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Clarifying interactions between genotype and environment and management in chickpea by focusing on plant and soil attributes

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The advancement of conservation agriculture (CA) as an efficacious methodology for sustainable production is contingent upon the introduction of suitable and adapted new cultivars for CA conditions. The objective of this study was to investigate the interaction effect of tillage × genotype and its consequences for the performance of chickpea genotypes under three distinct tillage systems during three cropping seasons (2016–2019) in the dryland conditions of northwest Iran. The results of this experiment demonstrate that the physicochemical attributes of the soil within the CA system have been enhanced. In particular, there has been an increase in the concentration of organic carbon (OC: 0.21%), potassium (K: 98 mg kg^{-1}), phosphorus (P: 0.93 mg kg^{-1}), nitrogen (N: 0.057%), and soil moisture (SM: 2.37%) in the zero-tillage (ZT) system compared to the concentration at the beginning of the experiment. Moreover, the findings confirm that chickpea genotypes cultivated under the ZT system demonstrated superior performance (41%) in comparison to those grown using conventional tillage (CT) practices during the third year. With regard to the interaction between genotype and tillage, chickpea genotypes demonstrated a positive interaction with conservation tillage, exhibiting superior performance compared to other systems. Genotypes G1, G2, G4 and G13 demonstrated the highest and most stable performance when cultivated under the ZT system, while genotypes G1, G2, G6 and G13 exhibited superior performance under the MT system, and genotypes G4, G13 and G8 under the CT system. Furthermore, a multi-trait stability analysis was conducted using the MTSI index, which indicates that: The G8 and G14 genotypes were identified as the most stable, with the G14 genotype also exhibiting an above-average yield.

Keywords Chickpea, Conservation agriculture, Crop productivity, Drylands, Tillage × genotype reciprocity

The chickpea is considered as the second most important pulse crop among legumes because it possesses high seed protein content and, therefore, is a predominant nutrient resource for human beings and animals[1]. From an agronomic point of view, chickpea with a key role in nitrogen fixation and enrichment of soil can be applied in the rotation schedule of strategic crops such as wheat, especially in rain-fed conditions[2]. One of the key solutions in sustainable agriculture is restoring diversity to agricultural ecosystems and effective management. In this way, chickpea-wheat rotation is an example of sustainable systems in agriculture which pursue goals such as creating ecological balance, more utilization of resources, increasing the quantity and quality of yield and reducing the damage of pests, diseases and weeds. One of the most important challenges to achieving sustainable chickpea cultivation is the presence of destructive diseases such as Ascochyta blight[3], Fusarium wilt[4], and botrytis gray mold[5]. Under favourable conditions and severe field contamination, these diseases have the potential to destroy 100 per cent of the chickpea field[3–5]. In addressing this challenge, conventional strategies such as the utilisation of fungicides, the employment of disease-free seeds, and crop rotation have been employed. However, a pivotal strategy for the management and control of these diseases, and consequently facilitating sustainable chickpea development, is the incorporation of improved and resistant cultivars[5–8]. In Iran, the majority of chickpea

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production occurs through spring sowing in dryland conditions[9]. This can result in drought stress at the end stage of plant development, particularly seed filling, which adversely impacts chickpea yield. In addition to water scarcity, the distribution of rainfall in several dryland regions may be uneven, limiting crop development[10,11]. Moreover, planting date affects disease incidence specifically for fusarium wilt in chickpea[12] and November-planted genotypes has been detected with low disease level compared with March-plant genotypes[12]. Likewise, late winter sowings coincided with higher rainfalls which intensify Ascochyta epidemics based on Naseri et al. (2024)[13]. In such circumstances, the autumn-sowing of chickpea (November to December) in dryland conditions has been proposed as a means of extending the growth period of chickpea and, consequently, its yield. It is imperative that the autumn sowing of chickpeas is accompanied by the implementation of an appropriate method for seed bed preparation, in addition to the consideration of diseases and the utilization of cold-resistant genotypes[9].

As mentioned before, seed bed preparation methods apart from conventional methods which are known as conservation agricultural systems, especially in rain-fed regions, could lead to sustainable agriculture and food security[14,15]. The practice of crop rotation, incorporating cereal-legume rotations, is a pivotal component of sustainable agricultural practices[16,17]. In cereal-legume rotations, the diversity of plant species with varied growth characteristics and life cycles disrupts the life cycles of plant pests and pathogens, thereby reducing their population and enhancing soil health[18]. Furthermore, the incorporation of legume crops into a rotation that possesses nitrogen-fixing properties has been demonstrated to enhance soil fertility, thereby increasing the productivity of the species present within the rotation[19,20]. Conventional tillage operations using reversible plows in rain-fed areas could damage the soil texture and may also cause a decrease in crop yield. In some rain-fed areas where cereal-legume rotation is common, the implementation of conventional tillage operations after the harvesting of cereal to prepare the legume seed bed has caused the formation of large clumps, and this causes the growth of previous cereal seeds and weeds, especially in clay soils[21]. While in conservation tillage systems, both no tillage and low tillage, some of the residues of the previous cultivation are preserved on the soil surface, so in addition to increasing soil organic matter and maintaining more soil moisture, the problem of soil erosion is also reduced. Considering the soil of rain-fed regions, significant amounts of soil nutrients are removed from the ground in the form of straw and stubble, and as a result, the sources of energy and food supply, especially organic matter in the soil, are reduced and ultimately the fertility is reduced[22]. So, preservation of plant residues in rain-fed regions is particularly important, because it provides the possibility of maintaining more moisture in the soil and raising the organic matter of the soil.

To achieve sustainable production, it is proposed that at least half of the former plant residues be preserved on the soil surface[22]. In an environment saturated with water vapour, plant residues have the capacity to absorb up to 37% of their weight in water, whereas clay materials only absorb up to 17% of their weight in water. It can therefore be concluded that the maintenance of plant remains on the soil surface to create an environment conducive to water permeability is an effective method of reducing evaporation from the soil surface, particularly in regions where rainfall is a significant factor. Conversely, the majority of breeding programmes assume conventional tillage to be the standard seed bed preparation system. Consequently, new cultivars are bred with regard to conventional tillage in the field. As a result, the yield of different cultivars under a conservation agriculture system is poorly understood[23]. In the present era, agricultural practices based on the production of crops without the use of tillage are becoming increasingly prevalent in both irrigated and rain-fed environments. Nevertheless, there has been a paucity of research conducted in farmers' fields for the purpose of selecting chickpea genotypes that are adapted to no-tillage systems. Furthermore, conservation agriculture is becoming an increasingly attractive proposition for farmers, as it demonstrably reduces production costs in comparison to conventional tillage[24,25]. This crop management approach has been widely adopted on a global scale as an effective strategy for mitigating the adverse effects of soil erosion, environmental pollution and greenhouse gas emissions[26].

