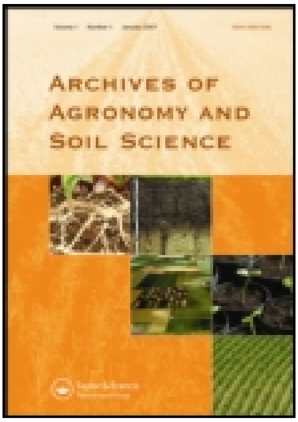

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A field experiment was conducted for three years at Ginchi in Ethiopia to study the effects of three drainage methods [broad-bed-and-furrow (BBF), ridge-and-furrow (RF) and flat beds (FB)] arranged as main plots. Sub-plots comprised a factorial combination of four sowing dates (18 and 31 August, and 14 and 28 September) and three Desi-type chickpea varieties (Worku, Akaki and a landrace) in a split-plot design with three replications. Improved drainage methods (BBF and RF) increased chickpea seed yield by an average of 45% over the flat seedbed. There was a quadratic relationship between seed yield and sowing date with a peak yield in mid-September. Improved varieties (Worku and Akaki) yielded 15–19% more than the local check. Improved varieties were significantly more yielding than the landrace variety under the improved drainage system but not under the flat bed system. Also, improved varieties yielded significantly more than the landrace variety in the first three sowing dates when waterlogging was a problem but not in the last sowing date after which drought stress normally sets in. Sowing of improved chickpea varieties in mid-September using BBF could markedly increase productivity of chickpea on Vertisols in Ethiopia.

Keywords: drainage method; chickpea genotypes; sowing date; Vertisol; waterlogging

Introduction

In Ethiopia, chickpea (*Cicer arietinum* L.) is an important food legume crop grown mainly on Vertisols in the highlands. About 12.6 million ha of Vertisols are found in Ethiopia, making up 10.3% of the total land area and 25% of the cropland area (Wakeel and Astatke 1996). In Ethiopia, despite their high agricultural potential, Vertisols are generally considered problem soils because of poor workability and prolonged waterlogging during the main rainy season (Belayneh 1987; Asamenew et al. 1988; Abebe et al. 1994). To avoid waterlogging stress, crops except tef (*Eragrostis tef* L. – because it is waterlogging resistant) are sown on Vertisols towards the end of the main rainy season. Such a late-sown crop mainly utilizes residual soil moisture for growth and development, often experiencing drought during seed filling, resulting in lower yields.

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In addition to late sowing, farmers cope with waterlogging by constructing a ridge-and-furrow (RF) drainage system, whereby parallel ridges of ~20 cm high and 30 cm wide are made by hand after broadcasting seeds (Erkossa et al. 2006). The crops grow on the ridges, allowing the excess water to drain out of the field through the furrows. In the RF system, land preparation starts during the April–May small rains, with occasional ploughing to control weeds throughout the summer until planting (Erkossa et al. 2006). To make improvements over the traditional RF drainage system, an animal-drawn device named the broad-bed maker (BBM) was introduced into Ethiopia by the International Livestock Center for Africa (Haque et al. 1988; Mamo and Mohamed-Saleem 2001; Erkossa et al. 2006). The BBM is used to make broad-bed-and-furrow (BBF) in which 80-cm-wide beds alternate with 20-cm-wide furrows. The crops are arranged for growing on the beds with furrows used to drain excess water.

Chickpea is sensitive to waterlogging. Because of this, in Ethiopia this crop is sown starting from about mid to late September, at which time the waterlogging problem has receded and drought stress is about to set in. The crop is sown with only one ploughing before sowing, using the traditional ox-drawn hand plough, followed by another to cover the broadcasted seeds on land that was kept fallow during the heavy rains from June to August. In general, no drainage practices are used for growing chickpea. Given the current practices, chickpea productivity on Vertisols is constrained by severe waterlogging when sown early and by drought when sown late. Improving drainage might enable early sowing, increase the growth period without drought stress, and therefore enhance seed yield.

Early September sowing of chickpea on Vertisol at Debre Zeit increased seed yield by 35% compared with later sowing dates (Eshete 1994). Debre Zeit (east of Addis Ababa) is largely a continuum of the Rift Valley system having lower altitude, warmer temperatures and less rainfall compared with Ginchi, which is ~90 km west of Addis Ababa on the way to the high rainfall belt of western Ethiopia. Being at Ginchi or at Debre Zeit, it can be surmised that late season drought stress on chickpea grown on Vertisols can be avoided by sowing even earlier than the recommended early September sowing dates, provided that the problem of waterlogging, for example, in August, is tackled. However, the hypothesis that sowing in August in the presence of improved drainage systems may be more advantageous than later sowing has not been supported by research data. Furthermore, whether improved drainage is important for chickpea sown in September has not been determined.

