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in

Cantero-Martínez C. (ed.), Gabiña D. (ed.).
Mediterranean rainfed agriculture: Strategies for sustainability

Zaragoza : CIHEAM
Options Méditerranéennes : Série A. Séminaires Méditerranéens; n. 60

2004
pages 63-71

Crop emergence and early crop growth of barley affected by crop residue under different tillage systems and N fertilization rates in semiarid conditions of Northeast Spain

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SUMMARY – The influence of tillage system and nitrogen fertilization on crop residue and its effect on crop emergence of barley under rainfed conditions were studied from 1998 to 2002. Evolution of crop residues was monitored from harvest to the next crop establishment. Crop emergence and early growth were also estimated. No-tillage presented higher crop residue on the surface than minimum tillage and conventional tillage during the whole period studied. Higher nitrogen rates also produced higher crop residue biomass. However, crop residue biomass did not affect crop emergence. Moreover, higher values of crop residue biomass, obtained by no-tillage and high nitrogen fertilization treatments, were associated with superior early crop growth. Higher soil temperature at 5 cm-depth shown by the no-tillage system during the crop emergence period could explain the higher early crop growth observed under no-tillage.

Key words: Barley, crop emergence, early growth, crop residue, tillage, fertilization, Northeast Spain.

RÉSUMÉ – *"Levée et croissance précoce d'une culture d'orge affectée par des résidus de culture sous différents systèmes de labour et taux de fertilisation azotée dans les conditions semi-arides du nord-est de l'Espagne". Cet article étudie l'influence du système de labour et de la fertilisation azotée sur les résidus de culture et leur effet sur la levée d'une culture d'orge en conditions non irriguées, de 1998 à 2002. L'évolution des résidus de culture a été suivie de la récolte jusqu'à l'établissement de la culture suivante. La levée de la culture ainsi que la croissance précoce ont aussi été estimées. Le fait de ne pas labourer a donné des résidus de culture plus élevés en surface qu'avec le labour minimum et le labour conventionnel pendant toute la période d'étude. Des taux d'azote plus élevés ont également produit une plus grande biomasse de résidus de culture. Cependant, la biomasse de résidus de culture n'a pas affecté la levée de la culture. De plus, des valeurs plus élevées de biomasse de résidus de culture, obtenues dans les traitements de non labour et forte fertilisation azotée, ont été associées à une plus grande croissance précoce de la culture. Une température plus élevée du sol à 5 cm de profondeur résultant du système de non labour pendant la période de levée de la culture pourrait expliquer cette plus grande croissance précoce de la culture observée en non labour.*

Mots-clés : *Orge, levée de la culture, croissance précoce, résidus de culture, labour, fertilisation, nord-est de l'Espagne.*

Introduction

Tillage and nitrogen fertilization are the most expensive techniques for farmers in dryland areas. Thus, conservation tillage and optimization of nitrogen fertilization help reach sustainability under semiarid conditions.

Conservation tillage systems are based on the maintenance of crop residues on the surface covering a minimum of 30% soil. Nitrogen management also influences crop residues left on the surface since biomass production is affected by nitrogen availability and crop residue decomposition.

Crop residue management is one of the most important factors for improving the soil's physical, chemical and biological properties. Residue helps reduce surface runoff and soil loss, conserving soil moisture and improving soil microbial populations (Al-Kaisi, 2002). The benefits of surface residues for erosion control and water conservation are well documented (Unger, 1978, 1988; Larson *et al*., 1978). However, high values of crop residue left on the surface could induce detrimental effects on the next crop. Many factors are involved but, where straw remains on the soil surface, mechanical impedance of seed drills increase, causing problems in seed distribution at sowing (Harper, 1989). Felton *et al.* (1987) also reported problems under no-tillage systems for weed control, incorrect nutrition, and, especially, the production of phytotoxins, which could affect the next crop growth. In addition, crop emergence and early crop growth could be negatively affected as a consequence of a reduction in soil temperature (Felton *et al*., 1987; Poole, 1987; Horton *et al.,* 1994).

