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Selection of Weeding Method and Plant Density in Maize (*Zea mays* L.) Based on Morphological and Physiological Characteristics

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

Aims: Maize is annual plant of the *Poaceae*, which, with a relatively short growth period and high yield, is ranked second in the world in terms of production after wheat. Choosing the most suitable different planting densities and weeding methods can have a favorable effect on increasing the yield of corn plants.
Study Design: To investigate the traits and choose the most appropriate planting density and weeding method in maize (*Zea mays* L.) using graphic methods, a factorial experiment based on randomized complete block design was conducted in three replications.
Place and Duration of Study: This study was conducted in Shahre-Rey region in 2020-2021.
Methodology: The hybrid cultivated in the SC647 experiment was selected. Each test plot included four cultivation lines with a width of 75 cm and a length of 4 meters. The experimental land was fallow the year before maize cultivation, which was prepared by spring plowing and disk operations.

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Results: Based on the analysis of variance, the effect of planting density in all traits except the thousand seed weight trait and the effect of weeding stages in all traits except the trait number of rows in the cob showed a significant difference at the probability level of 0.01. Based on the means comparison of D3W3, D1W3 and D3W2 were selected as suitable treatments. Based on the correlation intensity map between the traits, the highest correlation intensity was estimated for the ear length trait with the plant height and the grain yield trait with the harvest index. The grouping diagram of the treatments formed four groups based on the first and second main components that justified 50.45% of the total variance of the data. Based on the polygon graph, treatments D2W3, D1W3, D3W2, D3W3, D1W1 and D1W2 were identified as the best treatments. Based on the cluster analysis diagram and heat map drawn on the experiment data, the treatments were divided into two main groups.

Conclusion: In general, by reviewing all the analyzes performed on the experiment data, D3W3 (density of 85,000 plants per hectare and no weeding) and D3W2 (density of 85,000 plants and two stages of weeding 4 to 8 weeks after planting) can be used for maize cultivation.

Keywords: Maize; correlation; main components; weeding methods; planting density.

1. INTRODUCTION

Maize is an annual plant of the Poaceae, which, with a relatively short growth period and high yield, is ranked second in the world in terms of production after wheat, and third in terms of cultivated area after wheat and rice [1]. The first consequence of the presence of weeds next to crops is the increase in the density of the plant population, which causes the limitation of water, food and light, which ultimately causes a decrease in yield. The amount of yield loss caused by weed interference is completely different depending on the crop, weed and growing conditions. The main goal of humans to control weeds is to maintain crop productivity in different years. According to estimates, about 10 to 15 percent of the total commercial value of farm products is lost due to weeds [2]. Severe weed infestation during the entire growing season may lead to complete crop losses of some crops [3]. Increasing the density of agricultural plants is considered an effective factor in increasing the share of agricultural plants from the total resources. With the increase in corn density, the ability to grow and produce weed seeds from planting systems decreases[4]. Many researchers reported the increase in crop density in reducing the competitive effects caused by weeds [5]. In research conducted on investigating different weed management in corn fields, corn density was considered at three levels of 70,000, 80,000 and 90,000 plants per hectare and it was concluded that the density of 70,000 to 90,000 per plant can reduce the growth rate of grasses. Weeds are effective in the field [6]. In a research conducted on the reduction in weeds competitiveness effects due to enhancement in plant density of corn varieties, it was concluded that increasing the density has an effective role in increasing the ability of maize to compete with weeds [7]. The results of the research that was conducted on the interference of weeds on the yield and morphological characteristics of corn indicated that the use of a density of 80,000 corn plants per hectare had the greatest effect in controlling weeds and increased the yield of corn plants [8]. In the study conducted on the effects of plant density, number and stages of weed control in corn, it was reported that increasing the density of planting improves the ability of corn to compete with weeds and increases the yield of corn seeds [9]. Integrated management solutions for weeds in maize fields and the possibility of reducing herbicide consumption by increasing density can be very effective in the sustainable control of weeds in this product [6]. In another research, it was reported that increasing the density of corn up to 1.5 times the density significantly increases the yield of corn seeds [10]. The aims of this research include 1. Choosing the most appropriate weeding method and planting density in maize, 2. Examining the degree of correlation between the traits evaluated in the experiment, 3. Investigating the interaction effects of weeding methods and planting density, 4. The grouping of the studied treatments in the experiment is evaluated in terms of traits.