The national chickpea breeding program in Ethiopia has developed several improved varieties that are being promoted for large-scale adoption by farmers. The improved chickpea varieties differ in important agronomic attributes including seed size and grain yield. Nonetheless, chickpea landraces continue to be widely grown in large parts of Ethiopia. It is often believed that crop landraces display a specific adaptation that may confer yield advantages over modern varieties under abiotic stress situations such as drought (Ceccarelli 1994; Sinebo 2002). It may, therefore, be important to examine the differential performance of landrace and modern chickpea varieties when subjected to different levels of management regimes such as sowing dates and drainage methods.

Our objective was to study the main and interaction effects of sowing date, drainage method and variety on growth, seed yield and yield components of chickpea planted over several years on Vertisol of Ginchi, Ethiopia.

Materials and methods

Experimental site

The trial was conducted for three years (2003–2005) at Ginchi Research Sub-centre in the central highlands of Ethiopia. Ginchi is located at 09°02′N latitude and 38°12′E longitude at an altitude of 2200 m above sea level. The soil is a pellic Vertisol. The soil physical and chemical properties for the experimental site are given in Table 1. The rainfall is bimodal with long-term average annual rainfall of 1095 mm, of which ~76% is received from June to September and 24% from January to May (Table 2).

Land preparation, treatments, design and data collection

Tractor-mounted disc ploughing and disc harrowing was carried out in April as is common practice for general land preparation in the research centre. The BBF was constructed in June with a broad-bed maker (BBM) pulled by a pair of oxen. BBF was made in June because the soil was still relatively friable and workable at this time for using the BBM. Ridge-and-furrow was made by hand immediately before the first planting on 18 August for all treatments. At each sowing date, the BBF and RF were maintained or renewed by hand using hand hoes. Similarly, a hand hoe was used to disturb the soil before each sowing for the flat seedbed treatments.

The design was a split-plot with three replications. The three drainage methods (broad-beds-and-furrow, ridge-and-furrow and flat beds) were arranged in the main plots, and factorial combinations of four sowing dates (18 and 31 August, and 14 and 28 September) and three Desi-type chickpea varieties (Worku, Akaki and landrace) were used in the sub-plot. A sub-plot size of 3.6 m × 4 m was used. Seeds were drilled by hand in 30-cm-wide rows at an interplant spacing of ~10 cm and lightly covered with soil. Seed rate of 110 kg ha^{-1} for the improved varieties and 100 kg ha^{-1} for the landrace (adjusted for smaller seed size) were used. Fertilizer was applied at the rate of 18/20 kg N/P ha^{-1}. For the BBF, there were four beds, 80-cm-wide, separated by furrows in each plot. The two centre beds, each consisting of three rows of plants for a total of six rows per plot, were harvested for yield determination. In the case of RF, chickpea was sown in rows by hand on ridges that were 30 cm apart. Again the central six rows (six ridges) were harvested for yield determination. This means that, in each of the three drainage systems, each sub-plot consisted of 12 rows, 30 cm apart, and 4 m long. From each sub-plot, the centre six rows were harvested for a net plot size of 6 rows × 0.3 m wide × 4 m long =

Table 1. Physical and chemical soil characteristics (0–30 cm depth) of the experimental site at Ginchi, Ethiopia.

Parameter	Value	Parameter	Value
Clay (%)	66.4	P-Olsen (mg kg^{-1})	16.5
Silt (%)	22.3	Na (cmol kg^{-1})	0.42
Sand (%)	11.3	K (cmol kg^{-1})	2.04
pH (1:1 H_2O)	6.5	Ca (cmol kg^{-1})	39.1
OC (%)	1.8	Mg (cmol kg^{-1})	7.4
C/N ratio	10.1	Ca/Mg ratio	5.3:1
Total N (%)	0.13	CEC (cmol kg^{-1})	48.5

