Effects of winter wheat cover crop desiccation times on soil moisture, temperature and early maize growth

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ABSTRACT

Two tillage systems for maize (*Zea mays*) after soybean (*Glycine max*), no-till (NT) and conventional till (CT), which consisted of double disking in the spring, were included in the experiment on two sites in Indiana, USA. Each tillage plot had three winter wheat (*Triticum aestivum* L.) cover crop levels: no cover crop (N), early desiccation (E), 3–4 weeks prior to planting the maize, and regular desiccation (R), within the maize planting week. Due to the mulching effect, both E and R for both tillage systems increased soil moisture, except in the case of spring drought, when E proved dominant. Soil temperature for both tillage systems showed N > E > R order. Young maize plants tended to grow taller and have greater shoot biomass in NT than in CT. Both E and R improved early maize growth. In the case of drought, the E proved significantly better for maize on both tillage treatments, due to the better soil water conservation, therefore the winter wheat cover crop should be desiccated early in given climate conditions.

Keywords: cover crop; maize, no-till; disking; soil moisture; soil temperature; growth; biomass; root; drought

A cover crop practice can alleviate some soil physical properties deteriorated from different soil tillage systems, due to the living cover plants growth during the winter period. Due to shoot and root growth of the cover crop and the effect of cover crop residues on soil properties, cash crop yields can be substantially improved (Burgos and Talbert 1996, Drury et al. 1999). But cover crops were also found to have detrimental effects on cash crop growth in some special cases, mostly due to the effects of less optimum soil moisture conditions, as showed by Campbell et al. (1984) and Adbin et al. (1998). Inadequate cover crop management can also influence soil temperature, because a high amount of cover crop residues can result in higher soil moisture. This can be important at the beginning of the growing season for temperature sensitive summer crops, as observed by Teasdale and Mohler (1993) and Calkins and Swanson (1998). Early maize establishment and development after cover crop growth is also of great consideration. Since the stem apex (growth point) is below the soil surface up to the V5 vegetative stage (Ritchie et al. 1997), which makes young maize plants very susceptible to soil environmental modifications as affected by cover crops. Inadequate soil moisture, low soil temperature, poor maize seed contact with the soil and even adverse allelochemical influences of cover crop residues on young maize plants are the most quoted impediments to early maize growth after cover crops (Campbell et al. 1984, Opoku and Vyn 1997). In order to determine the benefits of cover crop practices in Indiana, USA, previously conducted research (Ryan 2000) showed that winter wheat might be a promising choice for the cover crop in a 2-year maize-soybean crop rotation, because it is well adapted to local environmental conditions and it can produce beneficial soil physical properties. But, data were lacking on the effects on soil moisture and temperature and an early maize development. Also, it is not known when is the best time to terminate winter wheat cover crop growth for achieving optimal conditions for early maize growth. The fulfilment of these knowledge gaps can lead toward higher rate of adoption of winter wheat as a cover crop by farmers, since it may justify additional costs of the cover crop establishment by achieving benefits for maize cash crop growth, and thus improve sustainability of maize production.

