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Clear Plastic Mulch Improved Seedling Emergence of Direct-seeded Pepper

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Abstract. **Pepper (*Capsicum annuum* L. 'Piquillo de Lodosa') was seeded and then covered with clear plastic mulch, and various cultural practices to improve seedling emergence were compared. Planting dates (8, 12, and 25 Apr. 1991), seeding systems (raised bed vs. flat, 1991), and one or two rows per bed (1991 and 1992, respectively) were evaluated for their effects on stand establishment and yield. Plant stand was 60% when seed was under plastic mulch, compared to 0% when no mulch was used. Maximum plant stand was obtained 4 weeks after seeding in mulched soil. With plastic mulch, earlier (on or before 12 Apr.) season plantings were best because soil temperatures were so high (≥35C) later as to reduce plant stands. The risk of excessive high temperatures was greater when seeding was on a raised bed rather than flat ground; however, using plastic mulch, temperatures were higher, often resulting in acceptable plant stands regardless of bed arrangement. Higher yields were realized with raised beds compared to flat ground sowing. When two rows per bed were used, higher temperatures on the south side reduced emergence compared to the north side of the east–west-oriented beds. Direct seeding of pepper appears to be commercially acceptable in our Mediterranean conditions, provided seed is under plastic mulch and seeding is completed on or before 12 Apr.**

Direct field seeding is a common commercial practice with vegetable crops, such as onions (*Allium cepa* L.) and processing tomatoes (*Lycopersicon esculentum* Mill.), but not peppers in Spain. Direct seeding of vegetables can be more cost effective than transplanting, particularly when the crop is destined for processing. With direct seeding, plant densities can be increased (Costa, 1991) with reduced labor and planting costs to improve yields (Stoffella and Bryan, 1988; Sundstrom et al., 1984).

Pepper is a species that requires relatively high soil temperatures for optimal germination and emergence, the optimum being between 25 and 31C (Bierhuizen et al., 1978; Coons et al., 1989; O'Sullivan and Bouw, 1984; Watkins and Cantliffe, 1983). When pepper is seeded directly in the field, soil temperature often can be suboptimal. For example, in the Middle Valley of the Ebro River (one of the commercial pepper production areas in Spain), the soil mean averages 10 to 20C at the 2- to 4-cm depth on typical seeding dates. Suboptimal soil temperatures result in delayed nonuniform pepper emergence. The problem is exacerbated as the length of time to emergence increases because the probability of soil crust formation becomes greater. This problem with pepper has been documented by numerous researchers in Spain (Costa, 1991; Rodriguez and Ayuso, 1988) and the United States (Gerson and Honma, 1978; McGrady and Cotter, 1984; Orzolek and Daum, 1984; Randle and Honma, 1981; Schultheis and Cantliffe, 1988). Obtaining ideal plant stands can be difficult, even with species that are less demanding in regard to temperature, such as tomato (Bussell and Gray, 1976; Herner, 1986; Maluf and Tigchelaar, 1980).

Direct seeding under clear polyethylene mulch reduces soil crusting, increases soil temperature, and has been used successfully in cotton (*Gossypium hirsutum* L.) (Marquez, 1990) and tomato (Guerard, 1990; Lopez, 1990; May, 1991). Our principal goal was to improve stand establishment and yields of direct-seeded pepper using this technique. Specific cultural management practices, such as planting dates, seeding system (raised bed or flat ground), and rows per bed, were evaluated to improve plant stands and pepper yields.

Table 1. Seeding systems tested for emergence of bell pepper seed.

Year and seeding system	Seeding date (April)
1991 (one row)	
Mulched raised bed	8, 12[z], 25
Mulched flat ground	12[z]
Nonmulched raised bed (one plot)	12
1992 (two rows)	
Mulched raised bed	8[z]
Mulched flat ground[y]	8[z]
Nonmulched raised bed (one plot)	8

[z]Treatments where yields also were recorded.
[y]Emergence data were not recorded.