Table 2. Monthly total rainfall, monthly mean maximum and minimum temperature and monthly mean sunshine hours for 2003–2005 cropping seasons and the 30-year average.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Total
Monthly total rainfall (mm)													
2003	7.5	48.2	62.4	136	5	125	254	280	96	5	5	5	1029
2004	53.8	5.6	28.1	156	46	120	211	249	169	11	8	0	1058
2005	64.7	2.4	97.8	59	135	144	219	218	132	14	6	0	1092
30-year mean	21.2	38.2	72.7	90	86	148	221	222	136	38	14	8	1095
Monthly mean maximum temperature (°C)													
2003	25.7	27.6	26.9	26.1	28.4	24.3	20.9	21.1	21.9	24.1	24.7	24.5	24.7
2004	25.9	26.4	27.1	25.7	27.1	23.6	21.5	22.0	22.0	22.8	24.9	25.2	24.5
2005	25.3	28.1	27.2	27.0	25.7	25.1	22.6	22.3	22.0	23.7	24.4	24.8	24.9
30-year mean	25.2	26.4	26.6	25.9	26.0	23.9	21.4	21.3	22.3	23.6	24.0	24.6	24.3
Monthly mean minimum temperature (°C)													
2003	6.7	8	9.1	9.8	9.2	9.6	11.2	11.5	10.5	6.8	6.6	5.8	8.7
2004	9.5	8.2	9.4	10.3	10.2	10.9	11.1	11.5	10.7	8.0	6.6	8.1	9.5
2005	3.4	4.5	7.3	8.0	9.4	7.0	8.7	8.8	8.3	4.3	1.9	−0.3	5.9
30-year mean	8.7	8.7	10.7	11.8	11.8	10.5	11.1	11.4	11.1	7.9	6.5	4.8	9.6

7.2 m^2. Harvesting was from 11 to 25 January in 2003, 4 to 18 January in 2004 and 13 to 27 January in 2005. Agronomic parameters such as plant stand count (plant m^{-2}) at complete emergence and at harvest, days to flowering, mature plant height, number of pods and number of seeds per plant, seed weight, total plant biomass and seed yield were recorded.

Statistical analysis

The data were subjected to analysis of variance using the GLM procedure of SAS statistical package version 8.2 (SAS Institute 2001). Data were combined over the three years and total variability for each trait was quantified using pooled analysis of variance over years based on the following model:

$$\begin{aligned} T_{ijklm} = \mu + Y_i + R(Y)_{ji} + D_k + YD_{ik} + R(YD)_{jik} + S_l + YS_{il} + DS_{kl} \\ + YDS_{ikl} + G_m + YG_{im} + DF_{km} + SG_{lm} + YDG_{ikm} + YSG_{ilm} \\ + DSG_{klm} + YDSG_{iklm} + e_{ijklm} \end{aligned}$$

where T_{ijklm} is total observation, μ = grand mean, Y_i = effect of the ith year, $R(Y)_{ji}$ is effect of the jth replication within ith year, D_k is effect of the kth drainage method, S_l is effect of the lth sowing date, G_m is effect of the mth variety, YS, YD, YG, SD, SG, DG, YSD, YSG, YDG, SDG and $YSDG$ are the interactions, and $R(YD)$ and e_{ijklm} are the variations due to random error for main and sub-plots, respectively. Significance of the year effect was tested against the $R(Y)$ mean square as the error term and the D and YD effects tested against the $R(YD)$ mean square as an error term. All other effects were tested against the residual. When interaction effects were significant, the slice option in the LSMEANS statement of the GLM procedure was used to determine the significance of simple effects. Means for the main effects were separated using the MEANS statement with the LSD option, in particular specifying the appropriate error terms for Y and D. Means for the interactions were separated using the PDIFF option in the LSMEANS statement of the GLM procedure, in particular specifying the $R(YD)$ as an appropriate error term for separating LSMEANS for the YD interaction.

Results

Weather

Rainfall for July and August was greater and for September was less in 2003 than in either 2004 or 2005 (Table 2), exposing the crop to more waterlogging at the early growth stage and to drought at later growth stages in 2003. When compared with the long-term average, rainfall in September was near average in 2005, less by 40 mm in 2003 and more by 33 mm in 2004, implying a favourable moisture regime in 2004, average conditions in 2005 and stress in 2003.