MATERIAL AND METHODS

This research was conducted in Indiana, USA, at two Purdue University research farms: Southeast Purdue Agricultural Center (SEPAC), and Throckmorton Purdue Agricultural Center (TPAC), during the growing seasons 2000, 2001 and 2002. Soils for both sites were determined as a humogley at the SEPAC site and a chernozem at the TPAC site. The main design for both sites was a split-split-plot design in four blocks, with the main treatment of two tillage systems, split into two sub-treatments of cash crop and split again into three sub-sub-treatments of cover crop. Tillage treatments included no-till (NT), and conventional tillage (CT), consisted of the spring double disking at 10–15 cm depth. Cash crop treatments were maize (*Zea mays*) and soybean (*Glycine max*) in maize (C) – soybean (B) crop rotation. Since the cover crop experiments were originally established earlier for investigation of different cover crop plants (Ryan 2000), a decision was made to investigate different dates of desiccation for the winter wheat 100% cover crop only. Plots were split into halves, and then half-plots were split again into early (E; with goal to desiccate the cover crop 3–4 weeks prior to maize planting) and regularly (R; with goal to desiccate a cover crop 2–3 days prior to maize planting) desiccated cover crop plots by random choice. The no cover crop control plots (N) were divided into halves in the same manner, and only the half-plot adjacent to the E or R cover crop treatments was used as the experimental unit, with plot dimensions of 4.6 × 7.6 m. The winter wheat was seeded at the sowing rate of 110 kg/ha, in order to achieve 350–360 plants/m^2, thus providing above 80% of the soil coverage by plant residues. The winter wheat cover crop was drilled into cash crop stubble in the fall of the year 1999, and air-seeded by hand into the standing cash crop 2–3 weeks before the cash crop was harvested in falls of years 2000 and 2001. The herbicide Roundup Ultra TM in dosage of 1.93 kg/ha of active ingredient glyphosate [N-(phosphonomethyl) glycine] was used for both winter wheat desiccation times. Early winter wheat desiccation coincided with the ending of the tillering stage (growth stage 3 by Feekes), leaving around 700 kg/ha of dry shoot biomass, whereas regular winter wheat desiccation, occurred at the end of stem extension (growth stage 10 by Feekes), resulted in average with 1500 kg/ha of dry shoot biomass. Maize hybrids, well adopted for research areas, were planted with John Deere 7200 planter with 6 rows spaced 76 cm apart, both for CT and NT. The fertilizers were applied uniformly as a combination of a starter (130 kg/ha of 19-7.45-0 NPK fertilizer in pure nutrients form) and a side-dressing (460–660 kg of 28% urea ammonium nitrate/ha, according to the soil test recommendations). The gravimetric soil water content for 0–10 cm depth was measured at SEPAC during the year 2000 and at TPAC during the years 2000, 2001 and 2002. The Hoffer soil testing tube (2 cm diameter tip) was used to obtain a composite sample from four plugs, randomly sampled from each plot. Samples were placed into a metal tin, transported to the laboratory, weighed in the wet condition, and oven-dried at 105°C. The gravimetric water content was converted to volumetric water content using soil bulk density values from each plot. The soil water potential was monitored at SEPAC at the 15 cm depth by tensiometers in years 2001 and 2002. Each plot had two tensiometers, monitored and serviced twice weekly. Recorded values from each plot were controlled for normality, calculated to express soil matric potential at the 15 cm depth, and averaged for further statistical analysis. Soil temperature was measured by thermocouple probe (model Omega HH21, with K type probe tip). At SEPAC (2002 only) and TPAC (in years 2001 and 2002 only) soil temperature was measured occasionally in a period before maize seeding, on the 5–8 cm depth at six randomly chosen locations per plot between 15 and 17 hours each day of sampling. Final soil temperature for each plot and day was then expressed as the average of the six readings per plot. For observed plots, five maize plants were flagged after full emergence in inner four rows, for a total of 20 individual plants. Growth of the 20 plants was measured weekly as a maximum length of extended leaf, together with recording the current vegetative stage for each plant up to the V4 stage (after Zadoks et al. 1974), when plant shoots and roots were sampled. The 20 maize plants observed from each plot were collected at the end of the monitoring period. The collected biomass was dried at 60°C for a week and weighed. The shoot collection was omitted at SEPAC in 2001, due to maize development beyond the desired sampling stage. Analysis of variance was performed by the split-plot experimental design. Data analysis showed no need for transformation. All statistical models with the same term of errors were considered together for pooling of error terms. Error terms were pooled for all cases where the majority of the F-values for a given error effect were not significant at 25% ($P > 0.25$). Fisher protected least significant differences at $P = 0.05$ significance level were calculated and used for treatment means comparisons. The statistical package SAS V8.2 (SAS Institute, Cary, NC) was used for all statistical analysis.

RESULTS AND DISCUSSION

Soil ecological factors

Soil moisture (Table 1, Figure 1) in most cases was higher under NT treatment than under CT as a result of the mulch effect and greater capability of water retention (Stipešević 2003), which was also observed by others (Hussain et al. 1999, Baumhardt and Jones 2002). It was expected that the R cover crop treatment would express the strongest mulching effect with greater shoot

Table 1. Soil volumetric water content (% vol.) for 0–10 cm depth on maize plots only, SEPAC and TPAC sites, years 2000, 2001 and 2002

