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Agronomic Performance of Rainfed Barley Genotypes under Different Tillage Systems in Highland Areas of Dryland Conditions

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Abstract: Conservation agriculture (CA) is becoming increasingly attractive to farmers due to advantages such as lower production costs and less destruction of soil structures compared to the conventional tillage. The cultivars introduced for the conventional systems may not be suitable under CA environments, and newly adapted cultivars need to be developed. Accordingly, four separate field experiments were conducted over two cropping seasons (2018–2019 and 2019–2020) to study the agronomic performance of seven barley genotypes under three tillage systems: conventional tillage (full tillage with residue removed), reduced tillage (chisel plowing with residue retained) and CA system (no tillage with residue retained on soil surface). The genotypes were grown under rainfed conditions in two different agro-ecological regions (Kamyaran and Hosseinabad locations) in the west of Iran. Significant genotypic differences were observed for grain yield and yield components except 1000-kernel weight. The results of this study showed that rainfed barley genotypes under a CA system produced yields equal to, or better (0.7%) than, the conventional tillage; while reduced tillage system decreased their performance by 4.9%. Regarding genotype × tillage interaction, the barley genotypes Catalhuyuk 2001 and Bulbule positively interacted with conventional tillage and showed higher performance than other genotypes, whereas genotypes Çumra 2001, Ansar and Abidar expressed highest performance under CA system. Consequently, genotypes Bulbule, Catalhuyuk 2001 and Gumharriyet 50 outperformed the domestic performance and the amount of grain yield and showed the highest adaptation to the tested environments. The results of the present study could be useful to improve the efficiency of a CA system in rainfed cultivation of barley and open new windows for the cereal production in arid and semi-arid regions with food security concerns.

Keywords: conservation agriculture; cold and temperate semi-arid regions; genotype × tillage interaction; barley

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1. Introduction

Feeding the growing population of the world and protecting the environment are challenges of modern-day agriculture [1]. Among different agricultural management practices, tillage has significant impacts on agroecosystems, crop production and the environment [2]. Crop yields have steadily increased over the past century in countries such as Australia, Brazil, United States, etc., because most farmers have achieved attainable yields by using improved cultivars and better crop management technologies such as zero-tillage (ZT), where crops are cultivated early in the season with minimal soil disturbance and storage of shredded material [3–8]. In recent decades, conservation agriculture (CA) has received a lot of attention with the aim of sustainable production of agricultural products. Several studies have been conducted comparing ZT with the conventional tillage (CT) method in West Asia. In a two-year study in Lebanon, Yau et al. (2010) reported that the effects of tillage varied by year and crop, e.g., grain yield in ZT was higher than CT for safflower in 2005–2006. Similar results were reported for chickpeas in 2005–2006 and for barley and safflower in 2006–2007, and lower yields for chickpeas in 2006–2007. In a three-year study in Iran, Hemmat and Eskandari [9] reported an increase of 27% and 24% in yields under ZT compared to CT for wheat and chickpea, respectively. Breeding programs are based on CT systems and most of them breed new cultivars for CT, so the yield of different cultivars is little known under CA [10]. For example, during the last two decades, 50 cereal varieties (30 bread wheat, 7 durum wheat and 13 barley varieties) were introduced by the Dryland Agricultural Research Institute (DARI) for different climate conditions of Iran, all of which were recommended for CT systems. Agriculture based on crop production without tillage is becoming common in both irrigated and rainfed environments. However, limited research has been conducted in farmers' fields for selecting genotypes adapted to no-tillage systems [11]. Thus, selected genotypes must meet not only productivity criteria, but also physiological characteristics for better stability, which are characterized by yield stability, soil quality and resilience to reduce unpredictable variation of changing climate [12]. In addition, CA is becoming increasingly attractive to farmers because it clearly reduces production costs compared to CT [13,14]. This crop management approach has been widely adopted worldwide as an effective approach to reduce the negative effects of soil erosion, environmental pollution and greenhouse gas emissions [15,16].

Barley (*Hordeum vulgare* L.) is one of the main cereal crops that ranks fourth (after wheat, rice and maize crop) by production and fifth by cultivation among cereals throughout the world, accounting for about 47 million hectares with an average grain yield of 3135 kg/ha [17]. In Iran, with an arid and semi-arid climate and average rainfall of less than 250 mm, barley is ranked as the second most abundant crop after wheat and is grown in about 1.5 million hectares—a total of 53% under rainfed (with an average grain yield of 1297 kg/ha) and 43% under irrigated conditions—and is mostly grown under CT systems in rotation with wheat, fallow or legumes [18]. CT involves two or three tillage operations before planting, with different types of ploughs and harrows (boards, discs, duck stands or chisels), and in some cases it may lead to a delay in planting by 3–4 weeks after the first effective rainfall in autumn.

Conservation agriculture-based crop management technology, however, is not common practice in most part of the dryland areas in Iran, and due to some of its advantages: low production costs, improving soil's physical, chemical and biological properties, and decreasing soil and water erosion—being more environmentally friendly—it has been recently promoted by government and well adopted by farmers. However, little is known about the response of several crop genotypes, including barley, under different tillage systems. Therefore, the main objectives of this study were to (i) investigate the effects of different tillage systems on the agronomic performance of barley genotypes on farmer's fields in highland dryland areas in the West of Iran and (ii) identify the superior genotypes in terms of high mean yield and stability performance for the recommendation of the cultivation of barley genotypes in the region. There is no study taking the tillage system into consideration as an environmental factor; therefore, the present study could be referred to as a pioneer in breeding for different tillage systems in barley. Taking the rainfed condition into account shows that the current study is the first among all other studies on different crops, considering the tillage system and water shortage condition together as an environmental factor to assess the genotype $\times$ environment (G $\times$ E) interaction and introduce strategies for breeding programs in such conditions. We hypothesized that the interaction of barley genotypes × tillage systems would be different in terms of grain yield and some genotypes would perform better under a CA system.

2. Materials and Methods

Seven winter barley genotypes, including two new cultivars and five promising breeding lines (Table 1) were evaluated under three tillage systems, i.e., conventional tillage (CT; full tillage with residue removed), reduced tillage (RT; chisel plowing with residue cover) and conservation tillage system (CA; no tillage with residue retained on soil surface) in farmer's fields in two locations of Kamyaran (34°49′ N; 46°57′ E; 1531 m a.s.l.) and Hosseinabad, Jebrilan village (35°10′ N; 47°30′ E; 1852 m a.s.l.), Kurdistan, Iran, for two cropping seasons 2018–2019 and 2019–2020.

Table 1. The code, name, type and origin of winter barley genotypes in the study.