2. MATERIALS AND METHODS

To investigate the traits and choose the most appropriate planting density and weeding method in maize (*Zea mays* L.) using graphic methods, a factorial experiment based on randomized complete block design was conducted in three replications. The experiment is located in the research farm in Share-Rey region with geographical coordinates of 36°35 North and 26°51 East. The maximum temperature in summer is 42°C and the minimum temperature in winter is -9 °C. The average annual rainfall in Share-Ray city was 250 mm. The climate of the project implementation area is moderate based on the climate classification, where the summer was hot and the rainfall was low and the winter was mild. Plant density was cultivated as the main factor in three levels: D1 (65,000 plants per hectare), D2 (75,000 plants per hectare) and D3 (85,000 plants per hectare). Weeding stages W1 (complete weeding), W2 (two stages of weeding 4 to 8 weeks after planting) and W3 (no weeding) were selected as secondary factors and in three repetitions and for one crop year. The hybrid cultivated in the SC647 experiment was selected. Each test plot included four lines with a width of 75 cm and a length of 4 meters. The experimental land was fallow the year before maize cultivation, which was prepared by spring plowing and disk operations. In order to meet the nutrition needs of maize based on the soil of the cultivation area, 300 kg of nitrogen fertilizer (urea) and 100 kg of phosphorus fertilizer (triple superphosphate) per hectare were added to the soil, one-third of the nitrogen fertilizer was added to the phosphorus fertilizer before cultivation and the rest In the stages of six to eight leaves was used. The evaluated traits were grain yield (GYLD), harvest index (HI), Ear length (EL), Ear diameter (ED), number of rows in ear (NRE), number of seeds in ear row (NSER), weight of 1000 seeds (W1000 seeds), leaf length (LL), leaf width (LW) and Plant height (PLH). In order to measure traits, 5 plants were randomly selected. and to remove the marginal effects, sampling was done from the middle two rows. In order to perform variance analysis and mean comparison, SasV.9 software was used, as well as graphical analysis including correlation map, treatment selection diagram based on the first and second principal components, polygon diagram, and cluster analysis and heat-map were used using Genstat V12.1 and Excel-stat 2020 software.

3. RESULTS AND DISCUSSION

3.1 Analysis of Variance and Mean Comparison

Based on factorial variance analysis in the form of a randomized complete block design with two factors and three levels each, it showed that the block effect in terms of grain yield traits, number of rows in the ear, number of seeds in the ear row, harvest index and Leaf width had a significant difference. The effect of planting density showed a significant difference in all traits except the 1000- seed weight trait and the effect of weeding stages in all traits except the trait number of rows in the ear at the probability level of 0.01. The interaction effect of planting density and weeding stages (D×W) was significant in all traits. The highest coefficient of variation was related to the traits number of rows in the ear (29.1) and number of rows in the ear (29.1) and the lowest coefficient of variation was related to the trait leaf length (8.6) (Table 1). Based on the means comparison done by Duncan's method on the data obtained from the experiment at the probability level of 0.01 and 0.05 in terms of grain yield trait, planting density of 85000 plants per hectare and complete weeding, in terms of ear length trait, Planting density of 85,000 plants per hectare and no weeding, in terms of ear diameter trait, planting density of 85,000 plants per hectare and complete weeding and 4 to 8 weeks after planting the crop, in terms of the number of rows of seeds in the ear, planting density of 85,000 plants and Weeding 4 to 8 weeks after planting the crop, in terms of the number of seeds in the ear row, planting 85,000 plants and weeding 4 to 8 weeks after planting the crop, in terms of the weight of a thousand seeds, planting 85,000 plants and no weeding. In terms of harvest index trait, planting density of 85,000 plants and complete weeding, in terms of leaf width trait, planting density of 65,000 plants and complete weeding, in terms of leaf length trait, planting density of 85,000 plants per hectare and complete weeding And in terms of plant height trait, planting density of 85,000 plants and complete weeding were selected as the most favorable maize crop planting density and weeding stages. According to the separate examination of the evaluated traits, in general, in terms of this analysis, in all traits, plant density of 85,000 and weeding 4 to 8 weeks after planting can be selected as the most favorable methods (Table 2). Considering that the grain yield trait is one of the most important and widely used traits in experiments, the means comparison chart was used to investigate the interaction effect of planting density and weeding methods (Fig. 1). Based on the means comparison made on the interaction effect of planting density and weeding method in terms of grain yield trait, treatments D3W3, D1W3 and D3W2 have the highest amount of use and desirability and treatments D3W1, D2W2 and D2W3 were selected as the least desirable treatments.