Numerous studies have reported a soil temperature decrease under conservation tillage as compared to conventional tillage due to the presence of crop residues on the surface (Unger, 1978; Gupta *et al*., 1981; Wall and Stobbe, 1983; Aston and Fischer, 1986). Although how tillage affects soil temperature depends mainly on the type of tillage, other factors such as air temperature, precipitation, the amount of soil cover and the time of the year are involved (Willis and Amemiya, 1973). Thus, the present study was developed with the purpose of studying the influence of tillage system and nitrogen fertilization on soil crop residue and its effect on crop emergence and early crop growth of barley cultivated under semiarid Mediterranean conditions.

Material and methods

Location

The experiment was established during the 1996-1997 growing season at Agramunt (1º7’10’’E, 41º 48’41’’N), located in Catalonia, in the northeast of Spain, in a semiarid area where conservation tillage is extensively used and continuous barley is the most important cropping system.

Climate and soil classification

Average annual precipitation is 429.1 mm mainly distributed in spring and autumn. Mean annual temperature is 13.6 ºC, with cold winters and hot summers. According to Papadakis (1966), the area climate is considered as a Temperate Continental Mediterranean.

Soil was classified as a Xerofluvent typic (SSS, 1994) with a pH of 8.5, 0.9% of soil organic matter content, 12 ppm of P (Olsen method) and 155 ppm of K ($AcONH_4$ method). The water holding capacity of the soil (0-1 m) is 236.7 mm.

Experimental design

The experimental design was a double factorial in randomized blocks with three replications. The plot size was (50 x 6) m. Two factors were tillage system and nitrogen fertilization. Tillage system treatments were: conventional tillage (mouldboard plough + cultivator + roller); minimum tillage (cultivator + roller); and no-tillage (glyphosate prior sowing). Three nitrogen fertilization rates were: zero, medium (60 kg N/ha) and high (120 kg N/ha).

Agronomic management

The agronomic management of the experiment was the traditional management in the area used by local farmers. Tillage was done at the beginning of the autumn, after the first fall rains. For the no-tillage system, a glyphosate herbicide treatment was applied before sowing. Fertilization prior to sowing consisted of 18 kg/ha of P (superphosphate, 18%), 50 kg/ha of K (potassium chloride, 60%) and 40% of nitrogen fertilization rates (ammonium sulphate, 21%). The 60% of the remaining nitrogen fertilization rate was applied at tillering as ammonium nitrate (33%). Continuous barley was cultivated in all growing seasons and sown from the end of October to the beginning of November with a rate of 450 seeds per square meter. The experiment was free of weeds through the use of herbicide treatments applied during February. Harvest was done at the end of June with a standard combine. Straw was chopped and spread.

Measurements

Daily temperature and precipitation were obtained from a standard station situated near the experimental fields.

Crop residue was measured during three consecutive growing seasons, 1999-00 to 2001-02, at crop establishment, considered when emerged plants had one leaf (December). Two variables were measured in order to estimate the presence of crop residues: crop residue biomass and soil residue cover. Crop residues were collected from three samples of 0.36 m^2, oven-dried at 70 ºC until constant weight, and weighed. Previously, crop residue samples were cleaned of soil contamination when necessary. Soil cover was determined four times in each plot by the transect line method using a band of 10 m long with marks every 10 cm (100 marks). The band was extended over the soil with an angle of 45º, and then checked at every mark to see if that point touched a piece of residue. The percentage of residue cover is the number of times residue touches the check points.

Crop emergence was also determined at crop establishment (December) and at the beginning of tillering (February). Plants were counted in a 50-cm-long section of one row, three times by plot.

Early crop growth was estimated measuring biomass at the beginning of tillering. Plant samples composed of a 50-cm-long section of three rows were taken, oven-dried for 48 h at 65 ºC, and weighed.

Soil temperature was estimated with temperature sensors (thermocouples). Three sensors per plot were placed at 5 cm-depth. Sensors were connected in a data-logger (Campbell CR10). Soil temperature was measured every 10 minutes and average temperature was recorded every hour.