In total, conservation agriculture-based crop management technology is not common practice in most parts of the dryland areas in Iran. Therefore, the main objectives of this study were to (i) investigate the effects of different tillage systems on the soil properties and agronomic performance of chickpea genotypes on farmers' fields in dryland areas in the northwest of Iran and (ii) identify the superior genotypes in terms of high mean yield and stability (manifesting genotype tillage interaction).

Methods

Site description

The experiments were conducted over three cropping seasons (2016–2017, 2017–2018, 2018–2019) in agricultural fields located in Joghol-e Olya village (latitude 37°18′ N; longitude 46°20′; 1817 m a.s.l.) in Hashtrood County, East Azerbaijan Province, Iran. In accordance with the Köppen climate classification system, the climate of the study region is defined as temperate continental with warm summers[21]. Figure 1 illustrates the monthly rainfall distribution and average temperature during the experimental period.

Experiment layout and tillage systems

A total of 16 cold-tolerant chickpea genotypes, kindly provided by the GenBank of the Dryland Agricultural Research Institute (DARI) of Maragheh-Iran (Table 1), were assessed under three tillage systems, including conventional tillage (CT); The tillage systems employed were moldboard plowing to a depth of 20–25 cm, followed by one pass of a tandem disk at the depth of 10 cm with residue removed; minimum tillage (MT), which entailed chisel plowing followed by one pass of a tandem disk at a depth of 10 cm with residue cover; and zero tillage (ZT), which involved no tillage and direct seeding with residue retained on the soil surface. The experiments were designed as split plot arrangements within a randomized complete block design, with three replications. The three tillage systems were thus designated as the main plot, with the chickpea genotypes

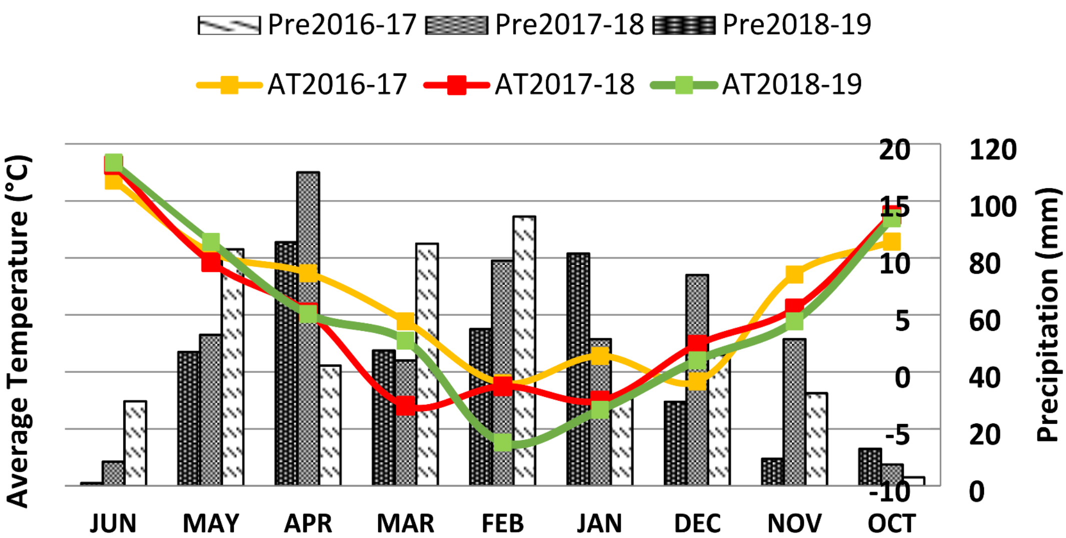

Fig. 1. Monthly rainfall distribution and average temperature during the experiments. Pre: precipitation; AT: average temperature.

No.	Name	Origin	No.	Name	Origin
1	Flip 86-05C	ICARDA	9	Ata	IRAN
2	Flip 09-7C	ICARDA	10	Urom1	IRAN
3	Flip 85-17C	ICARDA	11	Urom2	IRAN
4	Flip 09-289C	ICARDA	12	Barakat	IRAN
5	Uzbakestan 5	Uzbakestan	13	Zarein	IRAN
6	Guksu	Türkiye	14	Sofi	IRAN
7	Ana	IRAN	15	Flip 07-242C	ICARDA
8	Nosrat	IRAN	16	Flip 07-327C	ICARDA

Table 1. List of Chickpea genotypes utilized in the experiment (provided by the dryland agricultural research Institute gene Bank).

constituting the subplot. Each experimental plot consisted of seven rows, with a length of 20 m and an inter-row spacing of 35 cm, resulting in a plot size of 49 m^2. A winter wheat-chickpea rotation was established during the experimental period. The seeds of the chickpea genotypes were cultivated in October of each year with a sowing rate of 40 seeds per square metre, using a no-till drill (Askeh-2002).

Data acquisition and statistical analysis

Soil samples were obtained from the experimental site for each year and each tillage system, with three replicates. The content of organic carbon (OC), potassium (K), phosphorus (P), nitrogen (N), soil moisture (SM), and soil bulk density (SBD) were then measured. To evaluate the response of chickpea genotypes to tillage systems, yield and its related agro-morphological and phenological traits were recorded through harvesting a 1.75 m × 18 m area of each plot. Additionally, parameters such as days to flowering were monitored. The following parameters were recorded: days to flowering (DF), days to maturity (DM), plant height (PH), biological yield (BY), grain yield (GY), hundred seed weight (HSW), harvest index (HI), pod per plant (PP), and first pod formation height (FPH). The field data was assessed for normality using the Anderson-Darling test and checked for outliers. Subsequently, Levene's test was applied to verify the homogeneity of variance, thereby confirming the uniformity of individual error mean squares.

Combined analysis of variance and Duncan multiple range test for soil characteristics as well as chickpea`s data was done using SAS software version 9.4[27].To evaluate genotype stability across environments (genotype × tillage), a linear mixed model was employed[28]. The significance of each effect on the studied traits was determined using the likelihood ratio test (LRT) with a two-tailed chi-square test (one degree of freedom). Initially, for each environment, traits were modeled with a linear mixed-effects model, treating environment and environment-by-genotype interaction as random effects and genotype as a fixed effect[29]. This was done using the "gamem_met" function from the metan R-package[28], adhering to the standard linear mixed model[30]. The model can be expressed as:

$$y = Xb + Zu + \in$$

Where yy is a vector of response variables, bb is a vector of fixed effects, uu is a vector of random effects, XX is a design matrix of 0s and 1s relating yy to bb, ZZ is a design matrix of 0s and 1s relating yy to uu, and ∈∈ is a vector of random errors.