Table 1. Compound analysis of investigated traits in terms of planting density and weeding methods in the experiment

S.O.V	df	YLD	EL	ED	NRE	NGRE	TWG	HI	LW	LF	PLH
Block	2	18077857**	9.4ns	0.17ns	340.2*	268.4*	2929.1ns	900.9**	8.9*	54.1ns	455.2ns
Cultivation (D)	2	5197279.6*	4.7*	0.61*	134.6*	54.6*	429.2ns	501**	5.01*	102.8*	1249.9*
Weedeing Stages (W)	2	3608112*	3.7*	0.09*	58.9ns	1.96ns	7764.1*	235.8**	0.9*	13.2*	14.22*
D × W	4	3089168*	2.4*	0.21*	45.07*	24.4*	2174.4*	236.4*	0.5*	122.2*	197.5*
Error	43	3409515	3.9	0.42	82.3	55.4	4395.6	173.1	3.01	74.6	11.4
CV%		27.6	14.05	16.7	29.1	29.1	22.9	24.8	23.9	8.6	18.1

**, **, and ns: Significant at 5%, 1% and not-significant.*

(GYLD: grain yield, EL: ear length, ED: ear diameter, NRE: number of seed rows in ear, NSER: number of seeds in ear row, W1000seed: thousand seed weight, HI: harvest index, LW: leaf width, LL: Leaf length, PLH: plant height)

Table2. Comparison of mean by Duncan's method on studied traits in terms of planting density and weeding methods in the experiment

Traits	YLD	EL	ED	NRE	NGRE	TWG	HI	LW	LF	PLH
Cultivation										
D1	606b	13.5b	3.7b	20.1b	16.6c	46.7b	6.6b	293a	64b	183b
D2	6924a	14.1a	3.7b	23.8a	19.2b	55.3ab	7.4a	283b	69a	187ab
D3	7046a	14.5a	4.07a	25.5a	19.9a	56.3a	7.6a	288b	68a	199a
Weeding Stages										
W1	7097a	13.5b	3.9a	21.1b	18.2ab	246.6c	56.7a	7.4a	68.2a	191.5a
W2	6727ab	14.1a	3.9a	24.4a	18.8a	297.3b	52.1b	6.9b	67.3b	190.1a
W3	6206a	14.4a	3.7ab	23.9ab	18.7a	303.2a	49.6c	7.2a	66.5c	189.8a