Materials and Methods

Emergence 1991. Seeding date and system were evaluated (see Table 1). 'Piquillo de Lodosa' (Piquillo) sweet pepper was field-seeded on mulched raised beds on 8, 12, and 25 Apr. in a loamy soil (37.2% sand, 43.8% silt, 19.0% clay, 1.76% organic matter, pH 8.3) in Saragossa, Spain (lat. 41°43´N, long. 2°52´W). Plots were irrigated before each seeding such that soils were near field capacity at seeding. Mulched raised beds were 1 m wide and 20 cm high, with single rows 1.5 m apart (a distance between rows greater than that recommended commercially because the equipment was set for commercial direct-seeded tomatoes). Mulched flat ground culture comprised the second seeding system and was only included in the 12 Apr. planting; but in this case, seeds were seeded in single rows 1.2 m apart because of equipment constraints. For observation, one 30-m-long bed with the same characteristics of raised mulched beds, but without

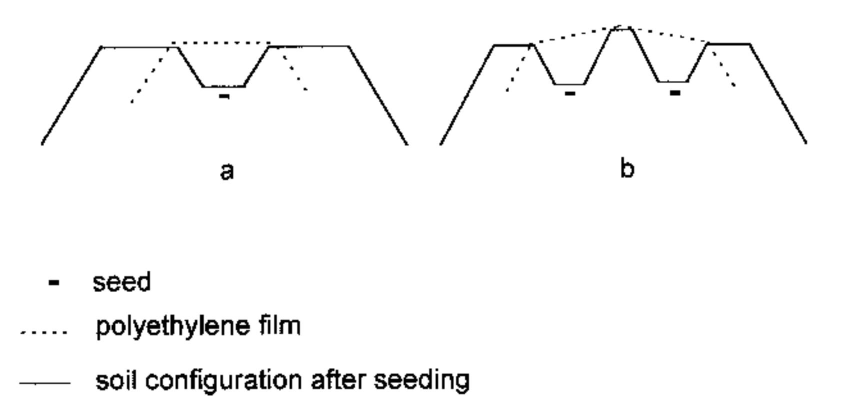

Fig. 1. Plastic mulch covering (**a**) one row or (**b**) two rows when seeded in the bed in 1991 and 1992, respectively.

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plastic mulch, also was seeded on 12 Apr. All rows were east–west oriented.

Seeding was performed with a commercial pneumatic seed drill (model SV260; Gaspardo, Pordemone, Italy). The drilling body was preceded by a small plow that made a furrow ≈8 to 10 cm deep. The drill placed the seed in the bottom of the furrow 1.5 to 2 cm deep. Distance between seeds was 4.1 cm. After seeding, diphenamid was broadcast-applied at 4 kg a.i./ha. The furrow formed in the bed center was manually covered with transparent polyethylene film (Fig. 1a). The film was 0.025 mm thick and 1 m wide. The number of seeds planted in every plot was standardized by using the same weight of seed.

Except for the nonmulched bed, the experimental plot unit consisted of three beds, each 8 m long. The nonmulched bed was only used to confirm the negative results experienced in previous years using direct seeding in bare soils; therefore, it was neither replicated nor included in the statistical analysis. Eight replications were used in the 12 Apr. planting while six were used for the remaining planting dates. Treatments and replications were arranged in a completely randomized design. Emerged plants (two cotyledons unfolded) were counted every 7 days in the central bed. Soil temperature at a 1.5- to 2-cm depth in nonmulched and mulched soil on raised beds and flat ground was recorded every minute using a data logger (1200 series; Grant, Cambridge, England). Weekly emergence data (mulch treatments only) were tested using analysis of variance and mean separations were calculated using Fisher's protected least significant difference test. When the soil temperatures under plastic mulch were consistently >35C, the plastic was perforated manually [one hole (3 cm in diameter) every 25 cm].

