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Research article

Effect of planting patterns of sunflower on yield and extinction coefficient

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Abstract – We studied the effect of different planting patterns and density of sunflower on yield and on extinction coefficient. The experiment was conducted in the field at the Seed and Plant Improvement Institute, Karaj, Iran on a loamy clay. Planting patterns included wide rows, conventional rows, twin rectangular rows and twin zigzag rows. Populations of plants were at 3 levels including 6, 8 and 10 plants per square meter. The results show that different planting patterns sometimes produced higher yield, but not always. Furthermore, equidistant plant distribution at equal plant densities produced a higher radiation interception and extinction coefficient. Moreover, when row spacing was reduced, grain yield increased. The greatest increase in radiation interception and in the extinction coefficient in response to planting patterns and plant densities was observed in twin zigzag rows of 8 plants m^{-2}. Twin zigzag rows of 8 plants m^{-2} and conventional rows of 8 plants m^{-2} produced the highest yield.

extinction coefficient / planting patterns / sunflower

1. INTRODUCTION

In Iran, approximately 80% of oilseed for human food is imported, so increasing sunflower production is an option to reduce this deficit. Adequate plant density and a planting pattern with optimum spatial arrangement (equidistant is superior) are important cultural factors that increase radiation interception (RI) and yield production. Decreasing row spacing at equal plant densities decreases plant-to-plant competition for radiation interception (RI) and biomass production (Bullock et al., 1988; Andrade et al., 2002) but the results of planting patterns on the cropping produced variable conclusions; some indicated that a clear difference in patterns caused high yield (Robinson et al., 1980; Ikeda and Sato, 1992), and others indicated that clear differences in yield were not found (Wiggans 1939; Wilocox, 1974; Nishiiri, 1976). Sunflower yield (Andrade et al., 2002) and soybean yield (Duncan, 1986; Ikeda and Sato, 1992) increased in response to narrow rows. From several plant population studies (Goubbels and Dedio, 1990), it was shown that a population of 7.4 plants m^{-2} produced higher yield in sunflower than 5.5 plants m^{-2}; with an increase in population to 14.8 plants m^{-2}, there is no effect on changing yield. When row spacing is reduced light interception increases. There are times during the crop cycle that are most critical for yield determination. These times comprise the period bracketing flowering in sunflower (Chimenti and Hall, 1992, Connor and Sadras, 1992; Cantagallo et al., 1997). Therefore, the response of grain yield to narrow rows can be analyzed in terms of the effect on the amount of radiation interception (RI) at the critical periods for kernel set. Higher crop growth rates during these periods may not be achieved with wide rows (Andrade et al., 2002). Increase in light interception by reducing row spacing has been reported for corn (Egharevba, 1975; Flenet et al., 1996; Andrade et al., 2002), sorghum (Clegg et al., 1974; Graham et al., 1988; Muchow et al., 1990; Flenet et al., 1996), soybean (Mason et al., 1980; Boared et al., 1990; Andrade et al., 2002) and sunflower (Flenet et al., 1996; Andrade et al., 2002). Greater light interception often increases yield (Alessi et al., 1977; Karlen and Camp, 1985; Parvez et al., 1989; MacGowan et al., 1991). Sunflower yield increase in response to narrow rows is closely related to the improvement in light interception during the critical period for grain set (Andrade et al., 2002). Maize biomass at maturity has a linear relationship with cumulative intercepted photosynthetically active radiation (Edwards et al., 2005). Light interception and leaf area are criteria to maintain optimum soybean yield (Board, 2004). Flenet et al. (1996) showed that the stage of development × row spacing interaction did not significantly alter k during the period of measurement in corn, sorghum, soybean and sunflower. The k-values calculated were 0.4 for corn (Muchow et al., 1990), 0.45 for soybean (Kiniry et al., 1992), and 0.8 (Steer et al., 1993), 0.6 (Sinclair, 1986) and 0.9 (Kiniry et al., 1992) for sunflower. Murphy et al. (1996) showed that 50-cm-row corn gave 16 to 21% greater suppression of late-emerging weeds than 75-cm-row corn and higher

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Table I. Treatments of planting patterns, number of rows sowing, planting densities (plants m^{-2}), distance between of plant on rows sowing (cm) and between rows (cm).