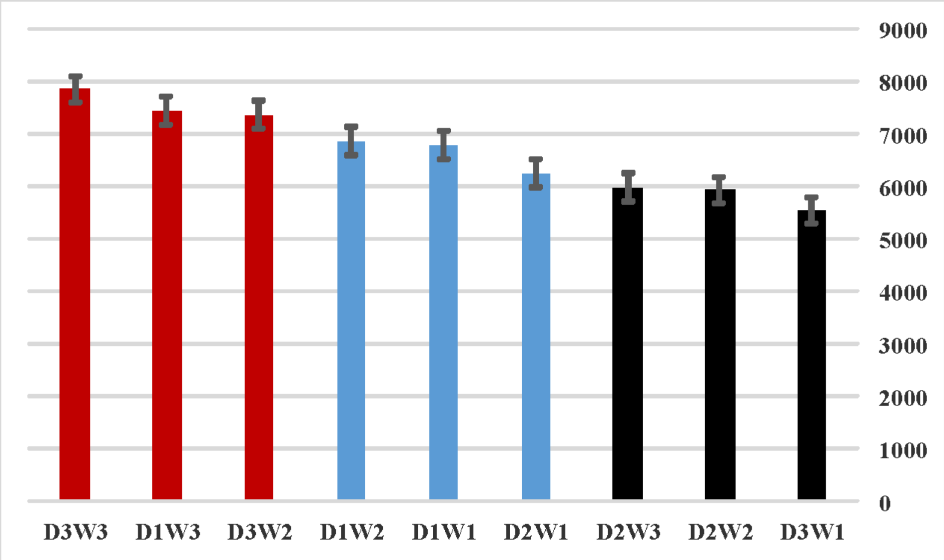

Fig. 1. Means comparison chart of the interaction effect of planting density and weeding methods based on grain yield trait in maize

(D1W1: density of 65,000 plants per hectare and complete weeding, D1W2: density of 65,000 plants per hectare and two stages of weeding 4 to 8 weeks after planting, D1W3: density of 65,000 plants per hectare and no weeding, D2W1: density of 75,000 plants per hectare and complete weeding Weeds, D2W2: density of 75,000 plants per hectare and two stages of weeding 4 to 8 weeks after planting, D2W3: density of 75,000 plants per hectare and no weeding, D3W1: density of 85,000 plants per hectare and complete weeding, D3W2: density of 85,000 plants per hectare and two stages of weeding 4 to 8 weeks after planting, D3W3: density of 85,000 plants per hectare and no weeding)

3.2 Graphical Analysis

Based on the correlation intensity map between the traits, which was drawn based on the colors red (highest correlation), blue (moderate correlation) and white (no correlation), the highest correlation intensity is related to the trait of ear length with plant height trait and grain yield trait with harvest index trait (Fig. 2). Semeskandi et al used the correlation map to check the intensity of the correlation on the studied traits [11]. Based on the treatment grouping diagram, four groups were formed based on the first and second main components that accounted for 50.45% of the total data variance. The first group included D2W2 and D1W2 treatments that had positive PC1 and PC2 coefficients. The second group included treatments D3W1, D2W3 and D1W3, which had positive coefficients of PC1 and negative coefficients of PC2. The third group included treatments D1W1 and D2W1, which had negative coefficients of PC1 and positive coefficients of PC2, and the fourth group included D3W3 and D3W2, which had negative coefficients of PC1 and PC2 (Fig. 3). Based on the polygon diagram, which is obtained by connecting the treatments that have the greatest distance from the origin, and the traits are divided by perpendicular lines on this polygon. Based on the polygon graph drawn on the data from the experiment, the first component accounted for 29.65% and the second component for 20.8%, and in total, the two components accounted for more than 50% of the variance of the total data. Based on this diagram, D2W3, D1W3, D3W2, D3W3, D1W1, and D1W2 were chosen as the planting density and appropriate weeding methods, considering the greatest distance from the origin of the diagram and placement at the vertex of the polygon. In each section, the leaf width trait with D2W3, the number of seeds in the ear row with D1W3, the harvest index and seed yield traits with D3W2, and the 1000 seed weight and ear diameter traits with D1W1 showed the highest yield (Fig. 4). Okoye et al. (2007) on rapeseed cultivars [12] and Dolatabad et al. (2010) and Shojaei et al. (2022) on maize cultivars [13,14] used this type of graph for their studies. Based on the cluster analysis diagram drawn on the experimental data, the treatments were grouped and divided into two main groups. The first group included two subgroups, the first subgroup included D3W1 and D1W2 treatments and the second subgroup included D1W1, D2W1 and D2W3 treatments. The second group was also divided into two subgroups. The first subgroup included the D3W3 treatment and the second subgroup included the D2W2, D1W3 and D3W2 treatments (Fig. 5). Based on the drawn heat map, the treatments were grouped into two main groups. D3W3 and D3W2 treatments were divided into the first group and other treatments were divided into the second group. In the heat map analysis, in terms of traits, the traits were grouped into two groups. The first group included the traits of the number of seeds in the ear row and leaf width, and the second group included other traits evaluated in the experiment (Fig. 6). Different researchers used cluster analysis and heat-map in order to group the treatments [15,16,17].