Year, drainage, sowing date and variety main effects on seed yield

All the main effects [year (Y), drainage (D), sowing date (S) and variety (G)] were highly significant ($p < 0.001$) (Table 3). Mean seed yield was 2519 kg ha^{-1} in 2004, 1548 kg ha^{-1} in 2005 and 887 kg ha^{-1} in 2003 (Table 4). On average, drainage increased seed yield by 45% compared with the FB system. There was no significant difference in seed yield between the BBF and RF drainage systems (Table 4). By and large, there was a quadratic response of seed yield to sowing date with a peak at about mid-September (Figures 1 and 2 and Table 4). Delaying the sowing date from 18 August to 14 September increased seed yield but a further delay until 28 September resulted in a decrease in seed yield due to a shortage of moisture. The improved varieties, Worku and Akaki, yielded significantly more than the landrace check (Table 4). There was no significant difference in seed yield between the two improved varieties.

Interaction effects on seed yield

The two-factor interaction effects of year by drainage method (Y × D), year by sowing date (Y × S), drainage method by sowing date (D × S), drainage method by variety (D × G) and sowing date by variety (S × G) were significant ($p < 0.01$) for chickpea seed yield (Table 3). The second-order interaction effects of year by drainage and sowing date (Y × D × S) and year by drainage and variety (Y × D × G) were also significant ($p < 0.01$) for seed yield (Table 3).

Slicing the Y × D × S interaction effect by year indicated the D × S interaction to be significant each year. The pattern of this interaction for individual years is given in Figure 1. Each year, there was large curvilinear response (R^2 of 0.97–1) of seed yield to sowing dates in the BBF and flat bed systems. The curvilinear response of seed yield to sowing dates in the RF system was weaker with R^2 values ranging from 0.64 to 0.83 in individual years. RF yielded more than BBF and FB systems across almost all the sowing dates in 2003 and in the first sowing

Table 3. Analysis of variance for chickpea seed yield and other agronomic traits tested at three drainage methods, four sowing dates and three varieties, 2003–2005.

Source	df	SY	BY	TSW	PPP	SPP	PH	DTF	SC_2	SC_1
Year (Y)	2	***	***	***	***	***	***	***	***	ns
Drainage (D)	2	***	***	ns	***	***	***	ns	ns	ns
Y × D	4	***	***	*	**	*	ns	ns	*	*
Sowing date (S)	3	***	***	ns	***	***	***	***	*	***
Y × S	6	***	***	**	***	***	**	ns	**	***
D × S	6	***	***	ns	*	ns	ns	ns	ns	***
Y × D × S	12	***	***	ns	ns	*	ns	ns	ns	***
Variety (G)	2	***	***	***	*	***	**	ns	***	ns
Y × G	4	ns	ns	***	***	***	**	ns	***	***
D × G	4	***	***	ns	***	*	ns	ns	ns	ns
Y × D × G	8	***	**	ns	ns	**	ns	ns	ns	ns
S × G	6	**	ns	ns	ns	ns	ns	ns	ns	ns
Y × S × G	12	ns	ns	ns	**	ns	ns	ns	ns	ns
D × S × G	12	ns	*	ns	ns	ns	ns	ns	ns	ns
Y × D × S × G	24	ns	ns	ns	ns	ns	ns	ns	ns	ns
Root-MSE		301.7	563.3	18.0	15.0	24.6	3.5	9.7	3.0	6.1
CV (%)		18.3	18.6	10.0	21.9	26.4	9.2	15.1	10.0	20.1

Note: SY, seed yield; BY, biomass yield; TSW, thousand seed weight; PPP, pods per plant; SPP, seeds per plant; PH, plant height; DTF, days to flowering; SC_1, stand count at emergence; SC_2, stand count at maturity. Significant at $*p = 0.05$, $**p = 0.01$, $***p = 0.001$; ns, not significant.

Table 4. Yield and yield components of chickpea as influenced by drainage method, sowing date and variety on Vertisol, 2003–2005.

Factor	SY (kg ha^{-1})	BY (kg ha^{-1})	TSW (g)	PPP (no.)	SPP (no.)	PH (cm)	DTF (d)	SC_1 (plant m^{-2})	SC_2 (plant m^{-2})	Mortality (%)
Year (Y)										
2003	887	1736	190	56	76	37	59	27	18	33
2004	2519	4509	173	86	118	42	68	33	26	21
2005	1548	2819	179	64	85	36	64	32	27	16
LSD	246.0	427.4	4.2	6.0	9.3	2.0	1.5	ns	0.8	
Drainage (D)										
BBF	1853	3398	182	74	101	39	64	32	26	19
RF	1831	3334	179	71	99	38	65	31	24	22
Flat	1270	2332	181	60	80	36	64	30	22	27
LSD	111.5	242	ns	3.5	7.6	0.9	ns	ns	ns	
Sowing date (S)										
18 Aug	1142	2161	176	56	73	36	61	23	13	44
31 Aug	1736	3206	182	74	103	39	62	31	24	23
14 Sept	1996	3473	182	74	104	39	69	33	27	18
28 Sept	1733	3246	183	69	92	38	64	35	29	17
LSD	93.5	174.5	ns	4.6	7.6	1.1	3.0	1.9	0.9	
Variety (G)										
Worku	1705	3221	218	66	78	39	64	31	24	22
Akaki	1763	3180	195	71	93	37	65	32	23	22
Landrace	1487	2663	129	69	108	38	63	30	21	27
LSD	81.0	151	4.8	4.0	6.6	0.9	2.6	ns	0.8	