Code	Name	Year of Released	Origin	Growth Habit	Row Type
G1	Abidar	2005	ICARDA	Facultative	Two
G2	Ansar	2014	ICARDA	Facultative	Two
G3	BKF magueione	promising line	Turkey	Facultative	Two
G4	Bulbule	promising line	Turkey	Facultative	Two
G5	Catalhuyuk 2001	promising line	Turkey	Facultative	Two
G6	Gumharriyet 50	promising line	Turkey	Facultative	Two
G7	Çumra 2001	promising line	Turkey	Facultative	Two

The experiments were set up as strip-plot (split-block) arrangements in randomized complete block design with three replications of two horizontal (tillage systems) and vertical (genotypes) factors. Each plot consisted of 13 rows with 20 m length and 17 cm inter-row spacing (plot size = 44.2 m^2). RT treatment was perfomed by a stubble cultivator (Chisel) at a depth of 10–15 cm immediately after the harvesting of the last crop (chickpea in Kamyaran and vetch in Hosseinabad), while CA consisted of direct seeding. Residues were not removed in both locations. CT has been conducted by moldboard in a depth of 20–25 cm followed by two times of harrow by a disc in the depth of 10 cm. Changing from CT to CA has begun from the two last crop seasons in these locations. Barley–chickpea and barley–vetch were two cropping cycles in Kamyran and Hosseinabad, respectively. A no-till drill, Askeh-2002, was used for sowing in the three systems. Seven winter barley genotypes, including released and breeding lines, were seeded in both locations in autumn and harvested in late June in Kamyaran and the mid of July in Hosseinabad. Except for Ansar (new introduced cultivar), all genotypes originated from Turkey. Sowing rate was 350 and 450 seed per square meter in Kamyaran and Hosseinabad, respectively. More information on test environments is given in Table 2. Weeds were controlled and managed by herbicide of U 46 combi fluid (2,4-D) 2 L/ha at tillering stage and hand weeding when required. Fertilizers were used at rates of 60 kg N/ha (N_{40} at planting and N_{20} as top dressing) and 50 kg P_2O_5/ha at the time of planting. Soil sampling had been conducted to analyze the organic carbon in each season before planting.

During the growing season, in addition to grain yield, several agronomic traits for each genotype in each plot were recorded. Plant height (cm), number of grains per spike (grain/spike), number of spikes per square meter (spikes/m^2) and 1000-kernel weight (g) were recorded for each genotype. Grain yield was measured as kg per plot, and then converted to yield per hectare (kg/ha).

Combined analysis of variance was performed using MSTAT-C software (Michigan State University, East Lansing, MI, USA) for grain yield and other related traits. Year and replication were treated as random and genotype and tillage systems as fixed effect; accordingly, the F-tests were applied.

Table 2. Description of tillage systems, locations and years.

Environment				Previous Crop	Practice Management	Sowing Date	Soil Properties					Rainfall (mm)
Cropping Season	Location	Tillage System	Code				Organic Carbon (%)	Potassium (ppm)	Phosphorous (ppm)	Nitrogen (%)	Soil Texture	
2018–2019	Kamyaran	CA [1]	Y1KCA	Chickpea	No-till with residue retained	27 October 2018	0.79	363.7	7.5	0.11	Clay-Loam	
		RT [2]	Y1KRT	Chickpea	Chisel plowing with residue retained		0.78	373.3	8.3	0.1	Clay-Loam	869.3
		CT [3]	Y1KCT	Chickpea	Plowed with moldboard and disked with residue removed		0.82	363.4	8.46	0.13	Clay-Loam	
	Hosseinabad	CA	Y1HCA	Chickpea	No-till with residue retained		0.29	210.1	1.84	0.09	Clay	466.5
		RT	Y1HRT	Chickpea	Chisel plowing with residue retained	12 October 2018	0.48	239.1	1.52	0.09	Clay	
		CT	Y1HCT	Chickpea	Plowed with moldboard and disked with residue removed		0.35	200.8	1.28	0.1	Clay	
2019–2020	Kamyaran	CA	Y2KCA	Chickpea	No-till with residue retained		0.81	421.1	6.12	0.11	Clay-Loam	
		RT	Y2KRT	Chickpea	Chisel plowing with residue retained	24 October 2019	0.78	370.1	7.3	0.11	Clay-Loam	467.5
		CT	Y2KCT	Chickpea	Plowed with moldboard and disked with residue removed		0.82	351.4	8.01	0.13	Clay-Loam	
	Hosseinabad	CA	Y2HCA	Chickpea	No-till with residue retained		0.33	305.1	2.8	0.1	Clay	
		RT	Y2HRT	Chickpea	Chisel plowing with residue retained	10 October 2019	0.5	267.7	3.04	0.1	Clay	396.3
		CT	Y2HCT	Chickpea	Plowed with moldboard and disked with residue removed		0.35	277.8	2.24	0.1	Clay	

[1] Conservation agriculture. [2] Reduced tillage. [3] Conventional tillage.

A mean comparison analysis using the least significant difference (LSD) test at the 5% level of probability was applied to find significant differences among treatments. The GGE biplot methodology [19] was also applied to investigate G × E interaction for grain yield and traits studied of genotypes across different environments. The analyses were performed utilizing the R software with the GEA-R package [20].

3. Results

3.1. Climatic Conditions

The amount and monthly distribution of precipitation varied in location and year (Figure 1). The precipitations recorded were 869.3 and 467 mm at Kamyaran and Hosseinabad in 2018–2019, and 467.5 and 396.3 mm in 2019–2020, respectively. For a barley crop with a reasonable grain yield, 400 mm is adequate, but most of the precipitation received in winter and was not effectively used by crops. Although precipitations during growing seasons exceeded or was around the long-term annual average, crops experienced severe terminal drought due to a deficiency of rainfall coinciding with high temperature during the grain filling period (Figure 1). The average temperatures in 2018–2019 and 2019–2020 in Kamyaran were 10.8 °C and 10.9 °C, respectively; and in Hosseinabad it was 7.8 and 6.2 °C, showing that the crops in Hosseinabad experienced more severe cold conditions during two seasons than in Kamyaran. However, in this study, drought stress was the most important limiting factor of barley crop productivity, as both water shortage and high temperature were happened at the stage of grain filling.