Following the analysis of variance, genotype and genotype-by-environment interaction (GEI) are assumed to be random effects[31] to predict genetic parameters using the argument "genpar" in the function "gamem_met". Subsequently, stability analysis was conducted by calculating the Weighted Average of Absolute Scores Parameter (WAASB) using the function "waasb" in the metan package. In this process, WAASB was estimated based on a singular value decomposition of the G×E interaction effects from the matrix of the Best Linear Unbiased Predictions (BLUPs) as follows:

$$WAASB_i = \frac{\sum_{k=1}^{p} |IPCA_{ik} \times EP_k|}{\sum_{k=1}^{p} EP_k}$$

Where WAASBi is the weighted average of absolute scores of the iith genotype or environment, $IPCA_{ik}$ is the absolute score of the ith genotype or environment in the kth IPC, and EP_k is the magnitude of the variance explained by the kth IPC.

As shown, WAASBYi is the superiority index with different weights between yield and stability for the gth genotype, Θ_Y and Θ_S are the weights for yield and stability, respectively; rG_g and rW_g are the rescaled values of the gth genotype for yield and WAASB, respectively.

$$WAASBY_i = \frac{(rG_g \times \theta_Y) + (rW_g \times \theta_S)}{\theta_Y + \theta_S}$$

In this study, GGE biplot analysis was implemented for further specific analysis of genotypes and environments[32,33]. Hence, the GGE model is fitted with the function "gge" in "metan" package. The generic function plot (GGE) is used to generate a biplot using as input a fitted model of class gge. The type of biplot is chosen by the argument type (type = 3 equal with which-won-where, type = 6 equal with ranking environments, type = 8 equal with ranking genotypes) in the function.

Finally, MTSI was utilized to assess both the average performance and the concurrent stability of various traits having significant G×E interaction comprising DM, FPH, PH, PP, HSW, BY, HI, and GY considering that higher values for studied traits except DM and DF are suitable. In this regard, the vector of trait importance as c (l, h, h, h, h, h, h, h) was defined and incorporated into the WAASB analysis before the MTSI approach[28]. Next, the MTSI analysis was conducted using the MTSI function within the "metan" package, implemented as outlined below:

$$MTSI_i = \left[\sum_{j=1}^{f} (\gamma_{ij} - \gamma_j)^2\right]^{0.5}$$

Where $MTSI_i$ is the multi-trait stability index of the genotype i, γij is the score of the genotype i in the factor j, and γj is the score of the ideal genotype in the factor j. Scores were computed through factor analysis for both genotypes and traits.

Results

Tillage systems could affect soil properties and Chickpea performance

Analysis of variance pertaining to soil physio-chemical properties showed significant difference during years of study regarding all measured characters of soil except for SBD (Table 2). Apart from SBD, tillage system has influenced over all soil properties. In this study, significant interaction of tillage system × year for OC, K, and SBD was found (Table 2). In the following, mean comparison among all possible interactions showed that the highest value of all soil physio-chemical characteristics belonged to the zero tillage system (Table 3). By focusing on soil characters variability within each tillage system, it is clear that recorded physio-chemical characters trend to increase during the first to third years of study but with a sharp slope for zero tillage system.

		Mean square					
Source of variation	df	OC	K	*P*	*N*	SM	SBD
Year (Y)	2	0.0243**	14210.14**	2.6270**	0.0042**	2.4766*	0.0050$^{n.s}$
$Error_1$	6	0.0001	6.51	0.0179	0.0002	0.4262	0.0055
Tillage (T)	2	0.0075**	1003.29**	0.1695*	0.0009*	4.7253*	0.0012 $^{n.s}$
Y×T	4	0.0089**	344.07**	0.0583 $^{n.s}$	0.0001 $^{n.s}$	1.4878 $^{n.s}$	0.0032*
$Error_T$	12	0.00006	2.66	0.025	0.0001	0.7705	0.0009
C.V (%)		2.6	0.64	7.57	12.6	5.32	2.42

Table 2. ANOVA for soil physiochemical characters during 3 consecutive years of experiment under different tillage systems. df: degrees of freedom; OC: Organic carbon, K: Potassium, P: Phosphorous, N: Nitrogen, SM: Soil moisture, SBD: Soil bulk density. * and **: Significant at 5% and 1% probability levels, respectively.

Tillage systems	Year	Environment code	K	P	OC	N	SM	SBD
			(mg kg^{-1})		(%)	(%)	(%)	(g cm^{-3})
ZT	2015–16	E1	204.13^{g}	1.66^{d}	0.24^{f}	0.073^{cd}	16.14^{bc}	1.26^{ab}
	2016–17	E2	282.77^{b}	2.43^{a-c}	0.31^{c}	0.105^{b}	16.87^{bc}	1.22^{bc}
	2017–18	E3	302.23^{a}	2.59^{ab}	0.45^{a}	0.130^{a}	18.51^{a}	1.2^{c}
MT	2015–16	E4	216.00^{f}	1.32^{e}	0.23^{f}	0.063^{d}	16.22^{bc}	1.2^{c}
	2016–17	E5	268.37^{d}	2.32^{bc}	0.33^{b}	0.090^{bc}	16.40^{bc}	1.2^{c}
	2017–18	E6	277.93^{c}	2.64^{a}	0.32^{c}	0.105^{b}	17.16^{ab}	1.23^{bc}
CT	2015–16	E7	202.67^{g}	1.44^{ed}	0.27^{e}	0.067^{d}	16.09^{bc}	1.29^{a}
	2016–17	E8	258.20^{e}	2.18^{c}	0.29^{d}	0.090^{bc}	15.47^{c}	1.2^{c}
	2017–18	E9	265.07^{d}	2.23^{c}	0.28^{d}	0.097^{b}	15.64^{bc}	1.2^{c}

Table 3. Duncan multiple range test for comparison between tillage systems across several years regarding soil related characters. OC: Organic carbon, K: Potassium, P: Phosphorous, N: Nitrogen, SM: Soil moisture, SBD: Soil bulk density. Values followed by different letters within the same column are different significantly at 5% level according to Duncan test. ns = not different significantly at 5% probability level. ZT: Zero-Tillage, MT: Minimum Tillage, and CT: Conventional Tillage.