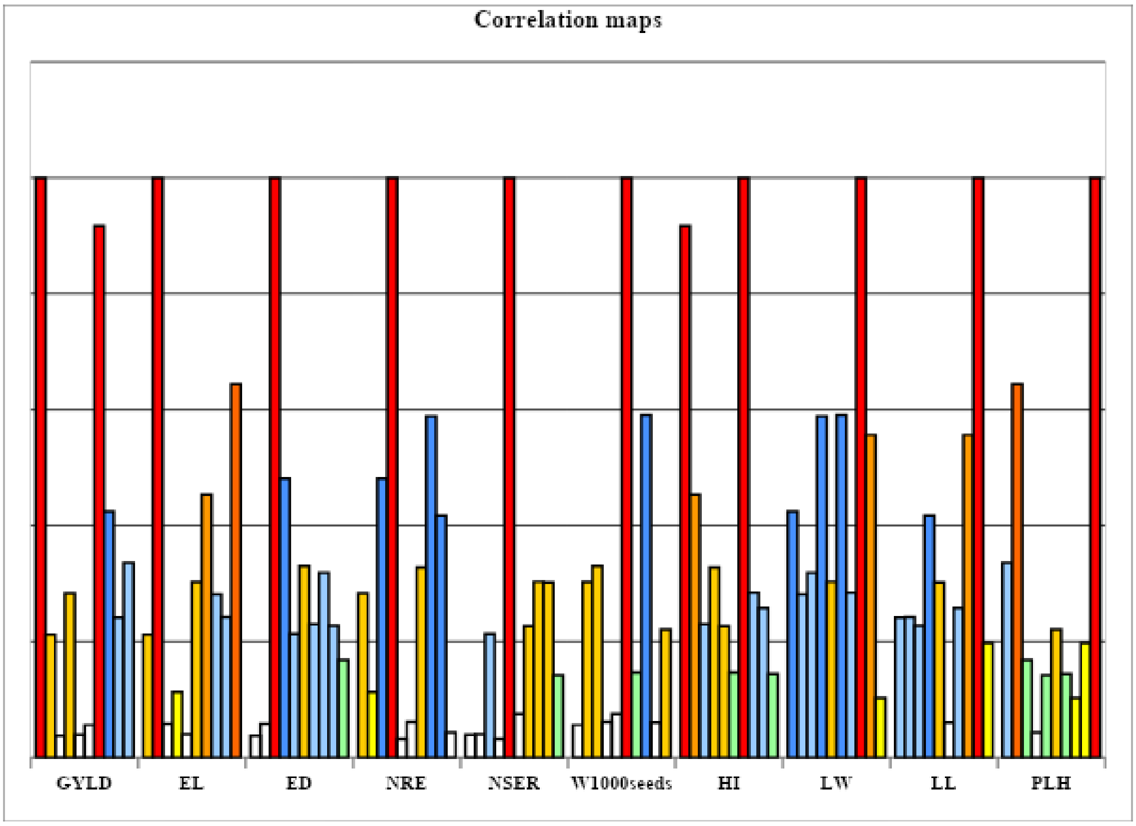

Fig. 2. The map of the intensity of correlation between the studied traits in the experiment (Red color: high correlation intensity, green color: medium correlation intensity, blue color: low correlation intensity, white color: absence of correlation)

(GYLD: grain yield, EL: ear length, ED: ear diameter, NRE: number of seed rows in ear, NSER: number of seeds in ear row, W1000seed: thousand seed weight, HI: harvest index, LW: leaf width, LL: Leaf length, PLH: plant height)