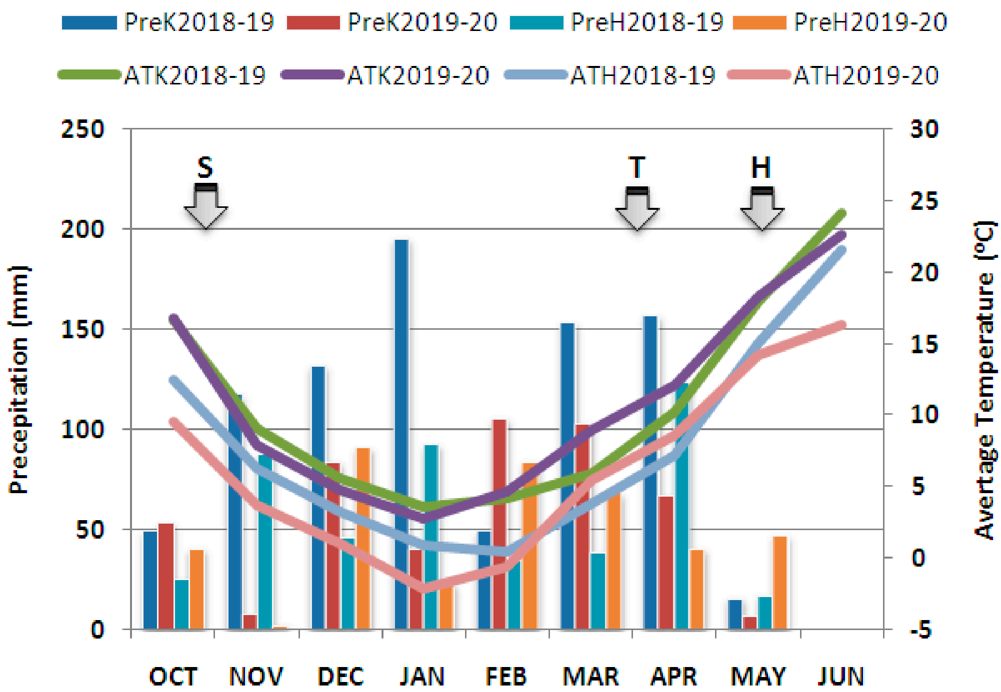

Figure 1. Monthly rainfall distribution and average temperature during the experiments. PreK: precipitation at Kamyaran: PreH: precipitation at Hosseinabad; ATK: average temperature at Kamyaran; and AVH: average temperature at Hosseinabad; S: sowing; T: tillering; H: heading date.

3.2. ANOVA and Partition of Variance for Studied Traits

The genotypes were significantly ($p < 0.01$) differed for grain yield, spikes/m^2, plant height and grains/spike ($p < 0.05$). No significant difference in tillage systems was observed for the grain yield and related traits (Table 3). The tillage × year, tillage × location and tillage × location × year interaction effects were found to be significant ($p < 0.01$) for grain yield, 1000-kernel weight and plant height. The year effect was significant for the grains/spike ($p < 0.01$), spikes/m^2 ($p < 0.01$) and 1000-kernel weight ($p < 0.05$). All components of G × E interaction (genotype × year, genotype × location and genotype × location × year) were found to be significant for grain yield and spikes/m^2. The genotype × location effect was the main contributor (63.7%) of grain yield variation, followed by location (4.62%) and genotype × year (2.75%) effects. For 1000-kernel weight, the genotype × location effect (20.8%), year (10.3%) and genotype × location × year (7.8%) accounted for highest variation; while for number of grain/spike, the year (37.9%) followed by location (7.5%) and genotype × year (6.2%) were recorded for highest variation. In the case of spikes/m^2, location × year (43.5%) followed by the year (24.7%) and tillage × year (2.7%) effects contributed to the highest variation. For plant height, the traits with the highest variation were location × year (26.6%) followed by location (16.8%) and genotype (8.3%) effects. These results show that the impact of treatments on genotypic performance varied from one trait to another, confirming the high fluctuations in environmental condition in the Mediterranean dryland areas (Table 3). The effect of tillage systems was significant on barley genotypes characteristics when interacting with environmental location and year parameters (Table 3).

Table 3. Combined analysis of variance for studied traits across tillage, location and years.

Source			df	Grain Yield		1000-Kernel Weight		Grains/Spike		Spikes/m^2		Plant Height	
	MS	EMS		MS	%VE	MS	%VE	MS	%VE	MS	%VE	MS	%VE
Year (Y)	M1	M1/M4	1	3004	0.01	825.1 *	10.3	2294.5 **	37.9	504,377.3 **	24.7	247.0	0.8
Location (L)	M2	M2/M3	1	12,745,803	4.62	448.0	5.6	454.4	7.5	7535.3	0.4	5280.0	16.8
Y × L	M3	M3/M4	1	175,717,400 **	63.69	1666.3 **	20.8	41.6	0.7	888,339.1 **	43.5	8337.5 **	26.6
R/(LY)	M4		8	3,783,966	10.97	78.8	7.9	29.8	3.9	14,993.5	5.9	116.8	3
Tillage (T)	M5	(M5 + M8)/(M6 + M7)	2	338,582	0.25	24.9	0.6	30.1	1	18,224.6	1.8	335.6	2.1
Y × T	M6	M6/M9	2	807,004 **	0.59	22.3 **	0.6	20.8	0.7	27,892.4 **	2.7	431.8 **	2.8
L × T	M7	M7/M9	2	1,195,754 **	0.87	235.4 **	5.9	19.3	0.6	1563.6	0.2	228.4 **	1.5
Y × L × T	M8	M8/M9	2	573,718 **	0.42	244.9 **	6.1	11	0.4	517.2	0.1	353.8 **	2.3
Error	M9		16	79,253	0.46	2.0	0.4	9.2	2.4	979.1	0.8	11.8	0.6
Genotype (G)	M10	(M10 + M17)/(M14 + M15)	6	731,939 **	1.59	49.5	3.7	51.2 **	5.1	4460.5 *	1.3	434.9 **	8.3
Y × G	M11	M11/M17	6	1,264,133 *	2.75	15.5	1.2	62.1 **	6.2	6771.2 **	2	281.9	5.4 *
L × G	M12	M12/M16	6	594,006 **	1.29	32.7	2.4	4.7	0.5	4301.6 *	1.3	172.4 **	3.3
Y × L × G	M13	M13/M17	6	756,989 **	1.65	104.4 *	7.8	22.3 *	2.2	8482.0 **	2.5	132	2.5
T × G	M14	M14/M17	12	45,932	0.2	21.4	3.2	11.0	2.2	1556	0.9	90.1	3.4
Y × T × G	M15	M15/M17	12	68,067	0.3	24.3	3.6	8.6	1.7	927.3	0.5	67.6	2.6
L × T × G	M16	M16/M17	12	191,470	0.83	20.6	3.1	8.1	1.6	1582.6	0.9	70.7	2.7
Y × L × T × G	M17	M17/M18	12	85,829	0.37	23.4 **	3.5	8.1	1.6	1104.1	0.6	91.3 **	3.5
Error	M18		144	175,451	9.16	7.4	13.3	10	23.9	1401.2	9.9	26	11.9 **
Total			251		100		100		100		100		100
CV%				17.1		6.4		15.7		13.1		7.3	

MS: mean square; EMS: expected mean square; df: degrees of freedom; %VE: percentage of variance explained. *, **: Significant at 5% and 1% probability level, respectively.