Trait	Year	Zero tillage			Minimum tillage			Conventional tillage		
		Mean	SD	*P* Gen	Mean	SD	*P* Gen	Mean	SD	*P* Gen
DF	2016	219.3	1.544	0.046	221.4	1.156	0.342	219.3	1.544	0.046
	2017	220.7	0.739	0.877	220.3	1.124	0.542	220.2	1.520	0.036
	2018	222.1	0.882	0.873	222.3	1.074	0.572	221.3	0.921	0.695
DM	2016	263.1	1.867	0.014	263.9	2.337	< 0.000	265.6	1.528	0.204
	2017	263.7	2.258	< 0.000	264.8	2.135	< 0.000	263.7	1.468	0.445
	2018	266.5	2.230	< 0.000	267.1	2.817	< 0.000	266.5	1.897	0.110
FPH (cm)	2016	13.30	1.247	< 0.000	13.90	1.099	< 0.000	15.42	2.039	< 0.000
	2017	14.55	1.240	< 0.000	14.05	0.834	0.017	13.00	1.247	< 0.000
	2018	15.41	2.157	< 0.000	15.35	2.779	< 0.000	15.63	1.690	< 0.000
PH (cm)	2016	24.18	0.960	< 0.000	23.25	1.908	< 0.000	27.20	2.866	< 0.000
	2017	26.37	1.466	< 0.000	25.05	1.162	0.001	23.11	0.884	< 0.000
	2018	28.39	1.399	< 0.000	25.63	2.518	< 0.000	27.31	2.501	< 0.000
PP	2016	9.817	1.138	< 0.000	12.21	3.401	< 0.000	15.33	4.347	< 0.000
	2017	16.27	4.259	< 0.000	13.31	2.818	< 0.000	9.632	1.254	< 0.000
	2018	17.28	4.422	< 0.000	13.49	2.701	< 0.000	14.95	4.362	< 0.000
HSW (g)	2016	30.79	2.988	< 0.000	29.62	3.794	< 0.000	34.22	1.223	0.918
	2017	33.39	3.334	< 0.000	30.88	3.805	< 0.000	29.89	2.988	< 0.000
	2018	37.94	1.351	0.534	38.71	1.173	0.746	35.28	1.286	0.474
BY (kg.h^{-1})	2016	2170	601.3	< 0.000	2964	529.5	< 0.000	2168	347.7	< 0.000
	2017	3997	876.3	< 0.000	3086	656.8	< 0.000	2452	772.1	< 0.000
	2018	2806	234.4	< 0.000	2367	297.5	< 0.000	2330	502.0	< 0.000
HI (%)	2016	34.14	7.293	< 0.000	29.19	4.366	< 0.000	39.10	3.983	< 0.000
	2017	28.89	4.644	< 0.000	28.52	4.521	< 0.000	27.73	5.853	< 0.000
	2018	49.79	2.157	< 0.000	42.13	4.334	< 0.000	41.95	3.548	< 0.000
GY (kg.h^{-1})	2016	706.8	111.5	< 0.000	848.3	96.83	< 0.000	846.3	167.4	< 0.000
	2017	1126	144.3	< 0.000	857.7	96.89	< 0.000	645.8	111.5	< 0.000
	2018	1399	177.3	< 0.000	992.9	161.1	< 0.000	986.8	272.8	< 0.000

Table 4. Descriptive statistics and genotypic probability level (*P*) under different management in three years. Days to flowering (DF), days to maturity (DM), plant height (PH), biological yield (BY), grain yield (GY), hundred seed weight (HSW), harvest index (HI), pod per plant (PP), first pod formation height (FPH).

Descriptive statistics of genotypes under varied tillage systems during three years showed discrepancy among studied chickpea genotypes considering their agro-morphological performance. As per shown in Table 4, GY as an economic part of chickpea was seen in high values during three years at zero tillage condition (706.8 kg.h^{-1}, 1126 kg.h^{-1}, and 1399 kg.h^{-1}) compared to other ones, specifically the conventional tillage system. As before, HI, BY, and HSW were also detected at higher levels for the zero tillage system (Table 4) albeit minimum tillage had

Model	*P*-value								
	GY	HSW	PH	PP	FPH	BY	HI	DF	DM
REP(ENV)	1.00E+00	1.00E+00	5.28E−03	3.05E−02	6.76E−01	5.60E−01	8.47E−02	1.88E−01	9.95E−01
ENV	1.03E−24	8.16E−18	5.12E−11	1.87E−16	1.89E−07	1.08E−20	5.54E−18	5.45E−05	3.27E−07
GEN×ENV	6.27E−139	8.68E−28	3.99E−55	4.37E−-132	7.56E−63	6.13E−143	2.18E−68	3.91E−01	8.95E−10
σ_p^2	25,852	9.21	4.22	12.1	3.2	339,228	25.9	3.8	6.9
GEIr2	0.823	0.407	0.735	0.661	0.584	0.81	0.735	0.0437	0.297
h2mg	0.567	0.818	0.198	0.796	0.779	0.606	0.49	0.404	0.622
Accuracy of selection	0.753	0.904	0.445	0.892	0.883	0.778	0.7	0.635	0.789

Table 5. Deviance analysis, estimated variance components and genetic parameters for agro-morphological traits of Chickpea. h^{2}mg, heritability on the mean basis; σ_p^2, phenotypic variance; GEIr2, the coefficient of variation for GEI effects. days to flowering (DF), days to maturity (DM), plant height (PH), biological yield (BY), grain yield (GY), hundred seed weight (HSW), harvest index (HI), pod per plant (PP), first pod formation height (FPH).

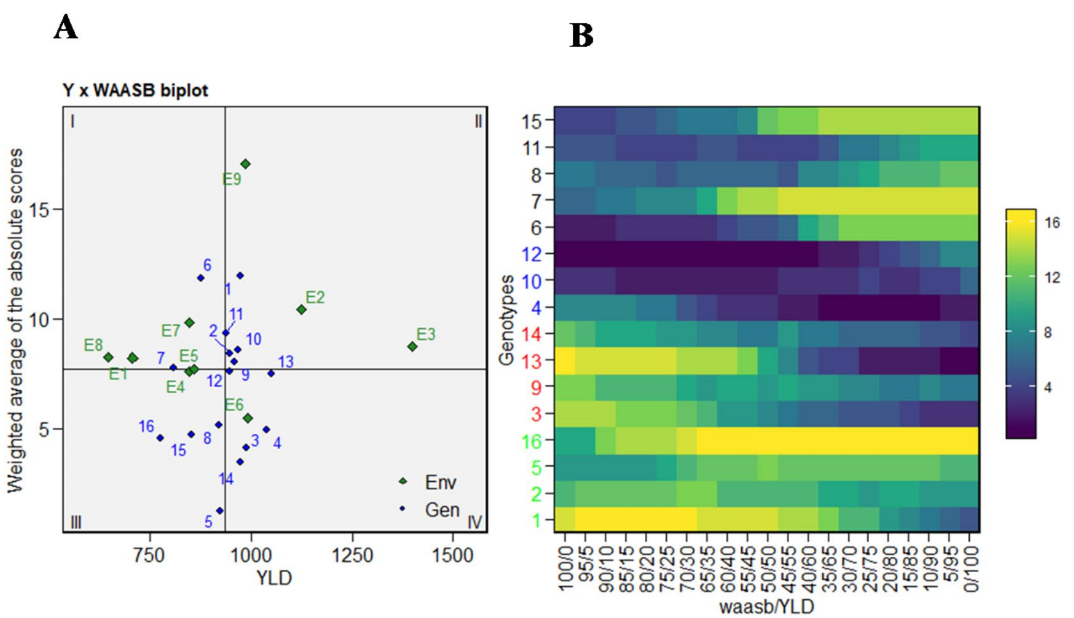

Fig. 2. Yield × WAASB biplot (A) and Heatmap (B) for GY as responsible variable across 9 environments.