Statistical analysis

Statistical analyses were made using SAS software (SAS, 1996). Variance analyses were made to determine the effects of the main factors and their interactions. Mean separations were obtained for significant effects with the Duncan test ($p < 0.05$).

Results

Climate characteristics

From November to February, all growing seasons were different compared with the long-term average (Table 1). During the 1999-2000 cycle, January was especially cold, with 1.9 ºC mean temperature in comparison to the 3.9 ºC of the long-term average. The following year, 2000-01, December and January had 2.4 ºC and 2.1 ºC higher mean temperature than average, respectively (Table 1). Finally, December 2001-02 was exceptionally cold, with a mean temperature of –1ºC (Table 1). Snow covered the field for 20 days and protected plants from temperatures below –10 ºC.

Precipitation during the soil recharge period (September to February), was similar to the long-term average in the 1999-00 growing season, whereas 2000-01 was wetter and 2001-02 was drier than the normal average (Table 1).

Crop residue biomass and soil residue cover

Crop residue biomass at crop establishment was affected by year, tillage system and nitrogen fertilization rate (Table 2).

Differences among tillage systems for crop residue biomass were statistically significant, with no-tillage showing the highest value for crop residue biomass (Table 2). Minimum tillage has a very low value, only 12% of the crop residue biomass presented by the no-tillage system, whereas conventional tillage practically has no residues on the surface at crop establishment (Table 2). The year x tillage interaction was of quantitative nature, since crop residue biomass was higher for no-tillage in all years (Table 2).

Table 1. Monthly mean temperature (ºC) and precipitation (mm) during the studied period compared to the long-term average (1976-2001) in Agramunt (Spain)

	Mean temperature (ºC)				Precipitation (mm)			
	1999-00	2000-01	2001-02	Log-term average	1999-00	2000-01	2001-02	Log-term average
September	20.1	20.8	18.1	19.6	79.8	25.0	26.7	28.9
October	14.4	13.8	16.5	13.8	52.4	39.3	27.2	43.7
November	5.9	7.5	6.0	7.7	38.1	50.9	33.2	54.2
December	4.0	6.9	-1.0	4.5	3.0	64.4	28.6	40.3
January	1.9	6.0	4.2	3.9	0.3	33.4	13.7	16.9
February	8.3	5.9	6.9	6.2	0.0	4.6	7.1	28.4
March	10.5	13.3	11.0	9.5	42.0	36.1	17.8	43.8
April	12.4	12.8	12.9	12.1	60.4	52.0	74.6	52.9
May	19.2	17.5	16.0	16.5	87.5	30.4	33.7	39.9
June	22.2	23.5	22.7	20.9	80.7	8.6	25.2	32.9
July	23.7	24.3	24.1	24.6	1.7	40.6	11.0	31.1
August	25.6	25.5	21.0	23.9	5.3	9.4	30.1	16.1
Annual mean	14.0	14.8	13.2	13.6	451.2	394.7	328.9	429.1

Table 2. Crop residue biomass (g/m^2) and residue soil cover (%) at crop establishment (December) for three tillage systems (CT: conventional tillage, MT: minimum tillage, NT: no-tillage) and three nitrogen fertilization rates (zero, medium: 60 kg/ha, high: 120 kg/ha) in barley cultivated from 1999-00 to 2001-02 in Agramunt (Spain)

	Crop residue biomass (g/m^2)				Soil residue cover (%)			
	1999-00	2000-01	2001-02	Average	1999-00	2000-01	2001-02	Average
Tillage system								
CT	0.1b	2.1b	0.2c	0.7c	0.1c	3.1c	0.1c	1.0c
MT	27.3b	20.6b	29.7b	25.9b	12.2b	15.3b	19.3b	15.6b
NT	277.8a	164.1a	197.9a	213.3a	95.3a	87.7a	88.2a	90.4a
Fertilization rate								
Zero	75.1b	33.6b	44.3c	51.0c	34.2b	32.2b	31.9b	32.8b
Medium	106.3a	59.9b	75.0b	80.4b	36.5a	36.5a	36.6a	36.6a
High	123.8a	93.4a	108.5a	108.6a	36.7a	37.2a	38.9a	37.6a
Annual average	101.7a	62.3b	75.9b	80.0	35.8a	35.3a	35.8a	35.6
	Analysis of variance							
Year (Y)	***				NS			
Tillage (T)	***				***			
Nitrogen (N)	***				***			
Y x T	***				***			
Y x N	NS				NS			
T x N	***				NS			
Y x T x N	NS				NS			