3.3. *Impact of Tillage, Location and Year on Agronomic Performance of Barley*

Trait performance of genotypes under tillage systems, locations and years showed significant differences (Table 4). The average grain yield in the experiment was 2444 kg/ha, and varied from 1322 kg/ha (corresponding to conventional tillage in Hosseinabad) to 3772 kg/ha (corresponding to conventional tillage in Kamyaran). The highest mean yields were observed under conventional tillage (3772 kg/ha) and conservation system (3651 kg/ha) in the Kamyaran location in 2018–2019, which significantly ($p < 0.05$) differed from other tillage options, while the lowest mean yields were exhibited under three tillage systems in Hosseinabad in 2018–2019. On average, barley genotypes expressed highest grain yield under conservation system (2489 kg/ha), followed by conventional tillage (2471 kg/ha) and reduced tillage (2371 kg/ha), showing only 0.7% higher production under the conservation system compared with the conventional system, while under reduced tillage the production was 4% less than the conventional system.

The 1000-kernel weight varied from 35.0 to 47.7 g under conventional tillage in Hosseinabad and Kamyaran in 2018–2019, respectively. No significant differences were observed between tillage systems in each location (Table 4). No remarkable difference in 1000-kernel weight, on average, was observed among the genotypes in different tillage system. The average number of grains/spike in the experiment was 20 grains/spike and varied between 15 grains/spike under RT and CT in Hosseinabad in 2018–2019 and 24 grains/spike for three tillage systems in Kamyran in 2019–2020. The average number of spikes per square meter in the experiment was 286 spikes/m^2 and varied from 174 spikes/m^2 (corresponding to CT in Kamyaran in 2019–2020) to 413 spikes/m^2 (corresponding to CT in Kamyaran in

2018–2019) (Table 4). The spikes/m^2 showed significant differences under different tillage systems in each location except in Kamyaran in 2019–2020. The average plant height in the experiment was 69.6 cm that ranged from 58.3 cm (corresponding to CT in Hosseinabad in 2018–2019) to 84.9 cm (corresponding to CT in Kamyaran in 2018–2019). In total, the order of tillage system for grain yield of barley genotypes was CA > CT > RT (Table 4).

Table 4. Mean performance of wheat genotypes under different tillage systems and location–year combinations for investigated traits of seven barley genotypes under rainfed conditions. The CA, RT and CT stands for conservation agriculture, reduced tillage and conventional tillage, respectively.

Cropping Season	Location	Tillage	Traits					Location Mean Yield
			Mean Yield	TKW	Grains/Spike	Spikes/m^2	PLH	
2018–2019	Hosseinabad	CA	1412 d	36.6 bc	16 f	288 d	59.1 f	1387
		RT	1428 d	39.3 abc	15 f	246 e	58.6 f	
		CT	1322 d	35.0 c	15 f	296 cd	58.3 f	
	Kamyaran	CA	3651 a	46.2 a	20 e	400 a	82.1 b	3507
		RT	3098 b	39.4 abc	17 f	340 b	70.0 cde	
		CT	3772 a	47.7 a	20 de	413 a	84.9 a	
2019–2020	Hosseinabad	CA	3031 b	45.5 ab	23 abc	300 cd	71.8 cd	3050
		RT	3134 b	45.3 ab	22 bcd	313 c	71.7 cd	
		CT	2986 b	45.3 ab	22 cd	305 cd	72.1 c	
	Kamyaran	CA	1863 c	42.9 abc	24 a	177 f	68.4 de	1830
		RT	1824 c	42.8 abc	24 ab	178 f	70.4 cde	
		CT	1804 c	42.8 abc	24 ab	174 f	69.6 de	
	Mean	Total	2444	42.3	20	286	69.6	
		CA	2489	42.5	20.7	291.4	70.3	
		RT	2371	41.7	19.5	269.2	67.4	
		CT	2471	42.7	20.4	297.1	71.2	
LSD ($p < 0.05$)			184.2	10.24	1.988	20.47	2.52	

Means followed by the same letters within columns are not significantly different at 5% probability level.

3.4. Genotype × Tillage Interaction for Grain Yield and Related Traits

The genotype × tillage-system interaction for grain yield pointed out some changes in the ranking of genotypes under different tillage systems (Table 3 and Figure 2). The highest grain yield was observed for genotype G5 (2577 kg/ha), followed by G6 (2548 kg/ha) under the CT condition; while genotype G3 (2561 kg/ha) followed by G7 (2555 kg/ha) under the CA condition, and G6 (2474 kg/ha) and G5 (2445 kg/ha) under the RT condition, expressed highest performance (Figure 2a). Regarding 1000-kernel weight, Figure 2 shows that the ranking of genotypes was not changed from one system to another. The genotypes G3 (45 g) and G1 (45 g) exhibited the highest 1000-kernel weight across three tillage systems, while genotype G6 (43.4 g) followed by G4 (43.6 g) and G5 (43.7 g) expressed the lowest 1000-kernel weight (Figure 2b). The highest number of grains/spike was recorded for genotype G5 (22 grains/spike) under CA and the lowest number of grains per spike was recorded under RT for genotype G1 (17 grains/spike) (Figure 2c). Number of spikes/m^2 for all genotypes under the RT condition was the lowest (Figure 2d).

The highest number of spikes/m^2 was expressed for all genotypes under the CT condition, except for G6 (284 spikes/m^2), which expressed the highest value under the CA condition (300 spikes/m^2). For plant height, the genotype × tillage interaction was not significant, but some changes in ranking of genotypes were observed (Figure 2e). The genotypes G2 (76.1 cm), G3 (73.8 cm) and G1 (72.1 cm) under the CT conditions expressed highest plant height, while G7 (73.2 cm) and G3 (71.6 cm) expressed highest plant height under the CA condition. The highest grain yield of studied barley genotypes was related to the G3 genotype under the CA condition (Figure 2a).