Site		SEPAC		TPAC								
Year		2000		2000		2001			2002			
Date		31.5.	5.6.	24.5.	2.6.	26.4.	15.5.	20.6.	29.4.	10.5.	14.5.	24.5.
T	CT	32.5*	28.4a**	23.0a	25.1a	22.5	15.4	24.1	34.3	34.5	35.1	26.7
	NT	35.8	34.9b	27.0b	28.0b	29.5	21.3	31.7	33.4	32.3	34.9	24.9
C	N	31.9a	29.7a	23.4a	25.3a	24.2a	15.6a	26.9	32.5	31.5	34.9	24.2a
	E	34.7b	32.2b	24.9ab	26.1a	28.4b	24.2b	27.6	33.5	33.1	33.7	25.4ab
	R	35.9b	33.1b	26.6b	28.1b	25.4a	15.3a	29.2	35.5	35.6	36.4	27.9b
T × C	CT N	30.0a	26.5a	22.3	24.1a	21.2	13.9a	24.0	32.9	32.7	35.4	24.8a
	CT E	33.4ab	29.1b	22.4	24.1ab	23.9	19.6b	24.4	33.6	34.2	33.0	26.3ab
	CT R	34.1b	29.5b	24.2	27.0b	22.3	12.8a	24.0	36.3	36.6	36.9	29.0b
	NT N	33.9a	32.8a	24.5a	26.6	27.2a	17.2a	29.9a	32.2	30.3	34.3	23.5
	NT E	36.0ab	35.2b	27.4ab	28.1	32.8b	28.9b	30.7a	33.3	32.1	34.4	24.5
	NT R	37.7b	36.7b	29.0b	29.3	28.5a	17.9a	34.4b	34.8	34.5	35.9	26.7
LSD $(T)_{0.05}$		n.s.	4.1	1.4	1.8	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
LSD $(C)_{0.05}$		2.6	1.6	2.3	2.0	2.9	3.5	n.s.	n.s.	n.s.	n.s.	2.5
LSD $(C\mid T)_{0.05}$		3.7	2.3	3.2	2.9	4.1	5.0	3.3	n.s.	n.s.	n.s.	3.6

CT = conventional tillage, NT = no-tillage, N = no cover crop, E = early, and R = regular desiccation of winter wheat cover crop
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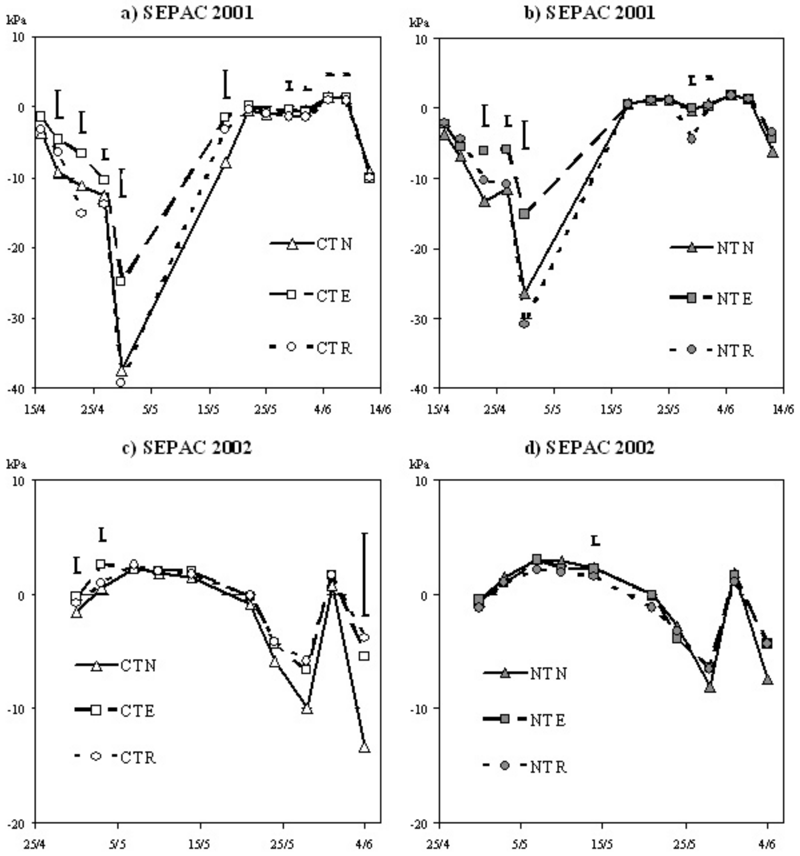
mass than E treatment. Also, it was expected that E treatment would record greater soil moisture than the no cover crop treatment, simply due to more organic residues with the E treatment. The cover crop treatments followed expectations, and the expected moisture pattern of R > E > N was shown. This pattern was present in both years without an expressed drought (2000 and 2002) and also for both tillage treatments. On the other hand, during the drought period in spring of 2001, the E treatment showed significantly greater soil moisture than R or N treatments. The greater moisture was the result of higher transpiration under R treatment, where winter wheat cover crop transpired more of the available soil water reserves, and greater evaporation under N treatment, where lack of additional mulch together with lower water retention capacity failed to conserve water in the soil. Naturally, after rainfalls, the R treatment with the most residues and the strongest mulch effect, would gain again supremacy in holding soil moisture better than other two cover crop treatments. Lower soil water content as a consequence of growing cover crops was observed by Wyland et al. (1996).