intermediate values. Interestingly, phenological characters (DM, and DF) (Table 4) of chickpea genotypes were not affected significantly by tillage systems. The highest mean of PH and PP were observed under zero tillage and conventional system (Table 4). Regarding Table 4, conservation systems as well as conventional tillage have no effect on FPH in chickpea.

Grain yield stability of Chickpea genotypes across studied tillage systems

Varied agro-morphological response of genotypes into tillage systems during several years is a prerequisite for further analysis to detect superior chickpea genotypes with high yielding as well as stable performance across environments (tillage systems × years). In this regard, mixed model analysis of variance has also shown significant interaction for interaction of genotype × environment (year × tillage systems) for overall traits except of DF (Table 5). Regarding calculated statistics through REML (Table 5), high level of phenotypic variability and broad-sense heritability were observed for the majority of traits. Also, the genotypic accuracy of selection (AS) (Table 5), which measures the correlation between predicted and observed values, was higher for all measured traits. The coefficient of determination for genotype environment interaction (GEIr2) (Table 5) also showed the existence of GEI for recorded traits of chickpea.

In the following, by utilizing GY as responsible variable against WAASB values (Fig. 2A and B), the chickpea genotypes with stable performance were distinguished. In the biplot of GY×WAASB (Fig. 2A), the first quarter is an indicator of unstable as well as low yield genotypes and environments, so G6, G7, and G11 deal with E1, E5, E7, and E8 were recognized. Similarly, the heatmap concerned with GY (Fig. 2A) also showed low mean values for the above-mentioned environments. In the second quarter, genotypes G1, G2, G9, G10 and G11 had a higher average performance than the overall average performance, but they had low WAASB values (Fig. 2A).

This means that E2, E3, and E9 (Fig. 2A) are good discriminators for genotypes like those located in quarter two. Here, some genotypes, such as G5, G8, G15, and G16 had poor GY but were stable (quarter three). As shown in Fig. 2A, genotypes G3, G4, G12, G13, and G14 with low values of the WAASB stability index as well as high GY could be considered the best ones, and environment E6 plays a key role in distinguishing these genotypes from other ones.

To customize the magnitude of stability index and yield performance in identifying interest genotypes, plotting WAASB values against the responsible variable (WAASBY) was done regarding several weights for each WAASB and yield across test environments (Figs. 2B). Accordingly, a change in the ranking of genotypes considering the weight of GY trait and the stability index (WAASB) was presented (Figs. 2B). In the first column on the left side (Figs. 2B), the ranking of genotypes based solely on the WAASB index (0/100) indicated that G12 is the most stable genotypes for GY. In the last column on the right side, the rankings of genotypes were based solely on grain yield (100/0), making G4, and G13 as the most superior genotypes regarding GY. By ranking the genotypes based on the equal weight for stability and the responsible variable (GY) (Fig. 2B), genotypes G4, G10, and G12 could be selected, which are similar to the ranking of genotypes in Figs. 2A.

The GGE-biplot analysis was done to identify suitable chickpea genotype for each environment (Fig. 3). According to GGE-biplot analysis, two first components explained 75.7% of total variation. As illustrated in Fig. 3, the specificity analysis for each environment (year × tillage system) (Fig. 3) clarified that in E1 (zero tillage in year 2015–2016) and E2 (zero tillage in year 2016–2017) the genotype G1 was the superior genotype with high yielding. In the state of minimum tillage (E4, E5, and E6) (Fig. 3), G1 was selected as the suitable genotype in years 2015–2016 and 2016–2017. Among studied genotypes, G4, and G13 were the highly productive genotype in the conventional tillage system regardless of years of study. These genotypes (G4, and G13) were also detected as desired genotype in the third year of experiments with both zero tillage and minimum tillage.

Ranking of studied chickpea genotypes was done by implementing of GGE-biplot analysis (Fig. 4A). The results showed that, compared with the "ideal" genotype (which represented by the small circle with an arrow pointing to it and having the highest yield in all environments) the genotypes could be ranked based on their distance from the ideal genotype. Accordingly, G4 and G13 were found to outperform the other genotypes. In addition, through GGE biplot, the "ideal" environment (Fig. 4B) is used as the center of a set of concentric lines that serve as a ruler to measure the distance between an environment and the ideal environment. It results that E3 is the closest to the ideal environment, and, therefore, is most desirable of all 9 environments. Moreover, a polygon view of biplot (Fig. 4C) showed the joining of G1, G4, G6, G7, G11, G13, and G16 together, which are also located farthest from the biplot origin. In this polygon biplot (Fig. 4C), the perpendicular lines to the sides of the polygon divide the biplot into sectors. Each sector has a vertex genotype. The vertex genotype is the highest-yielding genotype in all the environments that share the sector with it. Hence, G4, and G13 are suitable genotypes for E3, E6, E7, E9 while G1, and G6 are desired for other environments.

Multi-trait stability measurement
In the process of introducing a genotype for the target environment, the major challenge is multi-trait adaptation of selected genotype(s). So, via simultaneous selection for phenotypic traits, it will be possible to achieve better understanding of the genotype × environment interaction. In addition, crop yield as a dependent variable is correlated with several plant attributes and therefore, besides yield and its stability, it is important to enhance plant superiority based on other characters. In the present study, factor analysis based on measured traits showed that the first four factors explained 78.6% of data variation. After factor analysis, traits FPH, and HI showed the highest impact in the first factor while traits YLD, and BY showed in the second factor (Table 6). In the third factor, traits of PH, and PP, and in the fourth factor traits of HSW, and DM were recognized as significant. Regarding desired selection sense for chickpea under rain-fed region (Table 6), the goals were successfully achieved for all studied traits except for BY, PP, and DM. Results showed that genotype`s rank varies regarding MTSI value (Fig. 5) and genotype with the highest value of the MTSI is in the center and the genotype with the lowest value of the MTSI is located in the outermost circle. It is concluded from MTSI analysis that G8 (Fig. 5) is in the first rank followed by G14, as the most ideal stable genotype.