[a,b]Different letters within the columns indicate significant differences (LSD test at P = 0.05).
***Significant at P < 0.001.

Soil residue cover showed a similar trend as in the crop residue biomass (Table 2). No-tillage presented, on average, 90% of the soil surface covered by crop residues. Minimum tillage, with mean soil residue cover of 15.6%, always presented values below 30%, level established as the limit to be considered as conservation tillage system. Conventional tillage had values near 0% of soil residue cover (Table 2). Similarly to crop residue biomass, in all growing seasons no-tillage was the treatment with the highest soil residue cover and conventional tillage the treatment with the lowest.

Nitrogen fertilization rates influenced the level of biomass production, and higher values of crop residue biomass and soil residue cover were obtained for higher nitrogen rates (Table 2). However, response to nitrogen fertilization for crop residue biomass varied among tillage systems since the T x N interaction was significant (Table 2). Figure 1 shows the mean values of crop residue for each combination of tillage system and nitrogen fertilization at crop establishment. The lack of response of crop residue biomass to nitrogen fertilization can be observed under conventional and minimum tillage whereas no-tillage clearly presented high crop residue production, as nitrogen rate was increased (Fig. 1a). However, for soil residue cover no T x N was detected (Fig. 1b).

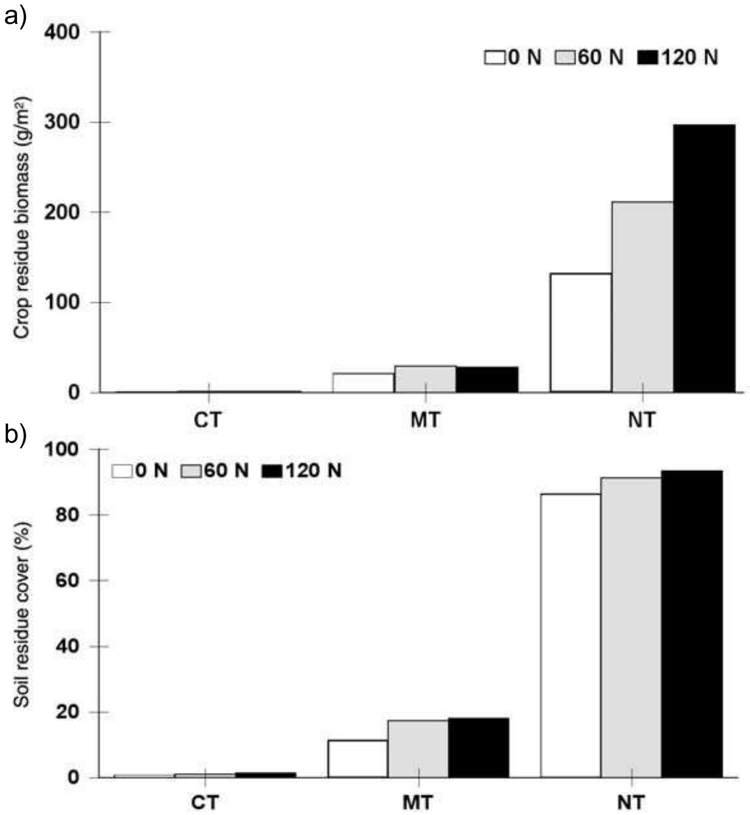

Fig. 1. Tillage system x nitrogen fertilization interaction for (a) crop residue biomass at crop establishment and (b) soil residue cover in barley cultivated from 1999-00 to 2001-02 in Agramunt (Spain).