Note: SY, seed yield; BY, biomass yield; TSW, thousand seed weight; PPP, pods per plant; SPP, seeds per plant; PH, plant height; DTF, days to flowering; SC_1, stand count at emergence; SC_2, stand count at maturity. LSD, least significant difference.

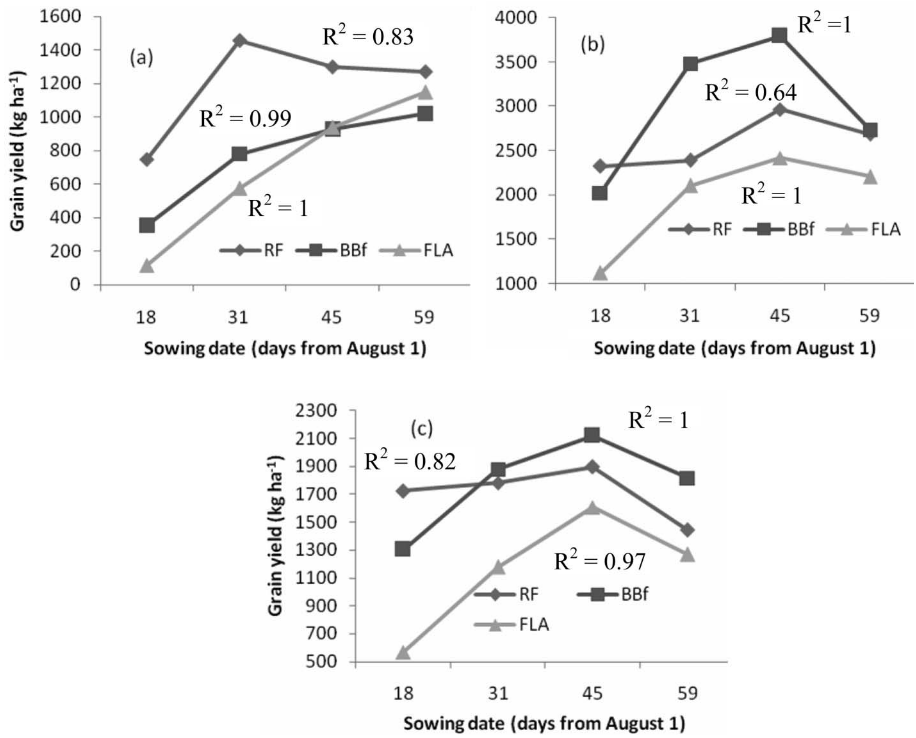

Figure 1. Interaction effects of year-by-drainage system-by-sowing date on seed yield of chickpea tested at four sowing dates and three drainage systems using three varieties at Ginchi, Ethiopia. a, 2003; b, 2004; c, 2005. R^2 values are for quadratic equations.

date in all the years. BBF was more yielding than either the RF or flat bed system for mid-September sowings in 2004 and 2005. The RF and BBF systems were more yielding than the flat bed system across almost all the sowing dates in all the three years.

Although it is appropriate to present simple effects as above when complex three-way interactions such as Y × D × S were significant, two-way interactions are more useful in providing meaningful agronomic insights. Thus, two-way interactions involving sowing dates are presented in Figure 2. When sliced by year, the average effect of sowing date in individual years was significant ($p < 0.0001$; data not shown). Examination of the Y × S interaction indicated no rank change (cross-overs) among the sowing date treatments in the three years (Figure 2a). Hence this interaction is due to scale effects. Also, in each of the three years, the maximum yield was obtained with the mid-September sowing date, implying a consistency of relative response of sowing dates over the years.