Discussion
Tillage is an important part of production operations. Tillage operations significantly affect soil fertility as well as all qualitative aspects of circumstances[34]. In this way, utilization of reversible plows for ploughing of soil even without any plant residues is common. As a consequence of such tillage method is increasing soil erosion, decreasing soil moisture supply, depreciation of agricultural machines and so on[35]. The chickpea is one of the most important pulse crops, and is grown in dryland regions in rotation with wheat. It is widely acknowledged that the key to achieving sustainable chickpea farming is to adhere to the principles of conservation agriculture and to sow the crop at the optimal time for the specific geographical location, that is, either in the spring or autumn. In order to achieve this objective, it is essential to have access to genotypes that are resistant to cold and disease. Depending on the region, chickpeas are traditionally planted in the spring. Nowadays, with the expression of cold and diseases-resistant chickpea genotypes[36], it is possible to do early planting in rain-fed regions. As an advantage of early planting, it increases plant yield following an increasing plant growth period.

Despite deficiencies of conventional tillage systems which use reversible plow, it has been applied frequently for preparation of chickpea seed bed in dry-land regions of Iran. So, it is important to introduce a suitable conservation tillage system for such condition. Likewise, it is important to express chickpea genotypes response into tillage system and recognize high yielding as well as stable genotype for the aforementioned state. In this study, conventional tillage operation accompanied with two conservation methods including zero tillage and minimum tillage were implemented in a dryland location across three consecutive years to inspect plant (chickpea) and soil aspects. Our findings showed that tillage operation systems could affect all of the soil properties, in particular

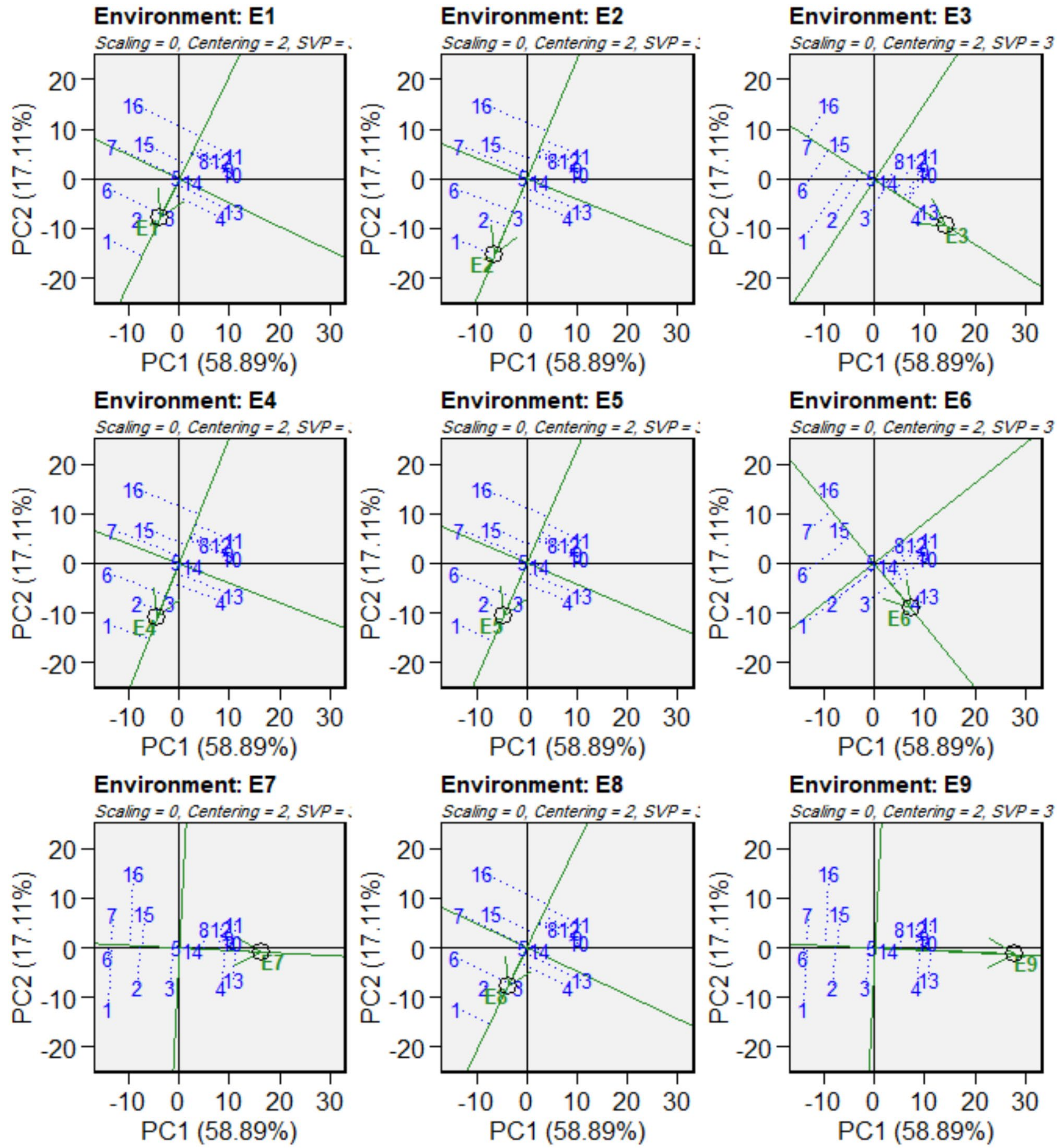

Fig. 3. GGE biplot analysis for depicting highly performance genotypes specific for each environment.

organic carbon, potassium, and soil bulk density which significantly have been impressed during years. As per resulted, soil moisture content of the studied location had been affected by tillage type and was higher in conservation tillage systems (zero tillage and minimum tillage) compared with conventional tillage. This output is controversy the findings of Niu et al.[37] in maize which is reported conventional tillage as treatment with higher level of SM than other tillage operations. In this way, Wang et al.[38] showed that zero tillage has a positive effect on SM. It is notable that the present study was done in rain-fed conditions and according to Wang et al.[38] discrepancy between the present study and previous findings is expectable.