Between rows (cm)	Distance between plants in rows sown (cm)	Planting densities (plants m^{-2})	Number of rows sowing	Planting patterns
75	22	6	1	
75	17	8	1	Wide row
75	13	10	1	
50	33	6	1	Conventional row
50	25	8	1	
50	20	10	1	
75	44	6	2	Twin rectangular row
75	33	8	2	
75	27	10	2	
75	44	6	2	Twin zigzag row
75	33	8	2	
75	26	10	2	

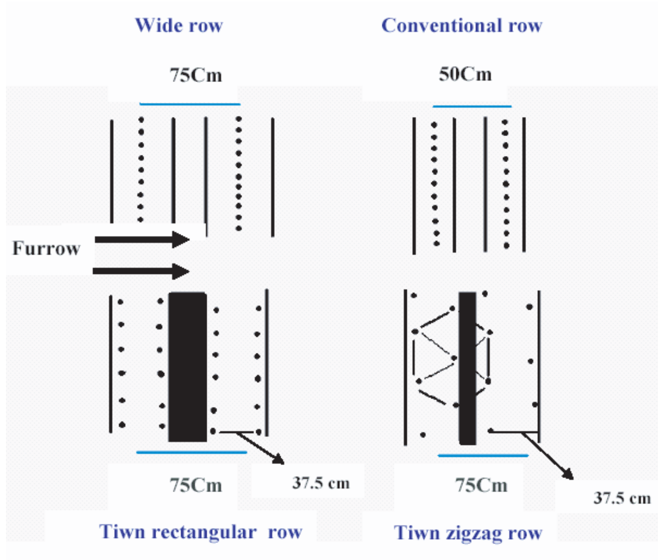

Figure 1. Treatments of planting patterns.

corn density also gave 30 to 41% greater suppression of late-emerging weeds than the control corn density, the greater light interception giving about 8% more light to the silk than a wide row.

2. MATERIALS AND METHODS

Hybrid azargol sunflower seeds with semi-dwarf and early maturity (the most popular sunflower in Iran) were hand-planted on 6 July 2003 in the field at the Seed and Plant Improvement Institute, Karaj, Iran on loamy clay (about 1323 m Alt, 35° 48' N Lat). Experimental plots were 21 m^2 (6 by 3.5 m). The sunflower planting date is normally 15 May, but it was planted on 5 July after the wheat harvest. Fertilizer was applied before planting at the rate of 150-100-0 kg ha^{-1} (N-P-K) according to soil test recommendations. Weeds were controlled by hand as needed and no problems with diseases or insects occurred. The seeds were sown at a rate of three to four seeds in shallow holes at a depth of 5 cm and firmly covered. Prior to V_4 [V (number) Vegetative Stages (i.e. V-1, V-2, V-3, etc.). These are determined by counting the number of true leaves at least 4 cm in length, beginning as V-1, V-2, V-3, V-4, etc. (Schneiter and Miller, 1981)] they were thinned to one stand (25 d after emergence). The experimental design was factorial with a complete randomized block arrangement of treatment in 4 replications.

2.1. Planting patterns and plant densities

The planting patterns were at 4 levels including wide rows with 75 cm between the rows (P_1), conventional rows with 50 cm between the rows (P_2), twin rectangular rows with 75 cm between the rows (P_3) and twin zigzag rows (P_4) with 75 cm between the rows. The population of plants was at 3 levels including 6 plants m^{-2} (d_1) (6 plants m^{-2} is the only population for optimal planting dates or early season planting in Karaj), 8 plants m^{-2} (d_2) and 10 plants m^{-2} (d_3) (Tab. I and Fig. 1). Row spacing was not changed in all cases and when densities became too high, the distance between plants in a row was changed.