A graphic representation of the pattern of the D × S interaction is given in Figure 2b. Differences among sowing dates were highly significant ($p < 0.0001$) under each of the three drainage systems. However, the response was large for the FB and BBF systems and very small for the RF drainage system. In all drainage systems, however, the maximum seed yield occurred around mid-September making the general sowing date recommendation robust. The advantage of improved

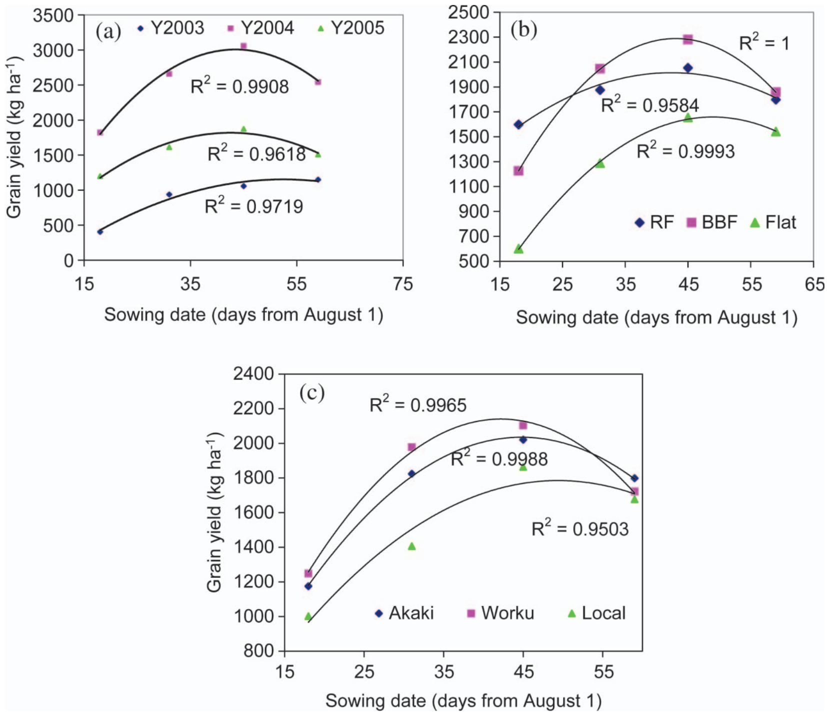

Figure 2. The relationship between sowing date and seed yield as affected by (a) year, (b) drainage system and (c) variety in chickpea tested under three drainage methods and three sowing dates in three years using three varieties at Ginchi, Ethiopia.

drainage was larger for earlier sowings and small for the last sowing. This is understandable because further delay in sowing induces low moisture stresses associated with the cessation of the season's rainfall.

The sowing date by variety (S × G) interaction is displayed graphically in Figure 2c. Differences among varieties were significant for all but the last sowing date. With early sowing, when waterlogging was high, improved varieties were more yielding than the local variety, but with the last sowing date at the end of September when the low moisture stress had set in, all varieties gave similar seed yields.

When the Y × D × G interaction was sliced by year, the D × G interaction was significant for each year (data not shown). The pattern of the Y × D × G interaction is given in Figure 3. In 2003, there was no difference among the three varieties under the BBF and FB systems, but the two improved varieties yielded more than the landrace variety under the RF system. In 2004 and 2005, either or both improved varieties yielded more than the landrace variety under improved drainage of RF and BBF. By contrast, the landrace variety was as yielding as the improved varieties under the FB system in 2004 and 2005. There was no significant difference between the two improved varieties in all but one combination of year and drainage system (under RF in 2005).

The two-way interactions of drainage with year and variety are given in Figure 4. Slicing the Y × D indicated that the interaction was significant each year. The RF drainage system gave a significantly greater yield than either the FB or BBF systems