Soil temperature measurements during springs in 2001 and 2002 showed that soil under NT was colder than soil under CT (Table 2), which was in accordance with soil moisture content differences nearest to the soil surface. Swan et al. (1996) and Opoku and Vyn (1997) showed similar findings. Differences between the two treatments were more pronounced during the drought in spring of 2001, when soil moisture differences were also greater. Regarding cover crop treatments, the R treatment was colder than the lesser covered E treatment and the bare N treatment, with as much as 3°C difference between R and N treatment (TPAC site, late May of 2002).

Plant response

As of maize response, in three seasons with different weather patterns (somewhat normal spring of 2000, very droughty spring of 2001 and very wet spring of 2002), maize growth measurements (Table 3) were mostly made up of the V4 growth stage, when the growing point is still below the



CT N = conventional tillage – no cover crop
CT E = conventional tillage – early desiccation
CT R = conventional tillage – regular desiccation
NT N = no-tillage – no cover crop
NT E = no-tillage – early desiccation
NT R = no-tillage – regular desiccation

Figure 1. Soil water matric potential Ψp (kPa) at 15 cm depth, SEPAC 2001 and 2002

soil surface, thus presumably under the greatest impact of environmental modifications caused by the applied treatments of tillage and cover crop (Ritchie et al. 1997). Under CT tillage, E cover crop treatment in most cases had either greater or similar maize growth when compared with the other two cover crop treatments (Table 4). In the case of a strong drought period prior to and during early maize development (year 2001), the E cover crop had an obvious advantage over R cover crop treatment through the better soil water conservation than the R cover crop, where additional cover crop development on R plots transpired a large portion of the soil moisture. The E cover crop treatment also had the advantage over the no cover crop control due to extra surface mulch that was preventing evaporation during droughty conditions. On the other hand, in seasons with near normal (year 2000) or extreme surplus (year 2002) of precipitation, greater maize growth on E cover crop treatment was either an effect of higher soil temperature compared with R treatment, or better percolation and soil structure if compared with bare soil control (Stipešević 2003). Certain exceptions (SEPAC in 2000) could be a result of the allelopathic influence of incorporated winter wheat residues on young maize plants. As stated by Tang and Waiss (1978), allelopathy would be more likely to occur in shorter period after wheat residues incorporation, exactly during the period when significantly shorter plants on R plots, when compared with N plot plants, were measured at SEPAC in 2000. Another rationale for presumable allelopathic expression at SEPAC in 2000 and also at TPAC in 2002, where CT R plots had significantly lower maize heights than CT N plots would be the highest recorded winter wheat cover crop biomass prior to the regular desiccation (2500–3000 kg/ha of winter wheat as dry biomass, versus 1700 kg/ha and less in all other cases). As for the NT tillage treatment, the greater soil water content through mulching provided in most cases an advantage in maize growth, except when presumably lowered soil temperature delayed maize growth, as it was recorded for E treatment at SEPAC in 2001. Similarly it was observed by Hayhoe et al. (1996) and Imholte and Carter (1987). It was also observed that shading by the still erect winter wheat straw forced maize shoot elongation in processes of plant reaction on received red/far-red light ratio, as described by Morgan and Smith (1979). This provided a slight advantage in maize height of R treatment over E and N cover crop treatments. The greater shoot extension as a result of stronger shading

Table 2. Soil temperature (°C) at 5–8 cm depth before planting maize, SEPAC and TPAC sites, years 2001 and 2002