Regarding water resource limitations in dryland regions, it is expected that tillage treatments containing crop residues were all significantly higher than those without mulch, which is consistent with the results of[39]. In this regard, it is proven that, mulching can reduce soil moisture evaporation to some extent[40], enhance precipitation harvesting[41], and increase soil moisture infiltration, and finally lead to improving soil moisture content and

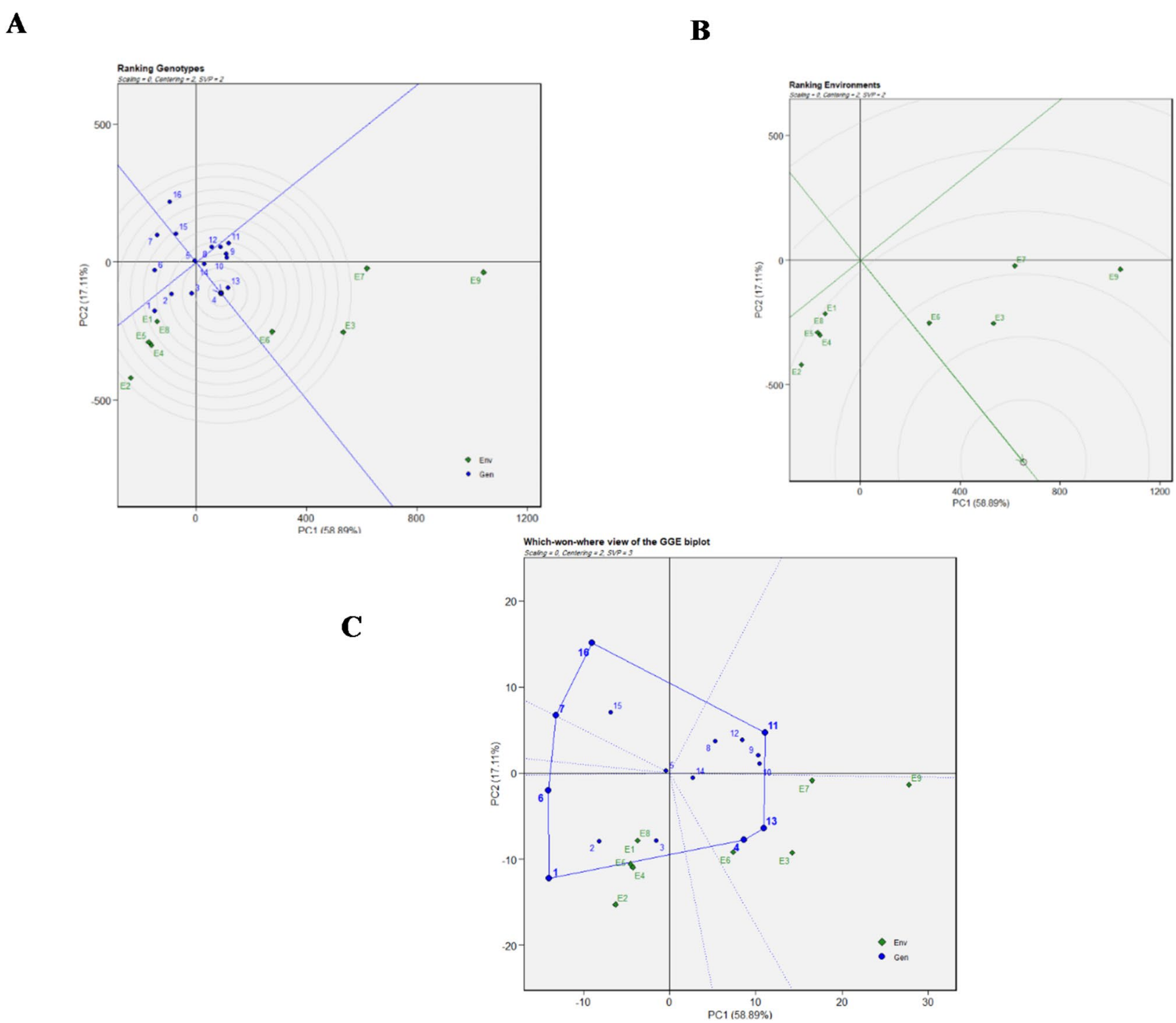

Fig. 4. Ranking of studied genotypes (A), environments (B), Which-won-where (C) regarding chickpea's grain yield.

VAR	Factor	Xo	Xs	SD	Sense	Goal
FPH	FA1	14.5	15.2	0.706	Increase	100
HI	FA1	35.7	36.4	0.651	Increase	100
YLD	FA2	934	948	13.3	Increase	100
BY	FA2	2704	2621	− 83.8	Increase	0
PH	FA3	25.6	25.8	0.155	Increase	100
PP	FA3	13.6	11.3	− 2.27	Increase	0
HSW	FA4	33.4	34.8	1.32	Increase	100
DM	FA4	265	266	0.655	Decrease	0

Table 6. Prediction of selection differential for studied traits based on MTSI index.

moisture use efficiency[42].Likewise, the plant residues can form a physical barrier to block solar radiation, which can regulate soil temperature and facilitate plant root growth and moisture nutrient uptake[38]. Our results showed that conservation tillage systems specifically zero tillage could increase OC of soil and this issue indirectly could improve the water retention of the soil[43] which plays instant role in dryland agriculture. As inferred from soil characteristics, the N, P, and K nutrients were preserved in the highest values when zero and minimum tillage while, conventional tillage had maximum value of soil bulk density. Several researchers[44,45] emphasized on