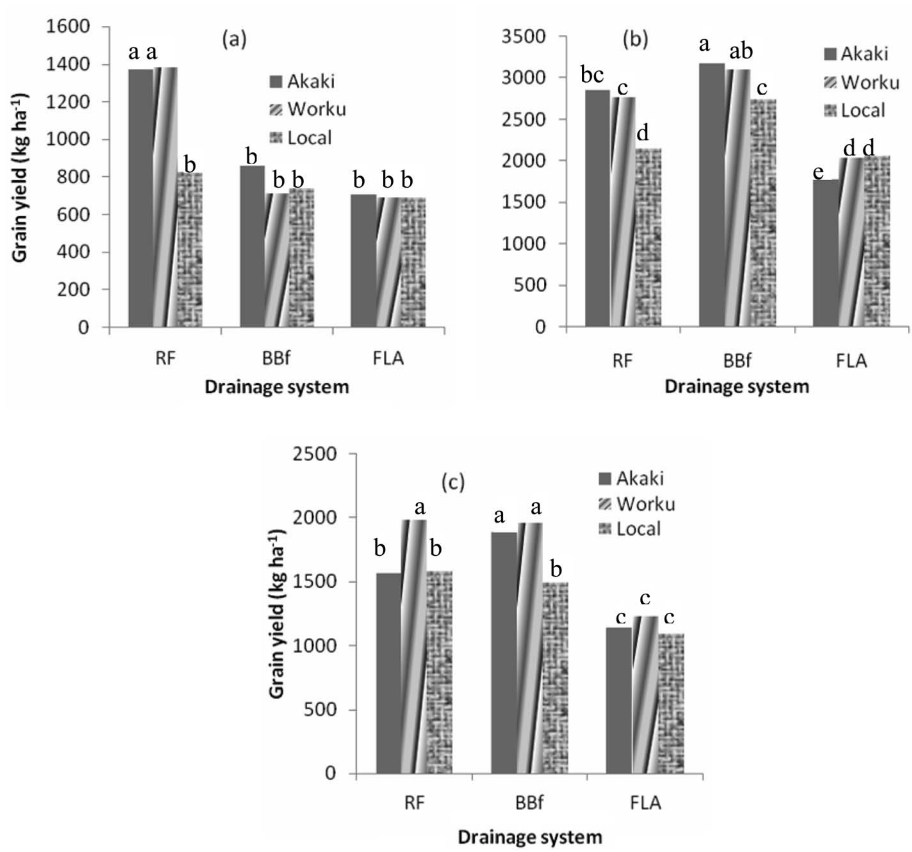

Figure 3. Interaction effects of year-by-drainage system-by-variety on seed yield of chickpea tested at four sowing dates, three drainage systems using three varieties in three years at Ginchi, Ethiopia. a, 2003; b, 2004; c, 2005.

in 2003 (Figure 4a). In 2004 and 2005, the two improved drainage systems gave significantly better yields than the FB system. Seed yields were similar for the two improved drainage systems in 2005, but BBF resulted in a better yield than RF in 2004 (Figure 4a).

The drainage method by variety (D $\times$ G) interaction is quite interesting (Figure 4b). In the improved drainage systems of RF and BBF, improved varieties gave higher yields than the local cultivar. But under the FB system, there was no significant difference in seed yield among the varieties.

Main and interaction effects on other agronomic attributes

Variance analysis results for biomass yield were similar to those of seed yield. Year, sowing date, variety, drainage and Y $\times$ S interaction significantly affected most of the other parameters measured (Table 3). Stand count at maturity was heavily influenced ($p < 0.01$) by year, variety and Y $\times$ G interaction (Table 3). Stand count at harvest was lower (18 plants m^{-2}) in 2003 than in 2004 and 2005 (average of 26

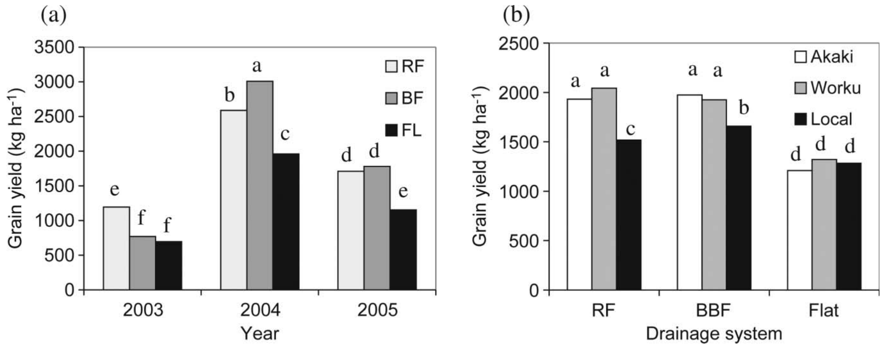

Figure 4. Interaction effects of drainage system with (a) year and (b) variety for seed yield of chickpea tested under three drainage systems and three sowing dates using three varieties in three years at Ginchi, Ethiopia. RF, ridge and furrow; BBF, broad bed and furrow; FL, flat.

plants m^{-2}). Stand count at harvest increased from 13 plants m^{-2} for the 18 August sowing to 29 plants m^{-2} for the 28 September sowing (Table 4). Plant mortality was highest in 2003 and lowest in 2005. Plant mortality was highest when sowing was early and the seedbed was flat compared with mortality percentages observed in the later sowing dates and the improved BBF and RF drainage methods (Table 4).