Site		TPAC	SEPAC		TPAC			
Year		2001	2002		2002			
Date		28.4.	23.5.	3.6.	29.4.	10.5.	14.5.	24.5.
T	CT	18.6*	22.3b**	28.7	12.6	17.1	17.4	20.8
	NT	16.6	21.3a	28.1	12.5	17.1	16.6	20.7
C	N	18.7c	22.5b	29.1b	13.0b	18.1c	17.5b	22.1c
	E	17.5b	21.6a	28.0a	12.4a	17.1b	17.1b	21.0b
	R	16.5a	21.3a	28.1a	12.2a	16.1a	16.4a	19.2a
T × C	CT N	19.5b	23.0b	29.6b	13.1b	18.1b	17.5	22.1b
	CT E	18.7ab	22.1a	28.2a	12.4b	17.2b	17.6	21.3b
	CT R	17.6a	21.7a	28.2a	12.2a	16.0a	17.1	18.9a
	NT N	17.9b	22.1b	28.6b	12.9	18.1b	17.6c	22.1b
	NT E	16.3a	21.0a	27.8a	12.3	17.0ab	16.6b	20.6a
	NT R	15.5a	21.0a	28.0a	12.3	16.2a	15.7a	19.4a
LSD $(T)_{0.05}$		n.s.	0.3	n.s.	n.s.	n.s.	n.s.	n.s.
LSD $(C)_{0.05}$		0.9	0.5	0.5	0.5	0.9	0.6	1.0
LSD $(C\|T)_{0.05}$		1.3	0.6	0.6	0.6	1.3	0.9	1.4

CT = conventional tillage, NT = no-tillage, N = no cover crop, E = early, and R = regular desiccation of winter wheat cover crop

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was confirmed by maize shoot weights for TPAC in 2000 and 2001 (Table 4). On NT treatment, the taller plants under E and R treatments in the case of TPAC in 2000 had lower dry weight than shorter plants on N control, and in 2001 taller plants on NT under R treatment showed lower mass than shorter plants under N treatment. At SEPAC, this elongation effect was also observed during all three years, although data at first sight did not show it, since the maize plant height and weight orders were rather consistent (R > E > N for both measurements in 2000 and for height in 2002, and E > R > N for weight measurement in 2002). But, the ratio of the plant height per dry weight shown for both years, 2000 and 2002, was higher for the maize in the N cover crop treatments (35.3 and 28.5 cm/g in 2000 and 2002, respectively) than for the other two cover crop treatments (27.6 and 28.3 cm/g for E and R, respectively in 2000, and 24.3 and 28.2 cm/g for E and R, respectively in 2002). But if early drought conditions were present as they were at TPAC in 2001, the greater soil water conserved by E treatment annulled any advantage of taller cover crop residues under R treatment. Whole maize root systems (Table 4), extracted from soil in the V3 growth stage at TPAC site only, showed corresponding patterns to the maize shoot height growth affected both by tillage and cover crop treatments. The results of this research are pointing out that the agricultural application of a cover crop practice should be planned thoroughly, in order to avoid further degradation of known limiting ecological factors. The benefits of the surplus soil water content by the mulching effect achieved with a cover crop should not impair soil temperature requirements for maize seed germination, plant emergence and early growth and plant development, which can be a very important issue if producers want to plant maize earlier, or in a colder climate. Also, negative effects of the cover crop growth for desired soil water management should be avoided by planning early desiccation for cover crops with strong biomass growth, or by choosing cover crops with shorter shoot growth and greater root production than the winter wheat cover crop studied here.

Table 3. Maize shoot heights (cm), maize shoot weight (g/plant), maize root length (cm) and maize root weight (g/plant) at SEPAC and TPAC sites, years 2000, 2001 and 2002