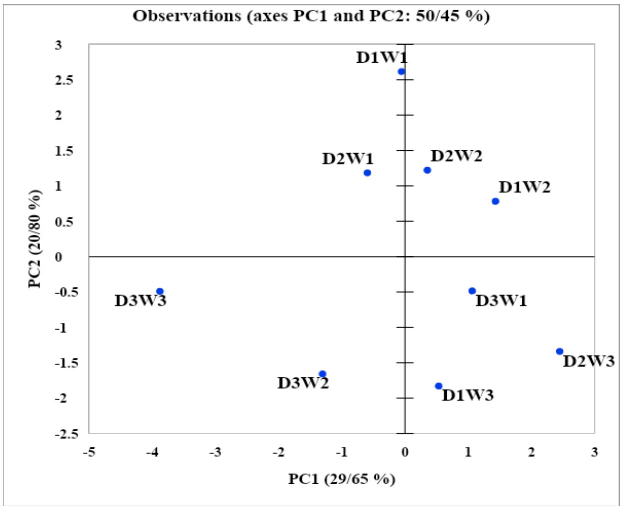

Fig. 3. The grouping diagram of experimental treatments based on the first and second components

(D1W1: density of 65,000 plants per hectare and complete weeding, D1W2: density of 65,000 plants per hectare and two stages of weeding 4 to 8 weeks after planting, D1W3: density of 65,000 plants per hectare and no weeding, D2W1: density of 75,000 plants per hectare and complete weeding Weeds, D2W2: density of 75,000 plants per hectare and two stages of weeding 4 to 8 weeks after planting, D2W3: density of 75,000 plants per hectare and no weeding, D3W1: density of 85,000 plants per hectare and complete weeding, D3W2: density of 85,000 plants per hectare and two stages of weeding 4 to 8 weeks after planting, D3W3: density of 85,000 plants per hectare and no weeding)

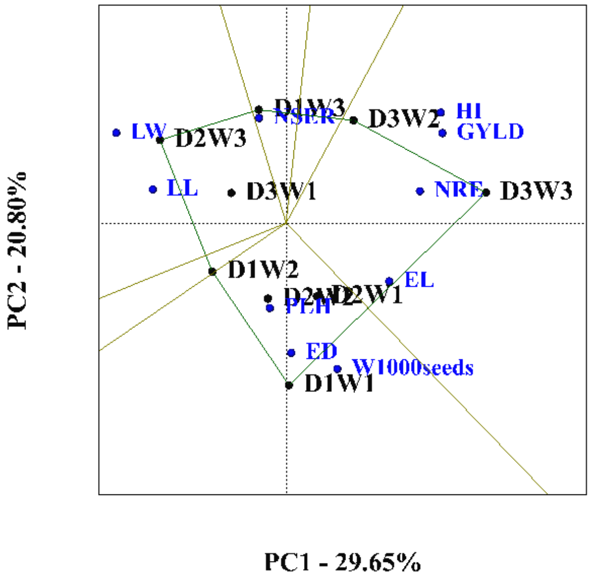

Fig. 4. Polygon diagram of reaction of different traits based on planting density and weeding methods and choosing the most suitable method

(D1W1: density of 65,000 plants per hectare and complete weeding, D1W2: density of 65,000 plants per hectare and two stages of weeding 4 to 8 weeks after planting, D1W3: density of 65,000 plants per hectare and no weeding, D2W1: density of 75,000 plants per hectare and complete weeding Weeds, D2W2: density of 75,000 plants per hectare and two stages of weeding 4 to 8 weeks after planting, D2W3: density of 75,000 plants per hectare and no weeding, D3W1: density of 85,000 plants per hectare and complete weeding, D3W2: density of 85,000 plants per hectare and two stages of weeding 4 to 8 weeks after planting, D3W3: density of 85,000 plants per hectare and no weeding)

(GYLD: grain yield, EL: ear length, ED: ear diameter, NRE: number of seed rows in ear, NSER: number of seeds in ear row, W1000seed: thousand seed weight, HI: harvest index, LW: leaf width, LL: Leaf length, PLH: plant height)

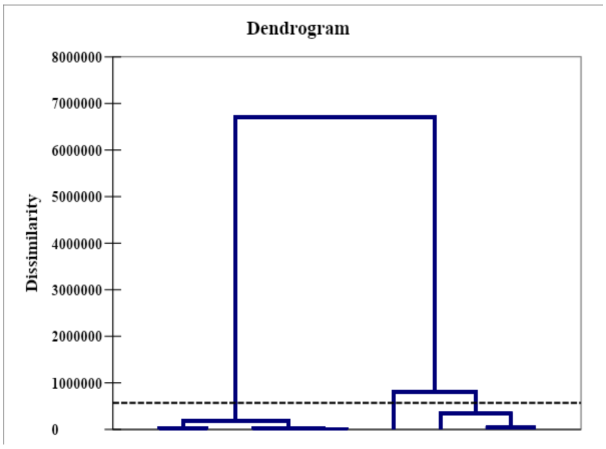

Fig. 5. Cluster analysis diagram and grouping of treatments based on the traits evaluated in the experiment