Crop emergence and early crop growth

At crop establishment no differences for crop emergence were detected between either tillage systems or nitrogen fertilization rates (Table 3), and, independently of crop residue level, the number of emerged plants was similar. The same results were observed at the beginning of tillering, although, on average, the plant density was 60 plants/m^2 higher at the beginning of tillering than at crop establishment (Table 3).

At crop establishment, year x tillage system interaction was significant (Table 3). In the 2001-02 growing season, the emerged plant number was significantly superior for no-tillage than for both minimum and conventional tillage. However, differences among tillage systems disappeared at the beginning of tillering (Table 3), suggesting that under no-tillage the crop emergence was faster than under both minimum and conventional tillage.

Early crop growth, estimated as total biomass at beginning of tillering, was dependent on the year, with mean values ranging from 13.9 g/m^2 to 85.6 g/m^2. On average, total biomass produced by the crop was 40% superior for no-tillage system than for both minimum and conventional tillage (Table 4). No-tillage presented values of total biomass from 18.9 g/m^2 to 105.7 g/m^2, with similar results for each growing season (Table 4).

Table 3. Crop emergence of barley at crop establishment (December) and at the beginning of tillering (February) for three tillage systems (CT: conventional tillage, MT: minimum tillage, NT: no-tillage) and three nitrogen fertilization rates (zero, medium: 60 kg/ha, high: 120 kg/ha) from 1999-00 to 2001-02 in Agramunt (Spain)

	Crop residue biomass (plants/m^2)				Tillering (plants/m^2)			
	1999-00	2000-01	2001-02	Average	1999-00	2000-01	2001-02	Average
Tillage system								
CT	351a	332a	231b	305a	454a	363a	311a	376a
MT	378a	340a	247b	322a	433a	361a	283a	359a
NT	361a	310a	301a	324a	414a	379a	306a	366a
Fertilization rate								
Zero	385a	312a	263a	320a	440a	345a	277a	354a
Medium	363a	350a	250a	321a	414a	368a	317a	366a
High	343a	320a	268a	310a	446a	390a	305a	381a
Annual average	364	328	260	317	433	368	300	367
	Analysis of variance							
Year (Y)	***				***			
Tillage (T)	NS				NS			
Nitrogen (N)	NS				NS			
Y x T	*				NS			
Y x N	NS				NS			
T x N	NS				NS			
Y x T x N	NS				NS			

[a,b]Different letters within the columns indicate significant differences (LSD tests at P = 0.05).
***Significant at P < 0.001.

Table 4. Early crop growth estimated as crop biomass at tillering (g/m^2) for three tillage systems (CT: conventional tillage, MT: minimum tillage, NT: no-tillage) and three nitrogen fertilization rates (zero, medium: 60 kg/ha, high: 120 kg/ha) in barley cultivated from 1999-00 to 2001-02 in Agramunt (Spain)

	Early crop growth (g/m^2)			
	1999-00	2000-01	2001-02	Average
Tillage system				
CT	30.6b	78.7b	11.6b	40.3c
MT	41.8a	72.6b	10.9b	41.8c
NT	49.1a	105.7a	18.9a	57.9a
Fertilization rate				
Zero	36.2b	64.8b	11.6b	37.5c
Medium	38.2b	92.7a	13.8ab	48.2b
High	47.1a	99.3a	15.9a	54.1a
Annual average	40.5	85.6	13.9	46.7
	Analysis of variance			
Year (Y)	***			
Tillage (T)	***			
Nitrogen (N)	***			
Y x T	***			
Y x N	***			
T x N	NS			
Y x T x N	NS			

[a,b]Different letters within the columns indicate significant differences (LSD tests at P = 0.05).
***Significant at P < 0.001.

Nitrogen fertilization also influenced early crop growth, increasing total biomass as nitrogen fertilization rate increased (Table 4). Also, the growing season affected the nitrogen fertilization response as can be deduced from the year x nitrogen interaction (Table 4). However, tillage systems responded similarly when nitrogen fertilization was increased, since tillage x nitrogen interaction was not detected (Table 4).