Site		SEPAC							TPAC						
Year		2000			2001			2002	2000			2001		2002	
Date		5.6.	14.6.	20.6.	14.5.	17.5.	30.5.	10.7.	30.5.	2.6.	6.6.	8.6.	11.6.	17. 6.	21. 6.
Growth stage		V1	V3	V4	V1	V2	V3	V5	V1	V2	V3	V2	V3	V2	V3
T × C	CT N	7.4*	24.2	39.5b**	9.5b	13.6a	33.1	46.7a	8.8	15.9	21.5	17.5a	24.2a	16.8ab	27.7b
	CT E	6.6	23.1	36.3ab	10.1b	14.7b	32.6	50.6b	9.3	16.8	23.0	24.7b	32.3b	17.5b	27.8b
	CT R	6.4	21.4	33.6a	8.4a	12.9a	32.5	50.5b	8.6	15.5	21.3	15.0a	22.0a	15.1a	24.8a
	NT N	7.9a	26.2a	41.1a	10.4b	14.9b	33.6b	47.5a	10.1	16.9	23.5	17.2a	24.7a	20.0a	32.8a
	NT E	9.4a	31.8b	47.7b	8.5a	13.3a	28.5a	52.8b	10.3	17.5	24.4	24.8b	34.4b	22.4b	35.7b
	NT R	11.4b	37.9c	53.7c	10.2b	16.6c	37.4c	56.8c	10.7	17.3	23.9	17.4a	24.8a	28.1c	43.0c
LSD (C|T)$_{0.05}$		1.54	3.79	5.49	0.81	0.74	3.25	3.63	n.s.	n.s.	n.s.	3.22	4.62	1.95	2.79

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Table 4. Maize shoot weight (g/plant), maize root length (cm) and maize root weight (g/plant) at SEPAC and TPAC sites, years 2000, 2001 and 2002

Measurement		Shoot weight (g/plant)					Root length (cm)			Root weight (g/plant)		
Site		SEPAC		TPAC			TPAC					
Year		2000	2002	2000	2001	2002	2000	2001	2002	2000	2001	2002
Date		20.6.	10.7.	6.6.	11.6.	21.6.	6.6.	11.6.	21.6.	6.6.	11.6.	21.6.
Growth stage		V4	V5	V3	V3	V3	V3	V3	V3	V3	V3	V3
T × C	CT N	1.15b*	1.96a**	0.53	0.52a	1.20b	144a	213ab	404	0.19	0.08a	0.14
	CT E	1.02ab	2.27b	0.60	1.07b	1.14ab	187b	256b	410	0.25	0.13b	0.14
	CT R	0.79a	2.19b	0.53	0.39a	0.83a	142a	176a	344	0.19	0.07a	0.12
	NT N	1.17a	1.67a	0.65	0.57a	1.53	150a	191ab	374	0.20	0.08a	0.14
	NT E	1.73b	2.18c	0.59	1.17b	1.74	194b	237b	441	0.26	0.13b	0.19
	NT R	1.90b	2.01b	0.58	0.47a	1.81	200c	146a	370	0.27	0.07a	0.17
LSD (C|T)$_{0.05}$		0.29	0.13	n.s.	0.23	0.32	4.2	64.2	n.s.	n.s.	0.03	n.s.

CT = conventional tillage, NT = no-tillage, N = no cover crop, E = early, and R = regular desiccation of winter wheat cover crop
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**means in the same column and group followed by the same letter are not significantly different according to the Fisher protected *LSD* test (*P* = 0.05)

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ABSTRAKT

Vliv termínu desikace ozimé pšenice jako mulčovací plodiny na půdní vlhkost, teplotu a počáteční růst kukuřice

Na dvou lokalitách v Indianě v USA byly ověřovány dva systémy zpracování půdy pro kukuřici (*Zea mays*) následující po sóji (*Glycine max*): bez zpracování půdy (NT) a konvenční (CT), založený na dvojím zpracování půdy talířovým nářadím. Každá plocha s uvedeným zpracováním půdy měla tři úrovně s mulčovací plodinou ozimou pšenicí (*Triticum aestivum* L.): bez pokryvu (N), časná desikace 3–4 týdny před setím kukuřice (E) a desikace v týdnu výsevu kukuřice (R). Vlivem mulčovacího efektu zvyšovaly systémy E a R půdní vlhkost s výjimkou jarního přísušku, kdy se projevil systém E jako dominantní. Teplota půdy při obou systémech zpracování půdy vykazovala pořadí N > E > R. Mladé rostliny kukuřice rostly lépe a měly větší hmotnost nadzemní biomasy při NT než při CT. Obě varianty E a R zlepšovaly růst kukuřice. V případě přísušku byla varianta E průkazně lepší pro kukuřici na obou systémech zpracování půdy z důvodu ochrany půdní vody, a proto by měla být pšenice jako mulčovací plodina v daných klimatických podmínkách desikována v časném termínu.

Klíčová slova: mulčovací plodina; kukuřice; bezorebné zpracování půdy; talířové zpracování půdy; půdní vlhkost; půdní teplota; růst; biomasa; kořen, sucho

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