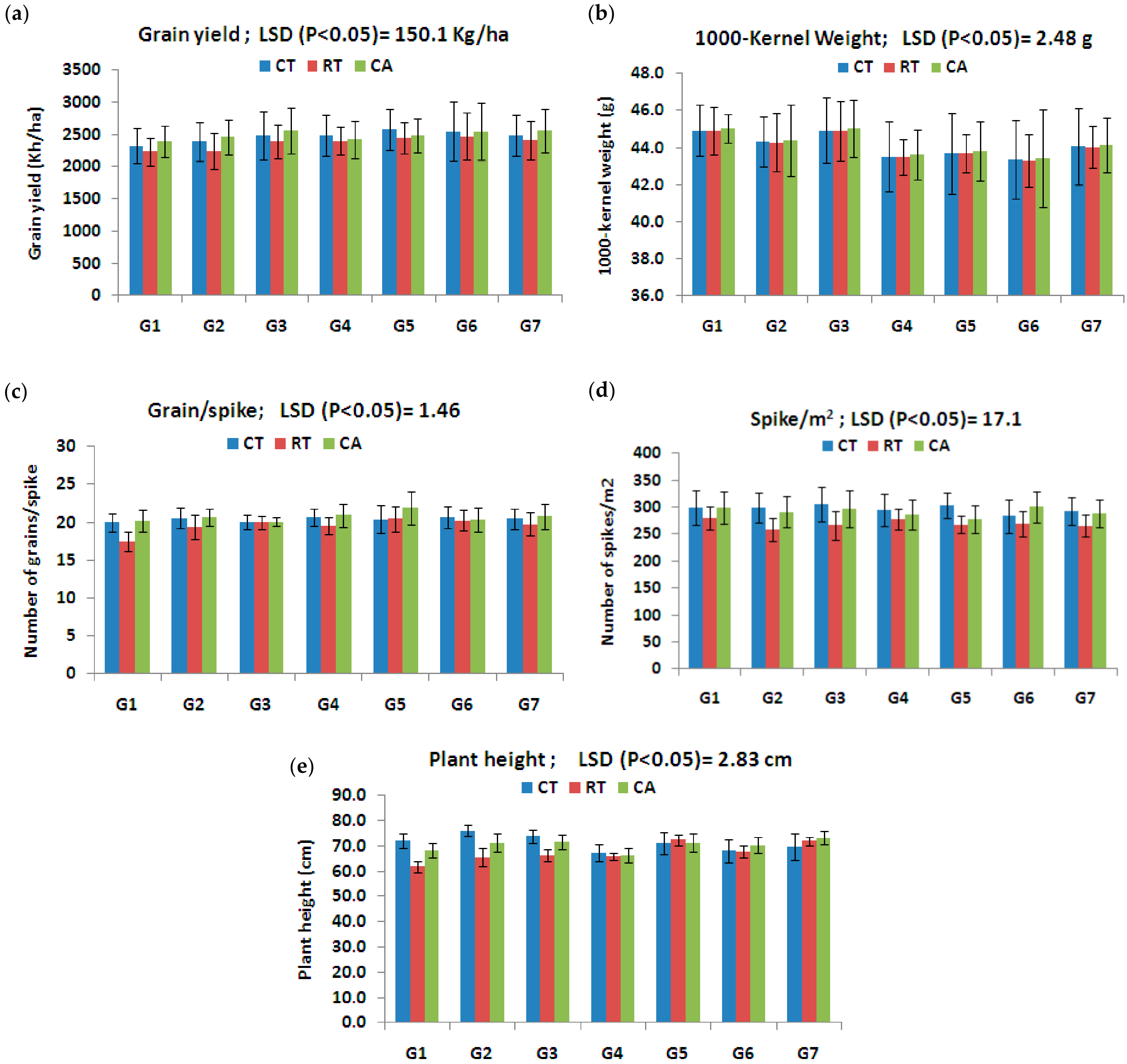

Figure 2. Genotype × tillage interaction for grain yield and related traits of seven barley genotypes (G1–G7) across locations and years. (**a**) Grain yield of barley genotypes under the effects of different tillage systems. (**b**) 1000-kernel weight of barley genotypes under the effects of different tillage systems. (**c**) Grain/spike of barley genotypes under the effects of different tillage systems. (**d**) Spike/m^2 of barley genotypes under the effects of different tillage systems. (**e**) Plant height of barley genotypes under the effects of different tillage systems.

3.5. Mean and Stability Performance of Genotypes

The GGE biplot analysis for grain yield of barley genotypes across 12 environments (combination of tillage systems, locations and years) captured about 67.90% of total variation (Figure 3a). The genotypes were grouped in four sections and environments in three sections. The genotypes G5 expressed the highest performance in environments Y2KRT, Y2KCA, Y2HCT, Y2KCT, Y2KRT, Y1HCT and Y1HRT, while genotype G6 was the best yielded in environments Y1K_CT, Y1KCA, Y1KRT and Y2HCA, and G1 was the best performer in environment Y1HCA.