Emergence, 1992. Seeding systems were evaluated (Table 1) in a field with a similar soil type as in 1991. To simulate a commercially recommended distance between rows, instead of one row per bed, two rows (35 cm apart) were seeded on east–west-oriented beds (1 m wide) on 8 Apr. A small dirt ridge was formed between the rows by two plows making two furrows just ahead of the two drilling bodies (Fig. 1b). Clear polyethylene mulch was mechanically placed using a plastic layer (Gadea, Saragosssa, Spain) linked to the seed drill covering the two rows in each bed. The center ridge was slightly higher than the remainder of the top of the bed. This procedure helped move rain water away from the furrows where the seeds were placed (Fig. 1b). Rain water, if excessive, can cause rotting of seeds and seedlings at the germination and emergence phases.

The experimental plot unit consisted of three raised beds, each 8 m long (with two rows in it), which was replicated 15 times. One observational plot consisting of a 30-m-long, raised, east–west-oriented bed without plastic mulching also was seeded, as in 1991. The soil temperature of beds under mulched and bare soil was recorded and emergence evaluation was performed as in 1991; however, rows on the north and south sides were recorded separately for each bed. Paired data were analyzed using a *t* test.

Yields. The effect of seeding system (raised bed or flat ground) on yield of Piquillo pepper was studied in both years. In 1991, the plots of 12 Apr. seeding were used. In 1992, plots seeded on flat ground with the same row placement as in raised beds were used in addition to those seeded in beds for the emergence study. The experimental plot unit was the same as in the emergence studies, but peppers were harvested only from the central 4 m of the central bed. At 7 weeks after seeding, plants were thinned to have 14.5 plants/m in the row in 1991. In 1992, the same plant rate was distributed between the two rows. Eight replications per system were used in a completely randomized design. Marketable red fruit (Boletin Oficial del Estado, 1995) were harvested three times (23 Sept. and 8 and 23 Oct. 1991, and 16 Sept. and 7 and 21 Oct. 1992), and yields were compared with a *t* test.

Fields used both years had been laser-planed in 1990. Crop management was according to recommended cultural practices (Elejabeitia, 1970). Chlorpyriphos at 3.5 kg•ha^{-1} and 10N–7.9P–13.3K fertilizer (calcium nitrate, superphosphate, and potassium chloride) at 600 kg•ha^{-1} were incorporated in the soil before seeding. A top dressing before bloom consisted of N at 50 kg•ha^{-1} as NH_4NO_3. Furrow irrigation was used. In 1991, plots were irrigated first on 21 May, and plastic was removed on 30 May. In 1992, the first irrigation was on 22 Apr., and plastic was removed on 12 May. Thereafter, plots were irrigated every 10 to 15 days until the end of August. Weed control was manual.

Table 2. Average temperature differences (± standard deviation) between mulched soil under transparent polyethylene and bare soil in the pepper beds at various time intervals.

Year and time interval	Temp mulched soil – temp bare soil (°C) Mean	Min	Max
1991			
10–30 Apr.	5.3 ± 1.9	4.4 ± 1.3	6.8 ± 3.1
1–16 May	7.1 ± 0.6	5.4 ± 0.8	9.5 ± 1.7
16–30 May[z]	2.7 ± 1.7	2.7 ± 0.8	3.0 ± 4.0
1992			
1–20 Apr.	6.6 ± 1.9	2.3 ± 0.9	13.5 ± 4.5
20 Apr.–12 May[z]	5.0 ± 2.5	3.4 ± 1.8	7.4 ± 4.8

[z]Perforated polyethylene.

