valley Experiment Station in 2003/4 cropping season.

Grain moisture content at harvest, days to silking and physiological maturity

In both seasons all genotypes matured in less than 120 days, confirming their early maturity. The observed highly significant ($p < 0.001$) differences in grain moisture content at harvest, days to silking and physiological maturity could be attributed to inherent genetic differences among the genotypes. In both seasons PAN413 had delayed silking and maturity than the other genotypes. The higher grain moisture content at harvest for PAN413 appears to be related to delayed maturity.

In both seasons tillage had a significant effect on days to physiological maturity. The TF system significantly ($P < 0.05$) delayed maturity in 2003/4 relative to other tillage systems. In 2002/3 season the two ridge/furrow tillage systems (FR and TR) hastened maturity compared to flat systems. Although the explanation for variation of tillage effects with season is not clear, it seems to depend on amount and distribution of rainfall during the cropping and their effects on soil water dynamics. The delayed maturity on flat systems (HH and NT) is attributed to water stress which is consistent with observations made by Nyamu-deza (1998) at the same site. A significant tillage and genotype interaction effect on days to maturity was also observed in 2002/3 season.

Yield components and grain yield

PAN413 produced a significantly higher number of cobs

per plot than the other genotypes in 2002/3 season but not in 2003/4. This was attributable to a high stand count at harvest than the other genotypes. Despite having a higher stand count than PAN413, ZM421 and ZM521, Silver King had the lowest number of cobs per plant. This implied that some Silver King plants were barren while the two hybrid genotypes (PAN413 and SC403) produced a cob per every plant or could have compensated by producing multiple cobs per plant. PAN 413 showed some prolificacy in 2002/3 by producing 54 cobs from an average stand of 42 plants. In general, the open-pollinated genotypes exhibited a tendency to produce barren plants in 2003/4 season.

The two hybrid genotypes consistently produced heavier seeds than the open-pollinated genotypes in both seasons. Lighter seeds for the open-pollinated genotypes might be explained by low tolerance to water stress at grain filling. Tillage system had no effect on yield components in both seasons but a significant tillage and genotype interaction effect on number of cobs per plot was observed in 2003/4 season.

Grain yield was affected by genotype in both seasons, with hybrids achieving higher yields. Grain yield increased linearly with total above ground biomass with about 42% of the total above ground dry biomass being attributable to grain biomass. The observation contradicts the general perception that genotypes with high stover production have poor biomass partitioning into grain. Within each group (hybrids and OPs), genotype did not signifi-

ntly affect grain yield. Across tillage systems, hybrid genotypes had a highly significant ($p < 0.001$) grain yield corresponding to 323 kg which was 44% more than OPs. A similar trend of 26% (195 kg) lower yields under flat systems than ridge/furrow tillage systems was observed in 2003/4 season although grain yield differences were not significant. The results support the yield superiority of hybrids over open-pollinated genotypes reported by Chidzuza et al. (1994) in a semi-arid area in Zimbabwe.

Grain yield only responded to tillage system in 2002/3 when the ridge/furrow tillage systems significantly out yielded the flat systems. The higher yields in 2002/3 were due to the water harvesting effect of ridge/furrow systems, which reduce the onset of water stress. However, during very dry weather conditions at critical stages of development, no tillage benefit was observed as happened in 2003/4 season. This inconsistency clearly supports previous observations that the effect of ridge/furrowing highly depends on seasonal distribution of rainfall and partly explains the low adoption of ridge/furrow systems even in semi-arid regions (Nyakata-tawa et al., 1996; Nyamudeza et al., 1992; Nyamudeza, 1998). Averaged across genotypes the ridge/furrow tillage systems increased grain yields over flat by 24% in 2003/4 and 145% in 2002/3 and such comparable yield advantages were reported by Nyakata-tawa et al. (1996) in semi-arid regions.

Total above ground biomass, harvest index and rainfall use efficiency

The total above ground biomass, harvest index and rainfall use efficiency for grain production were significantly affected by genotype. Open-pollinated genotypes generally produced lower above ground biomass than hybrids except for Silver King. Within a genotype group, SC403 and ZM521 showed the highest biomass partitioning into grain for the hybrids and OPs, respectively. Under low rainfall conditions hybrids showed a higher ability to convert assimilates into grain than open-pollinated genotypes with a harvest index of above 19%. In terms of grain production, the two hybrids (PAN413 and SC403) made better use of the available rainfall during the season with average RUEs of 1.2 kg/ha of grain per every mm of rainfall (in 2002/3) and 2.3 kg/ha/mm (in 2003/4 season) than Ops with average RUEs of 0.8 kg/ha/mm (in 2002/3 season) and 1.6 kg/ha/mm (in 2003/4 season). These results show that the hybrids had better biomass partitioning into grain and RUE than the OPs.

As expected ridge/furrow tillage systems (FR and TR) had higher RUE than flat systems (HH and NT) due to their water harvesting (concentration) effect although differences were not significant. Tillage main effects on total above ground biomass and RUE depended on season. This implied that tillage systems had a less consistent effect on biomass production when not combined with drought-tolerant genotypes.

Conclusions

The results of this study show that maize genotypes grown on tillage systems that concentrate moisture (ridge/furrow systems) perform better than those on flat systems in the semi arid regions. However, the performance (with respect to establishment, yield, HI and RUE) of the genotypes improves with the quality of the rainfall season irrespective of the tillage regime. Hybrid maize genotypes performed better than open pollinated genotypes, though the yields were very low ($<1\text{t/ha}$). Despite the low yields obtained, results also show that by selecting adapted genotypes grain yields can be increased without much additional investment in tillage systems. We therefore recommend that instead of farmers incurring further labour and draught power requirements through ridge/furrowing, the use of adapted genotypes appears to be an attractive option.

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