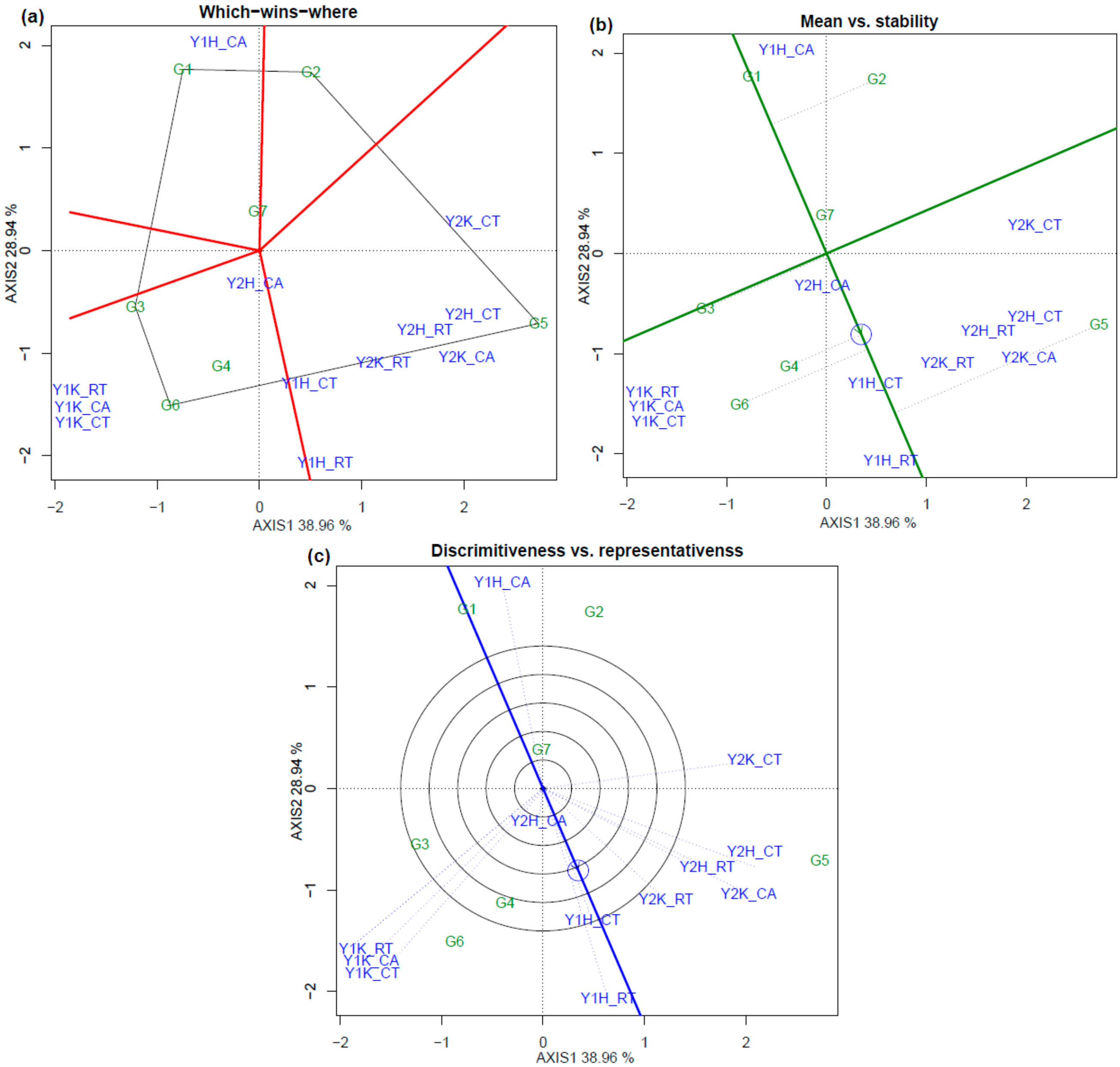

Figure 3. GGE biplot for grain yield of seven barley genotypes (G1–G7) across 12 environments showing (**a**) "which-wins-where" pattern, (**b**) "mean yield vs. stability" of genotypes and (**c**) "discrimitiveness vs. representativeness" of test environments for grain yield.

The evaluation of genotypes for grain yield (Figure 3b) indicated that genotypes G4, G6 and G5 were the best yielding genotypes, as they were positioned on the far right-hand side of the average tester coordinate (ATC). In addition, the biplot indicates that genotypes G5 and G6 expressed a longer distance from the ATC, showing their specific adaptation to particular environments, but G4 possessed a shorter distance, indicating medium stability. The genotypes G7 and G1 expressed highest stability, but with mean yields below the grand mean. The 12 environments clustered into two apparent groups (Figure 3c). Environments Y2KCA, Y2KRT, Y2HRT, Y2HCT, Y2KCT, Y1HRT and Y1HCT were positively correlated due to the acute angles between their vectors. The next group consisted of Y1KRT, Y1KCA and Y1KCT, which were positively correlated with each other and different from another group in genotypes ranking. Y1HRT followed by Y1HCT and Y2KRT were the most representative and discriminating environments that had a small angle with the ATC, whereas Y1KRT, Y1KCA and Y1KCT as well as Y2KCT, Y2HCT and

Y2KCA were discriminating but non-representative test environments. Y2HCA was the least discriminative environment for grain yield. In summary, genotypes G1, G2 and G7 were more adaptive to the CA system.

3.6. Genotypic Traits Performance and Characterization

The GGE biplot for 1000-kernel weight accounted for 69.49% of the total variation. The "which-wins-where" pattern of biplot indicated that genotypes grouped into five sectors and environments into four sectors. Genotype G2 had the highest 1000-kernel weight in environments Y1HCT, Y2KCA, Y2KRT and Y2KCT, as it was placed at the vertex on the section that these environments were positioned (Figure 4a). Genotype G6 followed by G7 and G5 had the highest 1000-kernel weight in environments Y2HCT, Y2HCA and Y2HRT; while G3 expressed highest 1000-kernel weight in environments Y1KCA, Y1KRT and Y1KCT; genotype G1 had the highest 1000-kernel weight in environment Y1HCA; and genotype G4 in environment Y1HRT.