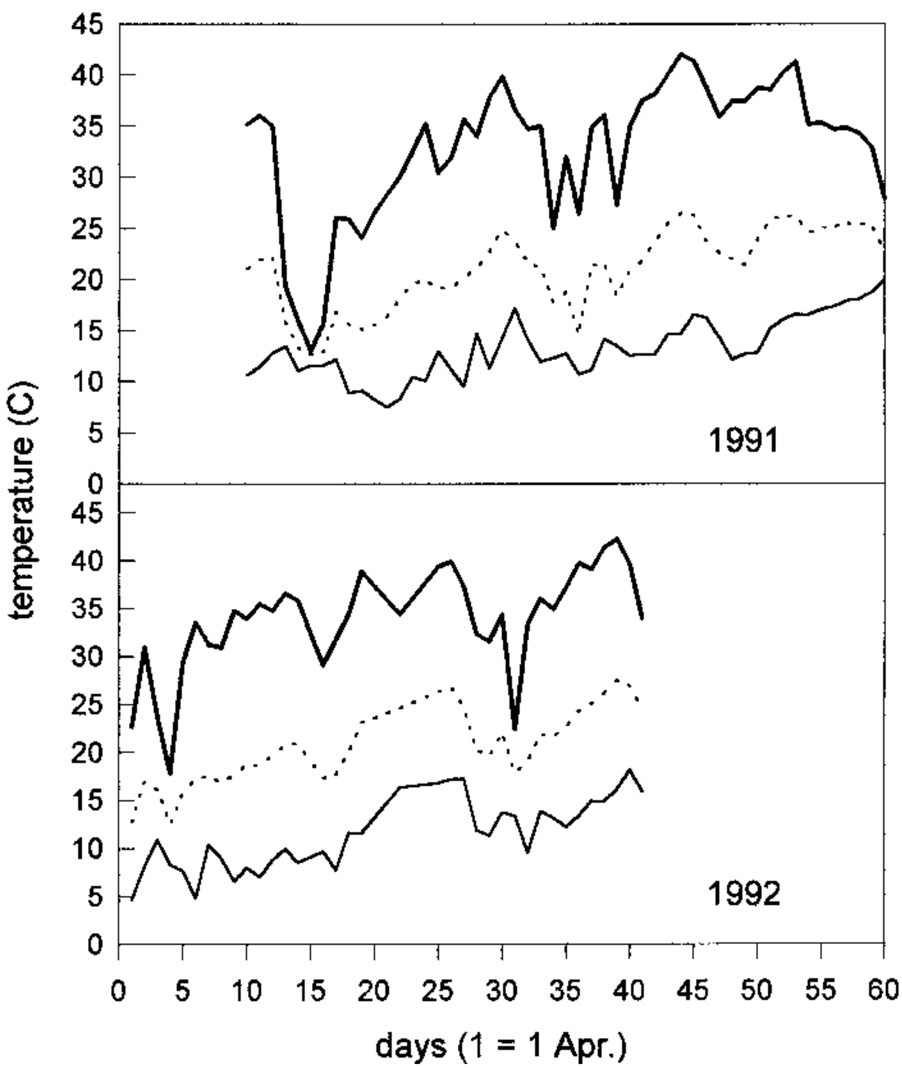

Fig. 2. (▬▬) Maximum, (——) minimum, and (-------) mean daily temperature (°Celsius) at seed depth in a mulched soil in 1991 and 1992.

Results

Temperatures

In the beds, plastic mulch (compared to bare soil) increased the soil mean 5 to 7C from 1 Apr. to 16 May, the minimum 2 to 5C through 30 May, and the maximum 7 to 13C from 1 Apr. to 16 May (Table 2). Thus, the mean daily temperature of soil at seeding depth under plastic mulch in the furrow was >15C almost every day, the daily minimum was >10C in 1991 and >7C in 1992, and daily maximum ranged between 13 and 43C (Fig. 2). Plastic perforation ameliorated the increase in soil temperatures relative to bare soil (Table 2).

Emergence

Emergence was absent on nonmulched beds in both years.

1991. Maximum percent emergence for all the planting dates was attained 4 weeks after seeding (Fig. 3). Emergence (81%) ($P \leq 0.05$) was highest for the 12 Apr. seeding date. Plots seeded on 25 Apr. had the lowest emergence (27%), which was significantly lower ($P \leq 0.05$) than for the 8 Apr. seeding. Emergence for the last seeding date likely was low due to the high soil temperatures under the polyethylene mulch (maxima >35C almost every day from 2 weeks after seeding). Percent emergence at other record dates were similar for the 8 and 12 Apr. seeding dates, probably because only 4 days separated seeding. The high soil temperatures recorded under plastic mulch after 10 May resulted in death of many plants and reduced plant stands (25% of emerged plants died in the 8 Apr. seeding, while 60% died in the 12 Apr. seeding).