(D1W1: density of 65,000 plants per hectare and complete weeding, D1W2: density of 65,000 plants per hectare and two stages of weeding 4 to 8 weeks after planting, D1W3: density of 65,000 plants per hectare and no weeding, D2W1: density of 75,000 plants per hectare and complete weeding Weeds, D2W2: density of 75,000 plants per hectare and two stages of weeding 4 to 8 weeks after planting, D2W3: density of 75,000 plants per hectare and no weeding, D3W1: density of 85,000 plants per hectare and complete weeding, D3W2: density of 85,000 plants per hectare and two stages of weeding 4 to 8 weeks after planting, D3W3: density of 85,000 plants per hectare and no weeding)

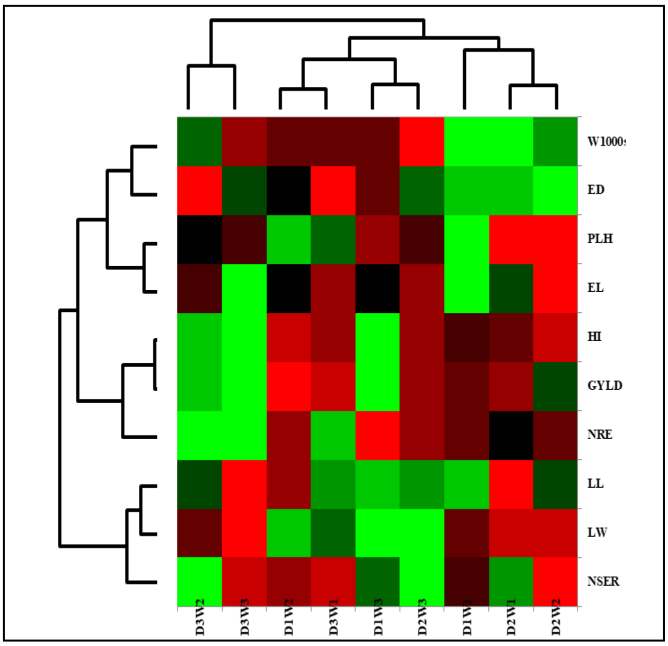

Fig. 6. Heat map grouping treatments and traits based on the data obtained in the experiment

(D1W1: density of 65,000 plants per hectare and complete weeding, D1W2: density of 65,000 plants per hectare and two stages of weeding 4 to 8 weeks after planting, D1W3: density of 65,000 plants per hectare and no weeding, D2W1: density of 75,000 plants per hectare and complete weeding Weeds, D2W2: density of 75,000 plants per hectare and two stages of weeding 4 to 8 weeks after planting, D2W3: density of 75,000 plants per hectare and no weeding, D3W1: density of 85,000 plants per hectare and complete weeding, D3W2: density of 85,000 plants per hectare and two stages of weeding 4 to 8 weeks after planting, D3W3: density of 85,000 plants per hectare and no weeding)

(GYLD: grain yield, EL: ear length, ED: ear diameter, NRE: number of seed rows in ear, NSER: number of seeds in ear row, W1000seed: thousand seed weight, HI: harvest index, LW: leaf width, LL: Leaf length, PLH: plant height)

4. CONCLUSION

According to the obtained results, it can be concluded that with the aim of organic agriculture, due to the ban on the use of chemicals in the agricultural system, the weeds of corn fields can be well controlled by increasing the density of maize up to 85,000 plants per hectare. Also, in order to apply sustainable agriculture, which aims to stabilize the system and reduce the consumption of herbicides, the amount of herbicide consumption can be reduced by increasing the density up to 85,000 plants per hectare.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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