Soil temperature

Mean daily soil temperature at 5 cm-depth decreased during the crop emergence period (15th November to 30th November) from 12.5 ºC to 9.5 ºC. In the period studied, no-tillage system had higher soil temperature than both minimum and conventional tillage (Fig. 2a). Conventional tillage had the lowest values for soil temperature at 5 cm-depth, especially at the end of November. Differences among tillage systems varied from 0.2 ºC to 1.2 ºC.

Figure 2b shows the hourly evolution of soil temperature at 5 cm-depth over three consecutive days. The lowest change between day and night soil temperatures was observed under no-tillage. Soil temperatures during the night were 4 ºC higher for no-tillage than for conventional tillage. Also, during the day, soil was 1.5 ºC cooler under no-tillage than under conventional tillage.

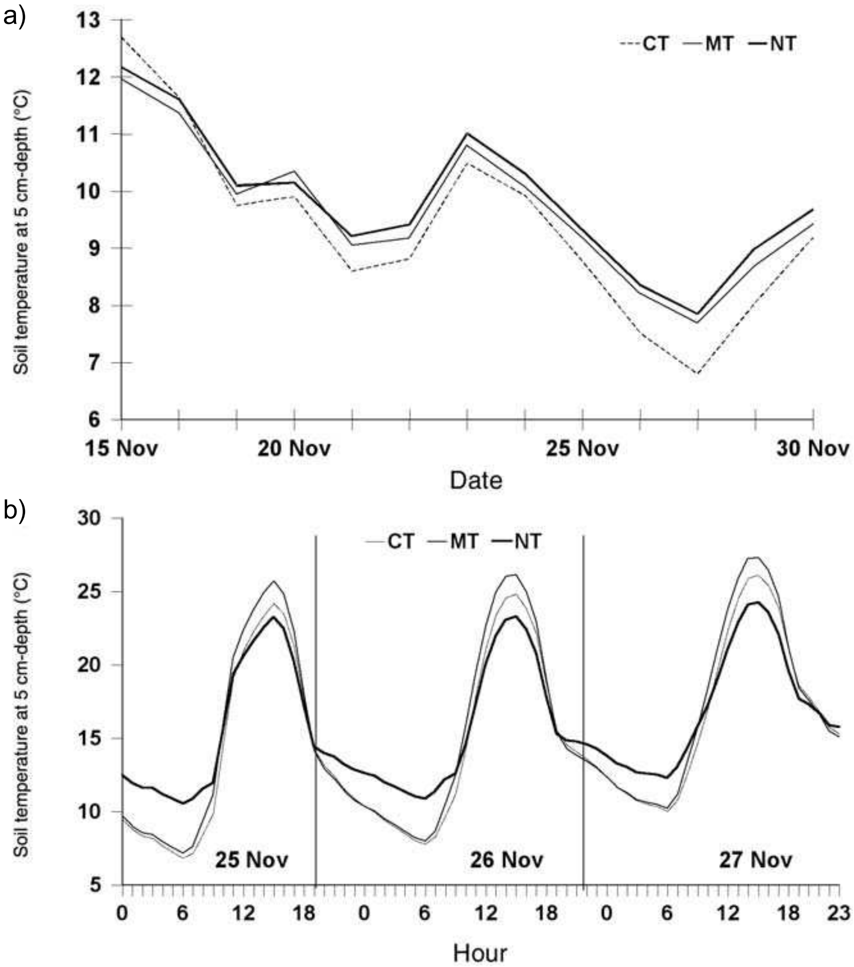

Fig. 2. Average soil temperature in 1999 and 2000 at 5 cm-depth (ºC): (a) mean daily soil temperature during the crop emergence period, (b) diurnal variation of soil temperature during three consecutive days in the crop emergence period.