For the 12 Apr. seeding, the percentage of emergence was similar for raised beds and flat ground 3 weeks after seeding but was higher on raised beds 4 weeks after seeding (Fig. 4). However, during the following 3 weeks, more plants died on beds than on the flat ground. Thus, 7 weeks after seeding, plant stands on beds were significantly lower ($P \leq 0.05$) than on flat ground, probably because temperatures were higher in beds (Fig. 4) and soil moisture was higher in flat ground (visual observation).

Piquillo pepper ripened regardless of seeding date, although ripening was delayed 1 to 2 weeks with the last sowing date (25 Apr.). For the 8 and 12 Apr. seeding dates, fruit ripened at about the same time as commercial peppers grown in adjacent farms where transplanting was used.

1992. At 3 to 6 weeks after seeding, emergence percentages on beds were significantly higher ($P \leq 0.05$) in the rows located on the north compared to the south side of the beds (Fig. 5). Soil on the south side may have dried because the plastic mulch on the south side was partially removed for several hours by high-speed wind. In addition, the maximum daily temperatures in the south-oriented rows were higher (>35C for many days) than in those of north-oriented rows (Fig. 5). After 20 Apr., soil temperatures in the south side were

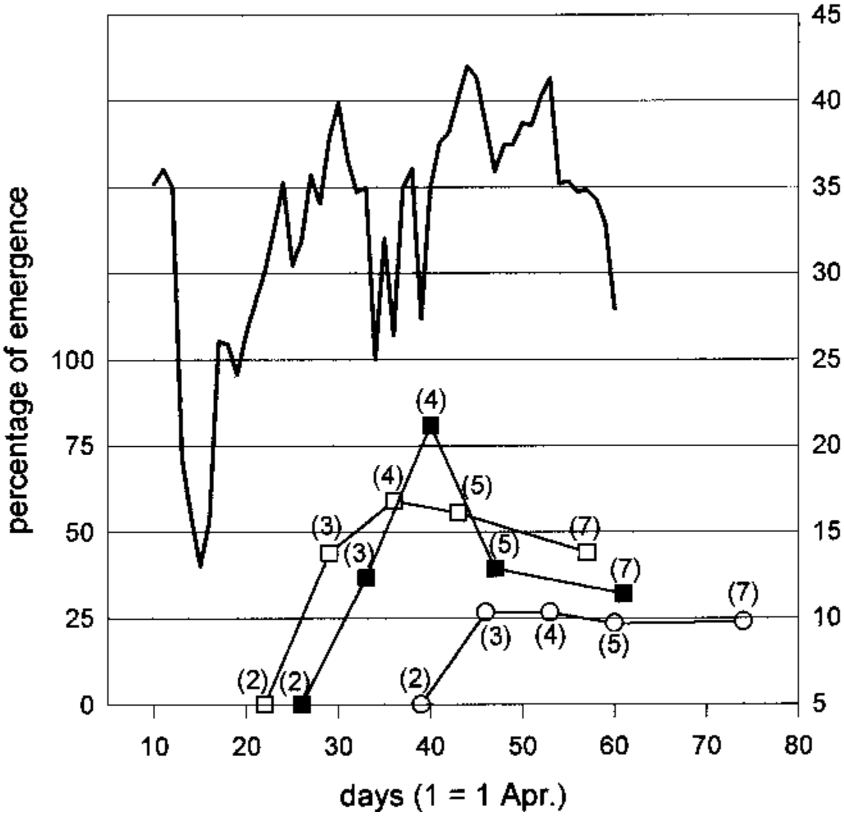

Fig. 3. Progress of emergence according to seeding date [(□) 8, (■)12, and (○) 25 Apr. 1991] and maximum daily temperature at seed depth under (▬▬) clear plastic mulch. Numerals in parentheses indicate the number of weeks after seeding.