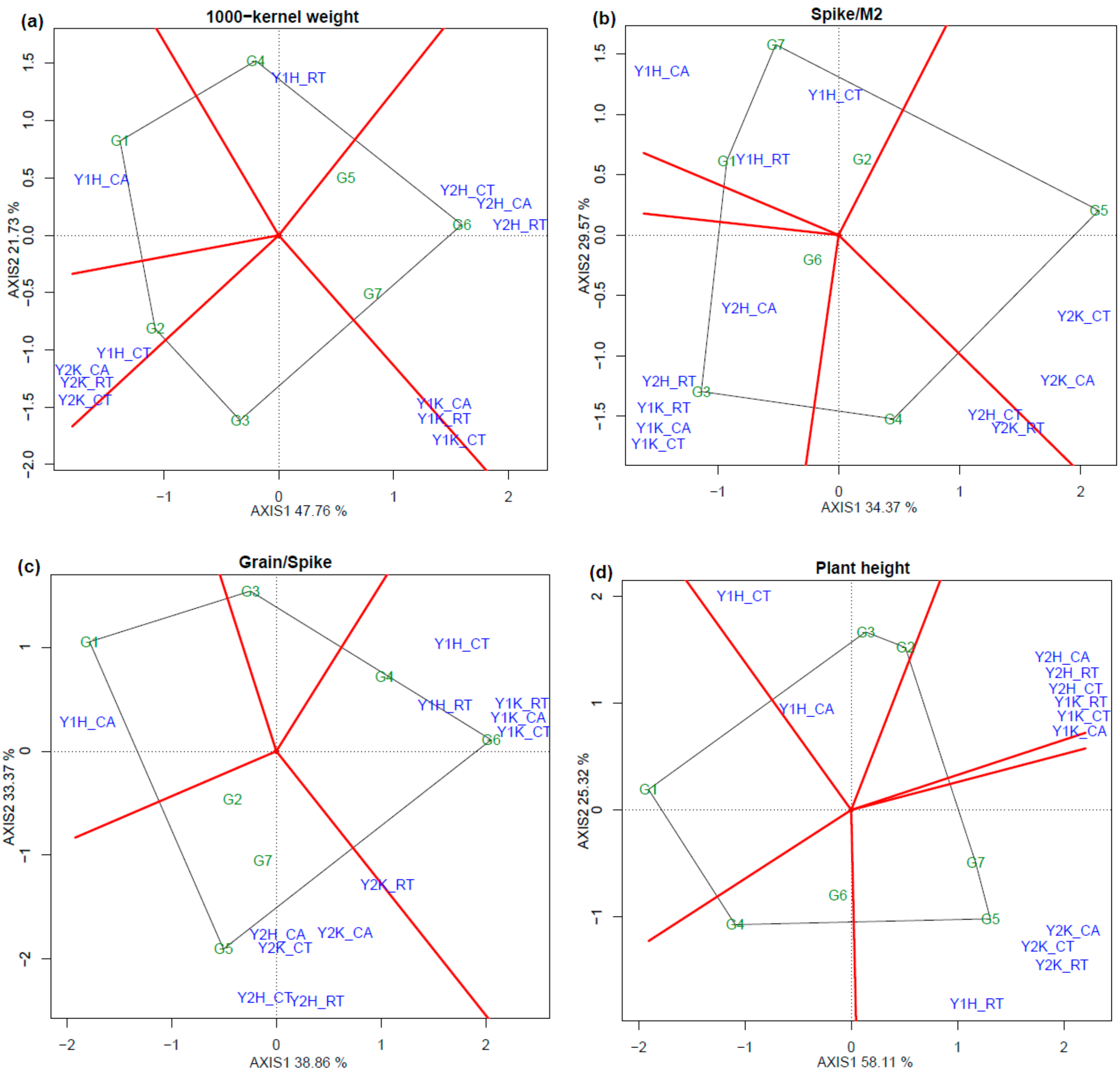

Figure 4. "Which-wins-where" pattern of GGE biplot for (**a**) 1000-kernel weight, (**b**) spikes/m^2 (**c**) grains/spike and (**d**) plant height of seven barley genotypes (G1–G7) across 12 environments.

For the number of spikes/m^2, the biplot captured about 63.94% of the total variation. The 12 test environments were grouped into four sectors and genotypes fell into four sectors (Figure 4b). Environments Y2HRT, Y2HCA, Y1KRT, Y1KCA and Y1KCT classified in the same group with G3 as a winner genotype; and G7 followed by G1 and G2 exhibited the highest number of spikes/m^2 in environments Y1HCA, Y1HRT and Y1HCT.

For number of grains/spike, the biplot explained 72.23% of total variation (Figure 4c). Environments were grouped into three sectors and genotypes fell in four sectors. The genotype G6 expressed the highest grains/spike in environments Y1KRT, Y1KCA, Y1KCT, Y1HRT and Y1HCT; while genotype G5 exhibited the highest in environments Y2HCT, Y2HRT, Y2KCT, Y2HCA, Y2KCA and Y2KRT; and genotype G1 had the highest grains/spike in environment Y1HCA. Similarly, G5 followed by G7 exhibited the highest plant height in environments Y2KRT, Y2KCT, Y2KCA and Y1HRT, while genotype G3 followed by G2 expressed the highest plant height in Y1HCA and Y1HCT; and environments Y2HCA, Y2HRT, Y2HCT, Y1KRT, Y1KCT and Y1KCA were grouped in the same environmental sector with any winner genotype (Figure 4d). In contrast, the genotypes G1 and G4 were placed on the vertices without any environment, showing that they did not express the highest plant height in any environment. In summary, different responses of yield components of the studied barley genotypes to different tillage systems were observed.

3.7. Relationships among the Studied Traits

In barley genotypes, a genotypic positive correlation was observed between the number of grains/spike with grain yield (r = 0.723), while the phenotypic correlation (r = 0.214) was less than the genotypic correlation, indicating the impact of environmental conditions—consisting of tillage systems, location and year—on this correlation. The 1000-kernel weight and spikes/m^2 showed negative genotypic correlation with grain yield but was not supported by corresponding phenotypic correlations. Significantly negative phenotypic (r = −0.83; $p < 0.01$) and genotypic (r = −1.00; $p < 0.01$) correlations were observed between grains/spike and spikes/m^2, indicating that the correlation between these two traits is not mainly affected by environmental conditions (Table 5). A similar trend was observed between plant height and number of spikes/m^2, showing barley genotypes with a lower plant height favored a higher spikes/m^2. In summary, grains/spike and plant height characteristics can be considered as selection criteria of grain yield for the barley genotypes studied under applied tillage systems.

Table 5. Phenotypic (below diagonal) and genotypic (above diagonal) correlation coefficients between grain yield and agronomic traits for seven examined barley genotypes across three tillage systems in two locations and two cropping seasons under rainfed conditions.

Traits	Grain Yield	1000-Kernel Weight	Grains/Spike	Spikes/m^2	Plant Height
Grain yield		−1.00 **	0.723	−0.888 **	0.523
1000-kernel weight	0.034		−0.900 **	−0.102	0.165
Grains/spike	0.214	0.042		−1.00 **	0.775 **
Spikes/m^2	0.110	−0.266	−0.873 **		−1.00 **
Plant height	−0.002	0.904	0.376	−0.495	

** Significant at 1% level of probability.

4. Discussion

In this study, the cropping seasons and locations varied in total precipitation and seasonal distribution as well as average temperatures during growing seasons. This condition provided contrasting crop growth and resulted in a terminal drought stress that coincided with high temperatures during the grain filling period. However, this is a typical phenomenon in Mediterranean environment conditions, including west of Iran [21,22]. Our results confirmed no significant genotype × tillage system interaction for barley genotypes. Weisz and Bowman [23] have reported no significant effect of tillage × genotype interaction. However, this interaction was significant in other reports [24,25]. It seems that one of the main reasons for the lack of significant interaction in this experiment is the small number of the studied genotypes, which is consistent with the findings of other researchers [26,27]. In most breeding programs, CT is common practice, and genotypes are developed under this condition, so many studies failed to detect genotype × tillage interaction [28].

Based on the results, genotypes showed a much lower percentage of superiority in the CA than the CT (0.7%) and RT (4.9%), indicating that the barley genotypes are most adapted to CT or CA systems. Seed preparation is usually performed more accurately in CT than RT because of multiple operations, so the seeds can emerge uniformly. In fact, land preparation is completely related to the type of chisel or moldboard and to soil moisture content. Based on farmer practice, in this study, chisel plowing was used immediately after the harvesting of crops in June and July in Kamyaran and Hosseinabad, respectively, when soil moisture was at least. This led to lump formation and inappropriate crop emergence, and finally lower spikes/m^2 as shown in Figure 2d. Małecka et al. [29,30] reported that spring barley yield is reduced by 8% and 12% under reduced and no tillage, respectively. Similar results have been reported by Martin-Rueda et al. [31], where spring barley yield was 29% significantly higher under conventional tillage compared to reduced tillage.