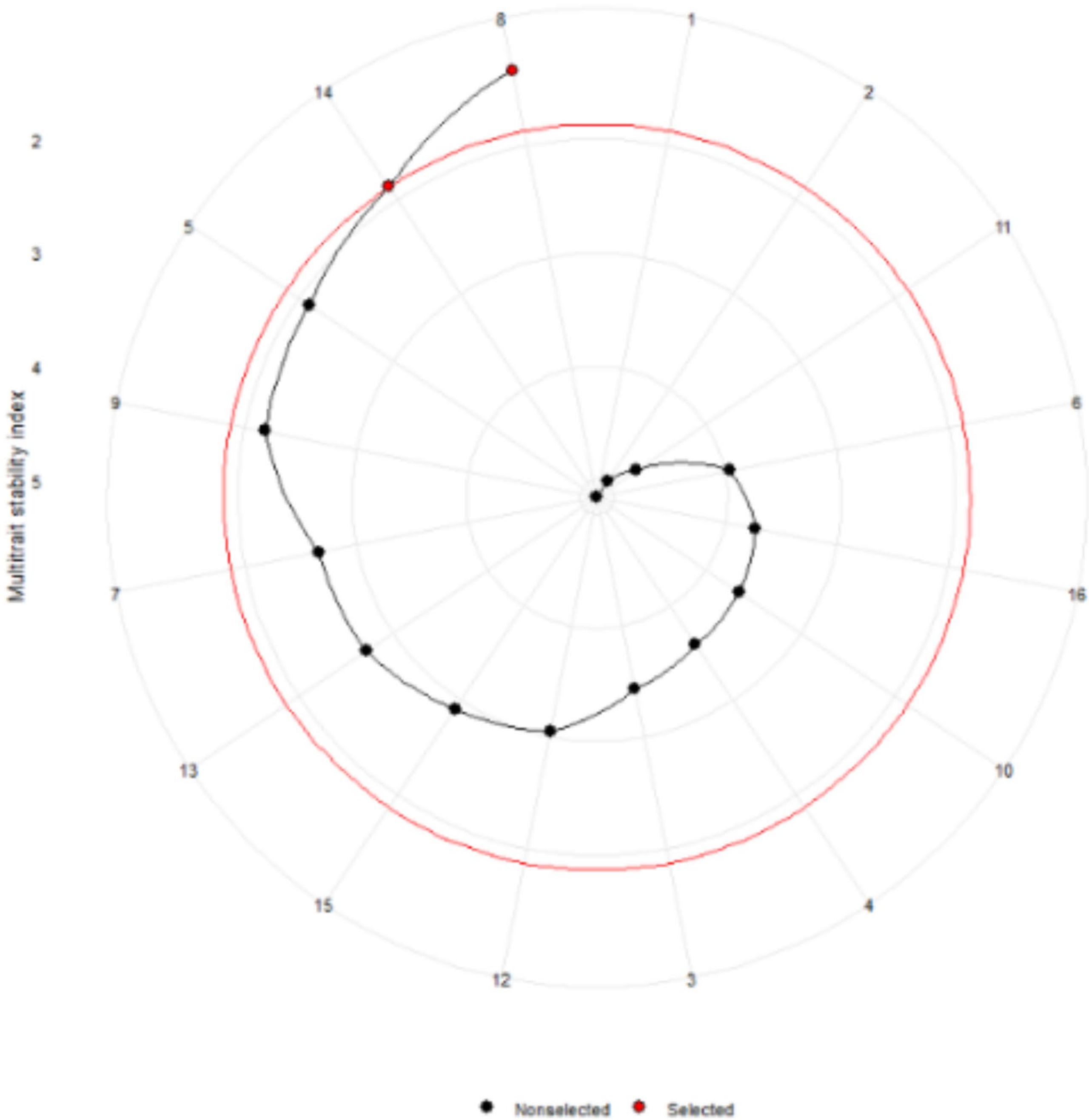

Fig. 5. Chickpea genotypes ranking based on the multi-trait stability index. Selection intensity of SI = 15 is selected. Genotypes out of red circle have the highest ranks.

higher BD in conventional tillage system and obviously the hardpan in conventional tillage[45] is major reason for this issue.

Our findings also showed that the tillage systems could affect chickpea agro-morphological traits beside the soil properties. In this regard, various genotypes had divergent morphological and phenological reactions in response to tillage operation. Similarly, diverse response of plant species such as wheat[45], barley[36], maize[37], and chickpea[14] into tillage systems was proven earlier. So, although the identification of the desired tillage system is vital in rain-fed conditions, significant genotype × tillage effect makes it mandatory to introduce chickpea genotype well adopted to each environment (tillage treatment) or even overall test environments. Here, for meticulous screening of chickpea genotype which possess high yielding and also stable in studied tillage systems, the yield based as well as multi-trait stability[9] criteria were applied. In this study, WAASB analysis was performed to identify stable genotypes based on GY×WAASB biplots. The WAASB method has been successfully applied in several field crops but there are few reports about its usage in chickpeas[9]. However, our findings showed that Y×WAASB biplot could distinguish adaptable and stable genotypes of chickpea. Accordingly, the genotypes

G3, G4, G12, G13, and G14 out of the studied chickpea genotypes were identified as high - yielding and stable ones. Since simultaneous evaluation of yield and yield stability[31] is very important in multi-environment trials, ranking genotypes based on different weights of the yield and WAASB (WAASB/Y heatmap) can be more useful. Here, by assuming equal weights for both yield and stability index, the G4, G10, and G12 had the best ranks for grain yield, but a plant breeder could designate differing weights for either yield or stability index through the key ability of WAASB analysis[29]. In this study, compared to stability, the grain yield of genotype was more desired, and so, considering higher weights for yield versus stability, genotypes G4, and G13 were chosen. Through inspection of specific yield performance of genotypes in each tillage system across years using GGE biplot, G4, and G13 resulted as suitable genotype in the majority of tillage × year combinations. Therefore, the recognized genotypes could be used as promising genotypes in the aforementioned dryland region even with all soil bed preparation. Another application of the GGE biplot driven graphs is to identify environments which are calculated as ideal genotypes for achieving a desired trait[32]. In this way, our results depicted E3 (zero tillage in third year of study) as the best one. To sum up, ideal environment influencing grain yield of chickpea is selected and genotypes possessing higher grain yield and stable are chosen but it is notable that varietal recommendations would be more reliable if they were based on the mean performance and stability of multiple agronomically desirable traits[29]. For this reason, multi-trait stability was done through MTSI index. Finally, G8, and G14 were win that G14 also had a yield higher than the average yield (Figs. 2A). According to Maleki et al. (2024), G14 is a promising genotype for planting in studied dryland regions regardless of tillage system. Likewise, regarding positive selection differential for majority of the studied traits[46], the selection intensity is effective.

Conclusion

It is evident that CA alters the soil properties. This is corroborated by the findings of the present study, which illustrate an improvement in the physicochemical attributes of the soil within the CA system. Consequently, the breeding of crop varieties optimized for CA systems has not constituted a significant area of focus, and cultivars developed for conventional systems may not be suitable for CA environments. It thus follows that the development of new cultivars adapted to CA conditions is required. The results of this study indicate that certain chickpea genotypes exhibit a positive interaction with tillage systems. Genotypes G4, G13 and G8 demonstrated a positive interaction with conventional tillage, whereas genotypes G1, G2, G4 and G13 exhibited the highest performance under a conservation agriculture system. The genotypes were then ranked according to their stability parameters and grain yield, with G1, G8, and G14 identified as the most promising. In particular, genotype G14 was identified as a promising genotype for all systems in dryland regions, based on both the MTSI index and the genotype-by-yield × trait approaches. The findings of this study indicate that chickpea genotypes cultivated under the ZT system demonstrated superior performance (41%) in comparison to those grown using conventional tillage practices during the third year. Consequently, under dryland conditions in the cold and temperate areas of northwest Iran, chickpea growers can utilize commercial and novel chickpea varieties without concern for yield reduction in the initial years of CA implementation.

Data availability

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

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Competing interests
The authors declare no competing interests.

Additional information

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