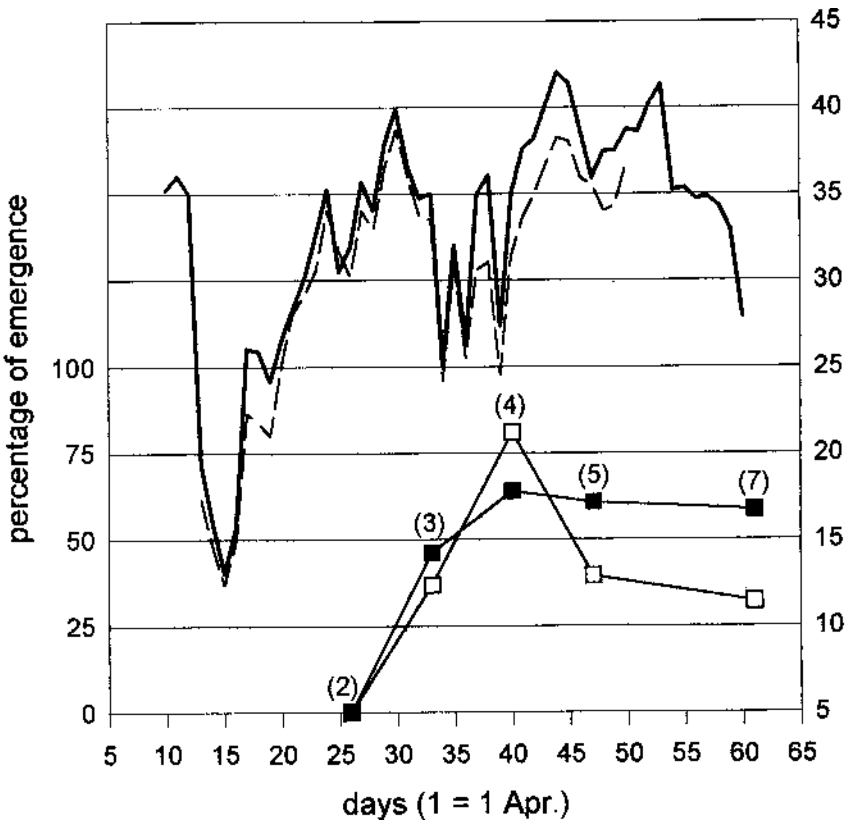

Fig. 4. Progress of emergence in (□) bed and (■) flat ground and maximum daily temperature at seed depth in the (▬▬) bed and (---------) flat ground in soil under clear plastic mulch in 1991. Numerals in parentheses indicate the number of weeks after seeding.

unavailable because of a problem with the data logger. Maximum plant stands were reached 4 weeks after seeding. Later, some plants in the north and south rows died, presumably due to high temperatures (Fig. 5).

Yield

In both years, significantly higher yields were obtained with raised beds compared to flat ground (Table 3).

Table 3. Yields of marketable red Piquillo pepper for two seeding systems, 1991 and 1992.

	Yield (kg•ha^{-1})[z]	
Seeding system	1991	1992
Raised bed	9,244 b	11,730 b
Flat ground	4,018 a	7,854 a

[z]For each year, mean separation according to a *t* test at $P \leq 0.05$.

Discussion

Our results indicate that using plastic mulch in the Saragossa area of Spain and similar climates provides an option for obtaining acceptable plant stands if pepper is direct-seeded in early April. At that time, the mean soil temperature of polyethylene-mulched beds is >15C, which is recommended for seeding pepper (Somos, 1984). The success of similar direct seeding, followed by mulch, in other crops and countries (Guerard, 1990; Marquez, 1990; May, 1991) indicates that this cultural practice can be extended to other areas where pepper is grown and low soil temperatures early in the season are a major constraint for pepper emergence.