The equal yields under CA and CT that are reported in this study, considering the advantages in CA, i.e., production costs, is interesting. Usually, yield increase under CA is attributed to improvement in soil properties [32]. This is possible when CA has been implemented for a long time and has caused significant changes to soil's organic matter and other physical and chemical properties of the soil. In this experiment, CA was implemented two years prior, hence it did not significantly affect the soil's organic carbon and other soil properties. In addition, our tested genotypes have been selected and introduced to the CT system from breeding programs and their selection has not been studied under CA. Therefore, there are no distinct traits specifically adapted to the CA conditions [11,28,33]. As suggested by Herrera et al. (2013), to achieve higher yields and to introduce cultivars that respond positively to the tillage system, it may be necessary to select breeding lines under both CT and NT as parallels. However, Honsdurf et al. [34] did not find relevant effects of selection under a given tillage system on the breeding process and final yield of the progenies in CIMMYT durum wheat genotypes, which is in line with our findings.

Most studies that compared the effect of CT and CA on cereal production resulted in conflicting reports that appear to depend on soil type, crop rotation and local climatic conditions [35–37]. In a long-term experiment conducted by Soane and Ball [38] in Scotland, under no-tillage, the grain yield of barley decreased by 9.2% in the first year and in the end year of study the negative response decreased to 4.2%. In another study conducted by Arshad and Gill [39] in barley, an increase in yields of 10% and 12% under reduced tillage and no-tillage conditions compared to conventional tillage, respectively, was obtained in dry years. This superiority in yield under RT and NT may be due to better soil moisture conditions compared to CT [9].

The genotypic and phenotypic correlations indicated that the grain yield of barley genotypes was significantly affected by yield components such as grains/spike, spikes/m^2, 1000-kernel weight and plant height. These results indicate that an increase/decrease in any of these traits may lead to an increase/decrease in grain yield. According to previous studies such as Zahedi et al. [40] and Saed-Moucheshi et al. [41], these results could guide barley breeders to utilize the indirect selection for increasing the performance of barley genotypes. Consequently, since grains/spike and plant height showed the highest positive genotypic and phenotypic correlations with grain yield, they could be used for indirect selection of high-performance genotypes. Although the positive genotypic correlation between grains/spike and grain yield were significant, their phenotypic correlation was not statistically significant. Significant higher genotypic correlation over the phenotypic correlation clearly indicates the impact of environmental conditions—consisting of tillage systems, location and year—on this correlation. Moreover, 1000-kernel weight showed negative genotypic and positive phenotypic correlations with grain yield. Indirect selection for features that are significantly associated with grain yield have been assessed by numerous studies (e.g., [42–44]); however, its application under water shortage conditions as a result of natural environment in barley have rarely been considered.

Using the "mean vs. stability performance" view of GGE biplot, the genotypes Catalhuyuk 2001, Gumharriyet 50 and Çumra 2001, all originating from Turkey, were identified as high-yielding genotypes and Bulbule was closest to the ideal genotype. Subsequently, on the basis of GGE biplot, the Bulbule is considered as the genotype with a high yield and stable performance across the environments; in addition, both of the genotypes Catalhuyuk 2001 and Gumharriyet 50 could be introduced as high-performance genotypes with adaptive capability toward the tested tillage systems as environmental factors. Screening for high grain yield along with yield stability in breeding programs has been considered to be the most important strategy in the selection of adapting cultivars to variable rainfed growing conditions [45–47]. Varied performance of genotypes from one environment to another indicates high genotype by environment interactions. Some previous studies [46,48] reported significant G × E interaction for grain yield and/or its components of barley genotypes, but there is no study taking the tillage system into consideration as an environmental factor; therefore, the present study could be referred to as a pioneer in breeding for different tillage systems in barley. Taking the rainfed condition into account shows that the current study is the first, among all other studies on different crops, to consider the tillage system and water shortage condition together as environmental factors to assess the G × E interaction and to introduce strategies for breeding programs in such conditions. The significant genotype × environment interaction indicates that the environmental factors and their interaction with genotypes plays an important role in determining the performance of genotypes. For example, in the Hosseinabad location, across three tillage systems, the barley genotypes expressed the lowest productivity in 2018–19 compared to a high productivity in 2019–2020. In contrast, in the Kamyaran location, the genotypes exhibited the highest productivity in 2018–2019, and an average productivity equal to 1830 kg/ha in 2019–2020.

G × E indicated that the test environments can be characterized on the basis of their ability in genotype discrimination (long vectors: more discriminating) and their representative ability for test environments in the experiment. The angle between the environment vector and ATC axis indicates the representativeness of the test environment, a more acute angle and a more representative ability [49]. Accordingly, Hosseinabad (Y1HRT and Y1HCT) and Kamyaran (Y2KRT) were exhibited as the most representative and discriminating environment for grain yield and, therefore, may be suitable to select more generally adapted genotypes and can be depicted as a mega-environment, while Kamyaran (Y1KRT, Y1KCA, Y1KCT, Y2KCT, Y2KCA) and Hosseinabad (Y2HRT) were discriminating, but non-representative test environments, so they are more suitable for specifically adapted genotypes. Thus, the Hosseinabad location can be considered as the most ideal location for testing and identifying widely adapted barley genotypes. In the GGE biplot, consistently non-discriminating sites will not provide any additional information on G × E interactions and such sites can be excluded from trials to save cost and time [50,51]. In our results, all environments except Y2HCA were highly discriminative for grain yield and would provide useful information on environments and, therefore, the majority of environments can be regarded as informative test environments.

5. Conclusions

It is clear that CA changes the soil properties, especially in top-soil layers. Therefore, the genotypes introduced and adapted to conventional systems may not perform well under CA environments and, specifically, newly adapted genotypes need to be developed. Based on this study, an analysis of genotype × tillage interaction showed that some barley genotypes positively interacted with tillage systems. Genotypes G5 and G4 positively interacted with conventional tillage; while genotypes G7, G2 and G1 expressed the highest performance under a conservation agriculture system. The results of this study showed that rainfed barley genotypes produced yields equal to or better than (0.7%) the conservation system compared to conventional tillage. Therefore, under rainfed conditions of the cold and temperate areas in the West of Iran, barley growers can use commercial and new barley varieties without worrying about yield reduction in the initial years of CA implementation.

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