2.2. Sampling and measurements

At 25, 35, 45, 55, 65, 75 and 85 d after planting, 6, 8 and 10 plants were systematically selected from the low (d_1 = 6 plants m^{-2}), medium (d_2 = 8 plants m^{-2}) and high plant (d_3 = 10 plants m^{-2}) population plots, respectively, for LAI (m^2 m^{-2}) and total dry matter (g m^{-2}). Samples were separated into leaves and stem. After leaf area measurement by placing the leaf blades through a leaf area meter (MK2; Delta-T Devices Ltd, Cambridge, UK), plant parts were dried in an oven at 60 °C to a constant weight. The data obtained were light interception [LI (%)], extinction coefficient (K), LAI (m^2 m^{-2}) and TDM (g m^{-2}). 15 measurements were taken above the canopy to determine ambient light and 15 below the rows (an average of 8 measurements made across the row and 7 measurements made parallel to the row). Determinations were taken at V_8, close to flowering at V_{18} and the R-1 growth stages [stage according to Schneiter and Miller (1981)]. A 1-m^2 section of the interior rows of each plot was hand-harvested at maturity (a week after R-9) and then the seeds were separated by combine to determine yield and yield components. Seed samples from each plot were dried in an oven at 60 °C, weighed, and seed oil content was determined by Inframatic_8000.

2.3. Methods of light interception and extinction coefficient

Radiation interception was calculated by using

$$(1 - I_t / I_0) \times 100$$

where I_t is incident PAR (photosynthetically active radiation). Just below the lowest layer of photosynthetically active leaves and I_0 is incident PAR at the top of the canopy. The light interception (I_t and I_0) was determined with a 1-m-long LI-COR

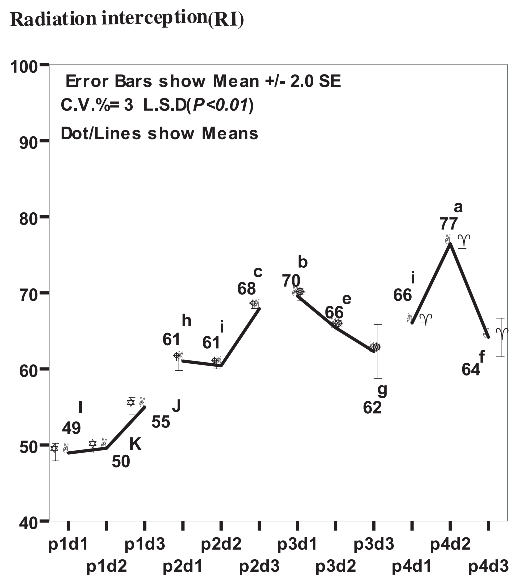

Figure 2. Relationships regarding radiation interception (RI) increase in response to planting patterns and plant densities. P = planting patterns; P_1 = wide rows, P_2 = conventional rows, P_3 = twin rectangular rows, P_4 = twin zigzag rows. d = planting densities; d_1 = 6 plants m^{-2}, d_2 = 8 plants m^{-2}, d_3 = 10 plants m^{-2}. Means comparison defined by Duncan's range test at the 5% level.

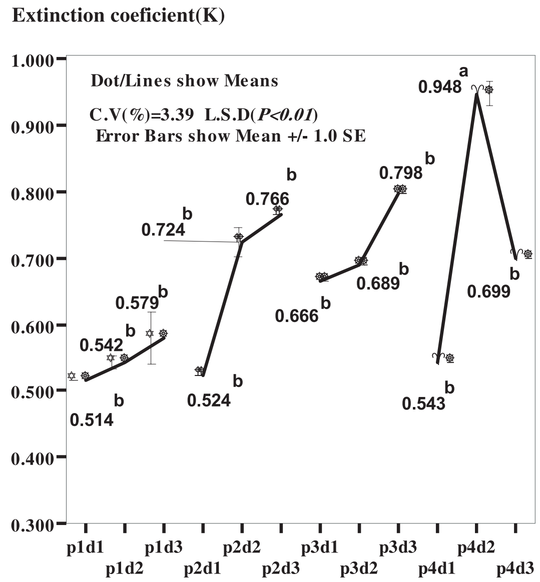

Figure 3. Relationships regarding extinction coefficient (k) increase in response to planting patterns and plant densities. P = planting patterns; P_1 = wide rows, P_2 = conventional rows, P_3 = twin rectangular rows, P_4 = twin zigzag rows. d = planting densities; d_1 = 6 plants m^{-2}, d_2 = 8 plants m^{-2}, d_3 = 10 plants m^{-2}. Means comparison defined by Duncan's range test at the 5% level.

line Quantum sensor (LI-COR, Lincoln, NE) under clear skies at noon (±1.5).