High soil temperatures (>35C) under the polyethylene mulch killed seedlings. Although pepper plants may tolerate high temperatures under plastic (Gerber et al., 1988), this is undesirable in the germination phase and as seedlings emerge. Thus, temperatures need to be monitored, and the plastic needs to be perforated or removed before temperatures become too high.

If plastic is perforated at seeding, the risk of high soil temperatures diminishes; however, the mean soil temperatures may become suboptimal (Marquez, 1990). In addition, rain water can drip through the perforations in the plastic into the seeding furrow, causing the rotting of seed and seedlings. This problem is more likely to occur in single-row plantings since the plastic more easily collects water in the furrow. When a double row is seeded, the plastic can be ridged at the center of the bed (Fig. 1b), which allows the rain water to collect on the outside of the bed. This shape also is advantageous if the plastic is perforated at seeding time. The emergence differences found between the two rows in 1992 suggest that north–south-oriented beds should be tested to obtain a more uniform temperature in the bed and similar emergence in both rows.

When considering only emergence, raised bed and flat ground seeding are recommended. Raised beds increase soil drainage (Marquez, 1990), which is important for emergence and yield in medium or heavy soils (as used in our work). However, supraoptimal temperatures that reduce stands and yield may be encountered more frequently when seeding on raised beds (Marquez, 1990).

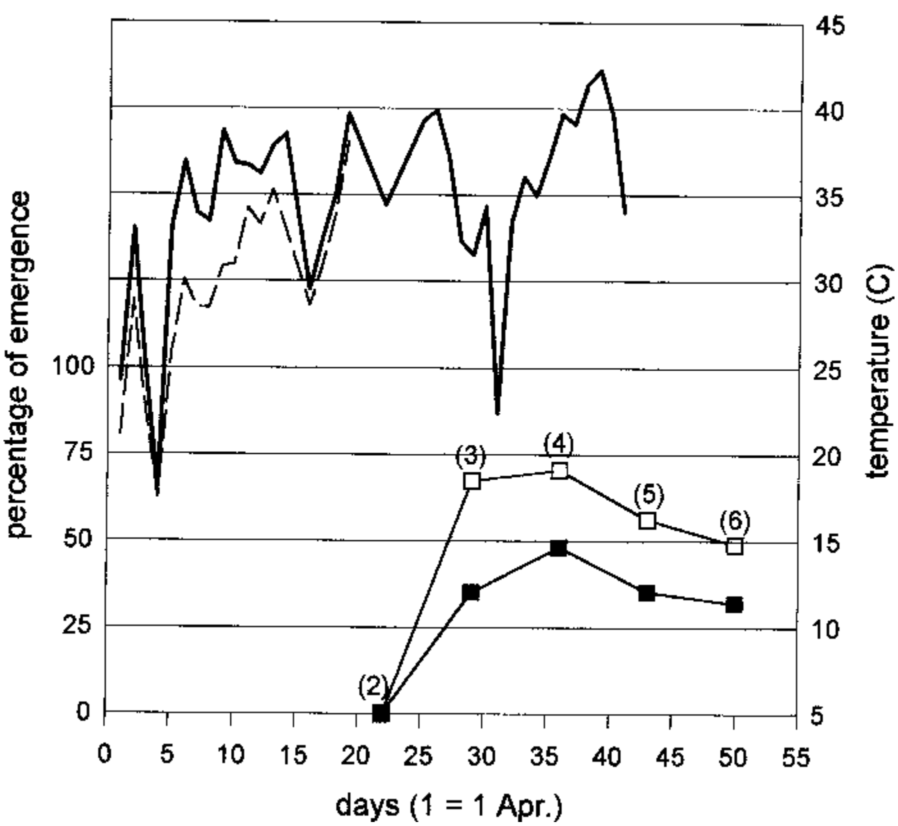

Fig. 5. Progress of emergence in (❐) north and (■) south sides of bed and maximum daily temperature at seed depth in the (---------) north and (▬▬▬) south sides in soil under clear plastic mulch in 1992. Numerals in parentheses indicate the number of weeks after seeding.

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