Seed number per plant (SPP) was strongly influenced ($p < 0.01$) by year, drainage, sowing date, variety, Y $\times$ S and Y $\times$ G interactions (Table 3). Seed number per plant was highest in 2004 at 118 SPP, compared with 76 SPP in 2003 and 85 SPP in 2005 (Table 4). Seed number per plant increased from 73 for the 18 August sowing to 104 for the mid-September sowing and decreased to 92 SPP for the last sowing made on 28 September (Table 4). Seed weight was strongly affected ($p < 0.01$) by year, variety and Y $\times$ G interaction. The landrace variety had the lowest seed weight but the highest SPP (Table 4). Days to flowering was affected by year and sowing date only. Plants flowered late when sown in mid-September, which was also the date at which seed yields were the highest.

Discussion

In Ethiopia, chickpea is a low-input crop grown with minimum tillage mainly on Vertisols that are prone to severe seasonal waterlogging. Chickpea is highly sensitive to waterlogging and is, therefore, grown largely with residual moisture after the main season rain has subsided. This crop faces drought stress, particularly during the critical period of seed filling. Hence, chickpea productivity on Vertisols in Ethiopia is constrained by poor drainage when sown early and by drought when sown late.

The advantage of improved drainage combined with early sowing on Vertisols has been demonstrated in several other crops (Haque et al. 1988; Abebe et al. 1994; Asamenew et al. 1988; Astatke et al. 2002; Agegnehu et al. 2006) but not on chickpea. This study has revealed that yield improvement on chickpea grown on Vertisols can be made by combining the use of optimum sowing dates, improved drainage systems and varieties with appropriate phenology. However, even with the best combination of these improved practices, a lethal combination of high rainfall early in the season and low rainfall towards end of the season, as observed in 2003, can severely affect chickpea growth and reduce seed yield. Low yield in such an adverse year results from poor vegetative growth, sparse stand at harvest and lower number of seeds per plant (Table 4).

Belayneh (1987) emphasized the advantage of improved drainage (camber beds) for chickpea yield at Ginchi (Ethiopia), and Bejiga et al. (1994) reported the importance of optimum sowing dates for obtaining better chickpea seed yield at Debre Zeit (Ethiopia). But the current study is the first to report the interactive effect of drainage methods and sowing date on several chickpea varieties grown on Vertisol in Ethiopia. Of the statistically significant interactions, no cross-overs were observed for the year by sowing date (Y × S) interaction, implying that sowing date recommendations are consistent over the years (Figure 2a). Similarly, the sowing date by variety (S × G) interaction did not involve significant rank changes, indicating the optimality of mid-September sowing for all the three varieties. Nonetheless, it is important to note from this interaction that there was no advantage of improved varieties when chickpea was sown in late September (Figure 2c). It appears that the improved varieties were more tolerant than the landrace to waterlogging but not to season-end drought.

Although improved drainage systems were better than the flat system in all years, there were rank changes between BBF and RF (Figure 4a). The cross-over was due to better seed yield from RF than BBF when waterlogging was severe, as in 2003, but lower yield in RF than in BBF when waterlogging was mild, as in 2004 and 2005. The RF system is likely to facilitate drainage more than BBF because the furrows are at shorter intervals in RF (~30 cm) than in BBF (~80 cm). With high drainage constraints, as was the case with early sowing, RF yielded significantly more than BBF (Figure 2b). However, with later sowings, because of reduced waterlogging stress, BBF gave higher yields than RF. From this study, it was apparent that sowing earlier than September did not offer any yield advantage with or without drainage, implying that improved drainage did not help in moving optimum planting date from September to August.

The highly significant drainage method by variety (D × G) interaction for seed yield was due to the greater yield of improved varieties under relatively improved drainage conditions, but not under flat bed conditions. This result confirms the often claimed better performance of modern varieties under optimal management conditions but not under stress conditions (Sinebo 2005).

Conclusion

Apparently, low chickpea seed yield from early sowing in this environment results from low field emergence, high plant mortality, low plant stand at harvest, fewer pods per plant, fewer seeds per plant and low biomass production (Table 4). Finally, we conclude that appropriate sowing date, improved drainage methods and improved varieties can substantially increase the productivity of chickpea on Vertisols in Ethiopia.

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