The extinction coefficient (K) was calculated by

$$TPAR/PAR = \exp(-K \times LAI)$$

where TPAR and K represent transmitted PAR and the extinction coefficient, respectively.

2.4. Irrigation

The location has a temperate climate with mild, rainy (250 mm) winters and dry, hot summers. All plots of wide row planting patterns and conventional row planting patterns consisted of nine east-west rows (2 rows were border rows) but all plots of twin rectangular rows and twin zigzag rows consisted of 6 twin rows (all plots of the treatment were 21 m^2) (Fig. 1). Therefore, in all plots of twin rectangular and twin zigzag arrangements were 7 furrows (every two rows were irrigated by one furrow) while in the other planting patterns it was 10 furrows (each row takes up water from two furrows) (Fig. 1). The amount of inflow of water was the same to all furrows.

2.5. Statistical analysis

Analysis of variance was according to SAS with mean separation by LSD.

3. RESULTS AND DISCUSSION

3.1. Light interception and extinction coefficient

In this experiment the greatest ($P < 0.01$) increases in the radiation interception (RI) and extinction coefficient in response to plant densities and planting patterns were observed in the twin zigzag arrangement with 8 plants m^{-2} at R – 1 (K = 0.94, RI = 0.76) (Figs. 2 and 3). Similar results were observed at V_8 and V_{18} (data not shown). Our results support the results of previous studies for the effect of row spacing on RI and K (Clegg et al., 1974; Egharevba, 1975; Mason et. al., 1980; Graham et al., 1988; Zaffaroni and Schneiter, 1989; Flenet et al., 1996; Andrade et al., 2002).

LAI during the vegetative period was not significant ($P < 0.05$), except that 45 d after planting conventional planting patterns × 8 plants m^{-2} had the highest LAI (Fig. 4). Decreasing row spacing at equal plant densities reduces the leaf area index required to intercept 95% of the incident radiation due to an increase in the light extinction coefficient (Flenet et al., 1996; Andrade et al., 2002).

LAI during the reproductive period in the twin zigzag arrangement was usually significantly ($P < 0.05$) higher than other planting patterns (Fig. 4).

The twin zigzag arrangement had significantly ($P < 0.05$) higher total dry matter during the growth season (Fig. 4).

3.2. Yield and yield components

At the rate of 6 plants m^{-2} there was no significant difference between planting patterns on thousand seed weight (Tab. II). Although ($P < 0.05$) planting pattern effects did not occur for thousand seed weight, plant densities had a significant effect ($P < 0.05$) (Tab. II). Maximum thousand seed weight was achieved at a plant population of 6 plants m^{-2} (Tab. II). Planting at the higher rate (8 and 10 plants m^{-2}) resulted in reducing thousand seed weight. Thousand seed weight for the highest rate (10 plants m^{-2}) was lower for wide rows and twin rectangular