Discussion

Retention of crop residues on soil surface is currently receiving much attention due to their benefits in terms of erosion control, soil fertility and water conservation (Unger, 1988). However, some concerns involving maintenance of crop residues in conservation tillage systems is one of the major obstacles to the adoption of reduced cultivation (Harper, 1989). Straw could induce detrimental effects on crop establishment and crop growth through different ways. Nevertheless, crop residue can be managed to minimize the risk of these factors reducing yield (Felton *et al.*, 1987).

Results obtained in the present study showed large differences for crop residue biomass and soil residue cover among tillage systems at crop establishment, considered when barley had one leaf, usually in December (Table 2). Clearly, more intensive tillage was associated with lower presence of crop residues on the soil surface. Thus, on average, no-tillage retained 213 g/m^2 of crop residue, whereas minimum tillage only retained 25.9 g m^{-2}. Conventional tillage had no crop residues on the surface after crop establishment (Table 2). Similar results were observed for soil residue cover, with values around 90% for no-tillage, 15.6% for minimum tillage and 1% for conventional tillage (Table 2). The effect of tillage system on crop residue retained on soil surface in terms of soil residue cover are comparable to other works in wheat and barley (Kabakci *et al.,* 1993; Al-Kaisi, 2002). Values of crop residue biomass and soil residue cover maintained at crop establishment are also related to prior biomass production, a fact that could explain observed differences for crop residue biomass and soil residue cover at crop establishment between years.

Despite the high values of crop residue observed at crop establishment, no negative effects associated to the presence of straw were detected for either crop establishment or early crop growth (Tables 3 and 4). Phytotoxicity problems have not appeared in these conditions during the studied period. Also, in any of the growing seasons, crop emergence has been decreased as a consequence of physical problems by the straw presence at sowing. The straw management, chopped and spread at harvest, help to avoid sowing problems.

Some detrimental effects on crop emergence and early crop growth associated to lower soil temperature have also been indicated as disadvantages of conservation tillage systems (Aston and Fischer, 1986). In this study crop residues had a great and positive influence in soil temperature during crop emergence. Diurnal soil temperature amplitudes under treatments with crop residues were much smaller (Fig. 2b), as has been reported by Van Doren and Allmaras (1978) and Horton *et al.* (1994). But in our case, in spite of a higher amount of retained crop residues (Table 2), no-tillage system presented a higher daily soil temperature at 5 cm-depth than both minimum tillage and conventional tillage from 15th to 30th November (Fig. 2a), contrarily to some reports previously published in corn (Wall and Stobbe, 1983; Beyaert *et al*., 2002) and wheat (Aston and Fischer, 1986). Results for soil temperature could explain the lack of differences for barley emergence among both tillage systems and nitrogen fertilization. Treatments with higher value of soil residue cover presented the same emerged plant number in December than conventional tillage, with 0% of soil residue cover. Then, residues did not interfere with crop emergence of barley cultivated under the conditions of this experiment. Additionally, in very cold years such as the 2001-02 growing season, the presence of straw mulch could help to protect soil from very low temperatures, and then, crop emergence takes place faster with crop residues than without it, as can be observed for no-tillage during the 2001-02 cycle (Table 3). The same year, in February, differences for emerged plant number disappeared, which could indicate that completed crop emergence needed more time under minimum and conventional tillage (Table 3), with lower soil temperature than no-tillage (Fig. 2).

Early crop growth was also greater under no-tillage, probably due to higher soil temperatures during autumn and winter. Van Doorer and Allmaras (1978) indicated that residues could produce warmer soil temperatures during winter. Also, Willis and Amemiya (1973) reported that conventional tillage warmed the soil quicker in the spring than soil not fall-tilled, but during the autumn the contrary effect is produced under tillage and soil quickly loses temperature.

Probably, differences observed for early crop growth are not only explained by soil temperature but also by available soil water. Some studies done in the same experiment demonstrated the higher soil water availability for no-tillage (Santiveri *et al.*, 2003). In fact, during the studied period, the performance of the no-tillage system was superior to both minimum and conventional tillage due to the higher soil water availability (Santiveri *et al.*, 2003).

As a conclusion, the results obtained in this experiment indicated that no-tillage system is the best option to improve sustainability for barley cultivated in these conditions.

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