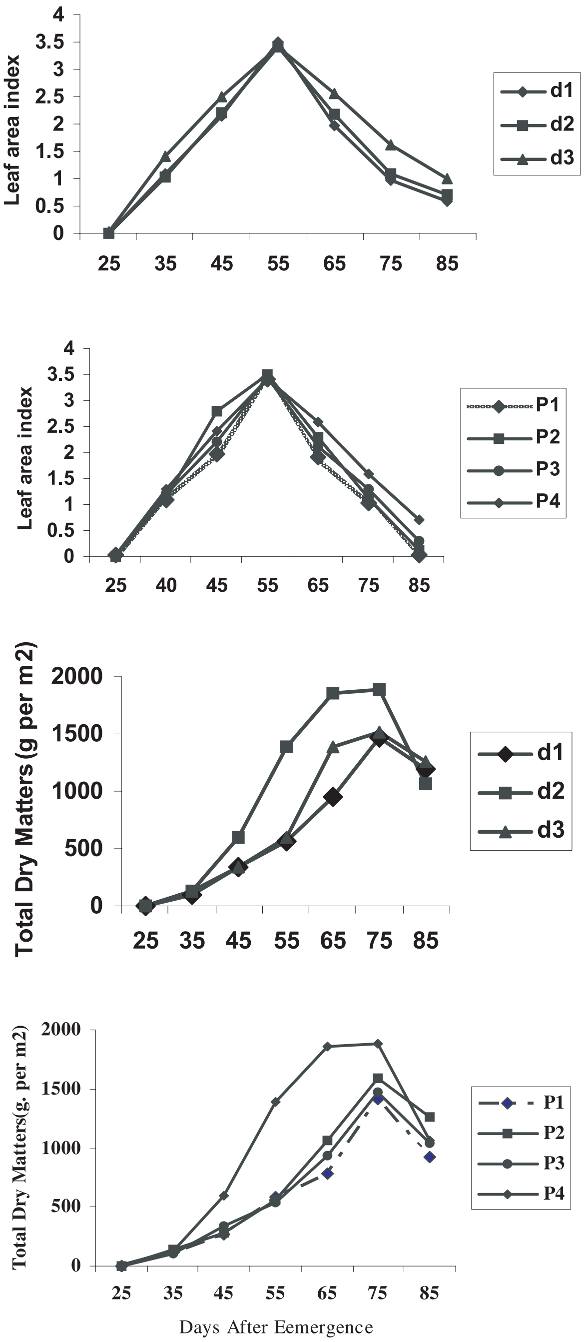

Figure 4. Relationship between leaf area index (LAI) and total dry matter during the vegetative and productive periods for sunflower grown in response to planting patterns and plant densities. L.S.D. ($P < 0.05$). P = planting patterns; P_1 = wide rows, P_2 = conventional rows, P_3 = twin rectangular rows, P_4 = twin zigzag rows. d = planting densities; d_1 = 6 plants m^{-2}, d_2 = 8 plants m^{-2}, d_3 = 10 plants m^{-2}. Means comparison defined by Duncan's range test at the 5% level.

rows compared with twin zigzag and conventional rows, while their thousand seed weight was equal at the lower plant density (8 plants m^{-2}) (Tab. II). As expected, according to previous

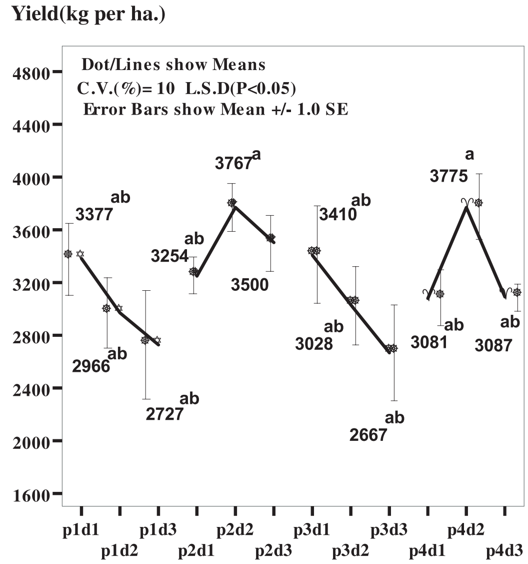

Figure 5. Relationships regarding grain yield increase in response to planting patterns and plant densities. P = planting patterns; P_1 = wide rows, P_2 = conventional rows, P_3 = twin rectangular rows, P_4 = twin zigzag rows. d = planting densities; d_1 = 6 plants m^{-2}, d_2 = 8 plants m^{-2}, d_3 = 10 plants m^{-2}. Means comparison defined by Duncan's range test at the 5% level.

studies (Miller et al., 1984; Majid and Schneiter, 1988; Zaffaroni and Schneiter, 1989). Planting patterns had no significant effect ($P < 0.05$) on number of seeds per head (Tab. II). Seed number decreased with increased density of planting. A higher number of seeds was achieved by low density (6 plants m^{-2}) (Tab. II).

Decreasing the plant-to-plant competition for available water, nutrient and light increases seed weight and seed number per head, but planting sunflower at the minimal population (6 plants m^{-2}) reduces number of seeds per m^{-2} (Tab. II). The maximum seed number per m^2 was obtained by twin zigzag rows and conventional rows × 8 plants m^2 (Tab. II).

Plant densities, Planting patterns and Plant densities × Planting patterns had a significant effect on yield ($P < 0.05$) (Fig. 5). Yield tended to increase in twin zigzag rows and conventional planting patterns at the rate of 8 plants m^{-2} (Fig. 5). Other studies demonstrate a high rate of yield when triangular (equidistant) planting patterns are used (Ikeda and Santo, 1992; Miura et al., 1987). The periods bracketing flowering in sunflower (Chimenti and Hall, 1992; Connor and Sadras, 1992; Cantagallo et al., 1997) are times during the crop cycle that are most critical for yield determination. Sunflower yield increase in response to narrow rows is closely related to the improvement in light interception during the critical period for grain set (Andrade et al., 2002). However, this research indicates that despite optimum spatial arrangement of twin zigzag planting patterns, its yield equaled conventional planting patterns. This may refer to the fact that every two rows of plants of this arrangement take up water from one furrow (Fig. 1). Moreover, sunflower has a high capacity to achieve full light interception at flowering, provided that adapted cultivars are grown without serious water deficits or other adversities during the vegetative period (Andrade et al., 2002).

Table II. Means comparison of defined characters by Duncan's range test at the 5% level.

Seed oil yield (kg ha^{-1})	Seed oil content (%)	No. of seeds m^{-2}	No. of seeds per head	1000 seed weight (g)	Treatments
					Planting patterns (P)
47.08^{a}	47.08^{a}	4948^{d}	824^{a}	48.5^{a}	P_1
46.60^{a}	46.60^{a}	7001^{a}	907^{a}	50.2^{a}	P_2
45.30^{a}	45.30 ^{a}	6065^{c}	809^{a}	49.5^{a}	P_3
46.32^{a}	46.32^{a}	6622^{b}	862^{a}	49.7^{a}	p_4
					Planting densities (d)
46.75^{ab}	46.75^{ab}	6563^{b}	1094^{a}	51.7^{a}	d_1
47.00^{a}	47.00^{a}	7040^{a}	880^{b}	48.8^{b}	d_2
45.23^{b}	45.23^{b}	5433^{c}	598^{c}	47.9^{b}	d_3
5	5.05	5	3	10	C.V (%)
S.	S.	S.	S.	S.	Interaction
1503^{ab}	47^{ab}	6768^{e}	1128^{a}	52^{a}	$p_1 d_1$
1420^{ab}	48^{a}	4806^{i}	801^{c}	47^{b}	$p_1 d_2$
1266^{b}	45^{ab}	3270^{k}	545^{e}	47^{b}	$p_1 d_3$
1566^{ab}	48^{a}	6504^{f}	1084^{a}	52^{a}	$p_2 d_1$
1775^{a}	47^{ab}	7528^{a}	941^{ab}	50^{ab}	$p_2 d_2$
1545^{ab}	45^{b}	6970^{c}	697^{cde}	49^{ab}	$p_2 d_3$
1579^{ab}	46^{ab}	6816^{d}	1136^{a}	53^{a}	$P_3 d_1$
1416^{ab}	47^{ab}	6048^{j}	756^{bcd}	49^{ab}	$p_3 d_2$
1067^{b}	43^{b}	5330^{i}	533^{e}	47^{b}	$p_3 d_3$
1207^{ab}	46^{ab}	6162^{g}	1027^{a}	51^{a}	$p_4 d_1$
1759^{a}	47^{ab}	7544^{a}	943^{ab}	50^{ab}	$p_4 d_2$
1442^{ab}	47^{ab}	6160^{h}	616^{cde}	49^{ab}	$p_4 d_3$

Mean seed oil content and seed oil yield showed no significant difference among planting patterns (Tab. II). However, there was a significant difference between seed oil content and seed oil yield in planting densities and planting patterns × densities of planting (Tab. II). The wide, zigzag and conventional planting patterns × 8 plants m^{-2} cause higher seed oil yield (Tab. II). Robinson et al. (1980) reported that equidistant planting patterns cause higher yield and seed oil yield in sunflower. Gubbels and Dedio (1990) reported that with increased planting density, seed oil yield was increased.

4. CONCLUSION

Equidistant plant distribution produced a higher radiation interception and extinction coefficient. Moreover, when row spacing was reduced, grain yield increased. The greatest increase in radiation interception and in the extinction coefficient in response to planting patterns and plant densities was observed in twin zigzag rows × 8 plants m^{-2}. Twin zigzag rows × 8 plants m^{-2} and conventional rows × 8 plants m^{-2} produced the highest yield.

The greater light interception led to greater suppression of late-emerging weeds; therefore, selection of appropriate planting patterns could be an option for controlling weeds in sustainable agriculture.

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