Effects of tillage and reduced herbicide doses on weed biomass production in winter and spring cereals

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ABSTRACT

The effects of different tillage systems and dose reduction on the efficacy of triasulfuron & chlortoluron mixture in the post-emergence control of annual broad-leaved weeds in winter wheat and spring barley were studied on lessive pseudogley soil in north-eastern Croatia during 1997–2000. Total dry biomass production in untreated plots was significantly influenced by tillage and it was lowest in continuous mouldboard ploughing (99 kg/ha), medium and similar in mouldboard ploughing/disk harrowing alternating every second year and in chisel ploughing (218 kg/ha) whereas the biomass was highest in continuous disk harrowing (422 kg/ha). Thereby the proportion of annual broad-leaved weed biomass was 70, 63, and 28%, respectively. *Chenopodium album* L., *Ambrosia artemisiifolia* L., *Ch. polyspermum* L. and *Polygonum aviculare* L. are the most abundant annual weed species in all tillage treatments. One half and one quarter of the recommended rate decreased the control efficacy of total weed biomass by 12 and 19%, respectively in wheat and by 6 and 15%, respectively in barley compared to the highest dose but they still provided a very good biomass control of main annual weeds (94–96 percentage units). The efficacy of reduced herbicide doses in the control of annual broad-leaved weeds did not vary significantly between tillage treatments and growing seasons. Significant interaction with continuous disk harrowing tillage and one-quarter herbicide dose was detected in the last year of wheat trial when perennial weeds increased their biomass proportion 8 times compared to four years before.

Keywords: winter wheat; spring barley; soil tillage; herbicide doses; weed dry biomass; weed control efficacy

Cereal cropping based on deep tillage and high herbicide rates is becoming less rational because of economic and environmental reasons. The general trend of conservation tillage practices for cereal crops under different climatic and soil conditions was found in recent reviews by Brown and North (1984), Butorac et al. (1986), Légère et al. (1990), Arshad et al. (1994). The observation of weed species under conservation tillage suggested that the replacement of conventional tillage based on ploughing by conservation tillage caused changes in the composition of weed species (Froud-Williams et al. 1981). However, other studies reported that most weeds showed no consistent response to tillage (Pollard at al. 1982), but that the changes in weed communities were influenced to a larger extent by environmental factors than by tillage systems (Derksen et al. 1993).

The introduction of new weed control management in cropping systems with low herbicide doses invites a systematic investigation of weed population changes in the soil tillage systems without ploughing. Weed control management must be accommodated to tillage systems and also to all other factors such as crop rotation, crop competition and environmental factors, as reported by Pallutt and Bennewitz (1996). According to Kudsk (1989), the long-term successive applications of reduced herbicide doses increase weed seedbank and influence future weed infestation, in spite of adequate weed control and no significant yield reduction. On the other hand, in some cases no changes in the weed infestation were found after continuous use of low herbicide doses (Salonen 1992, Rasmussen 1993). Therefore in the last years there has been an increasing need for more information about the effects of crop weed competition at reduced herbicide inputs in new tillage practices (reduced, minimum or no tillage).

In our trials chemical weed control was obtained with a herbicide tank-mixture of triasulfuron & chlortoluron (Dicuran forte 80 WP, Ciba Geigy) that is registered in Croatia for annual broad-leaved weeds and some grasses in wheat and barley at pre- and post-emergence applications (Maceljski et al. 2002). In most cereal fields in Croatia, the triasulfuron & chlortoluron mixture is applied most frequently at the highest recommended rate of 15 g a.i./ha.

The objective of this study was to determine the effects of some reduced tillage practices and chemical weed control, particularly with lower than recommended herbicide rates and their interaction on air dry biomass of weed populations in winter wheat and spring barley on lessive pseudogley soil.

MATERIAL AND METHODS

Field experiments with winter wheat (cv. Demetra) and spring barley (cv. Jaran) were conducted on lessive pseudogley soil at Čačinci locality in the north-eastern part of Croatia during 1997–2000. Tillage experiments were set up in the autumn 1996 for winter wheat with maize rotation and lasted during 1996–1997, 1997–1998 and 1999–2000 growing seasons. In March 1999 spring barley following maize (wheat could not be sown due to the wet autumn 1998) was sown on the same plots. Winter wheat and spring barley were fertilised annually with 231 kg N/ha and 120 kg N/ha, respectively, and with 150 kg/ha of P_2O_5 and 100 kg/ha of K_2O. Top dressing by N was carried out at tillering and forking stages in March and April for winter wheat and at the beginning of the forking stage in April for spring barley. Monthly average temperatures and total precipitation in the winter wheat and spring barley growing seasons are presented in Table 1.

The experimental design was a split-plot with tillage as the main factor (T) and weed control as a sub-factor (W). The main plots had five tillage treatments: 1. CT – conventional (ploughing with mouldboard plough at 30–35 cm depth in autumn with standard sowing), 2. CT/DH – conventional tillage alternated with disk harrowing every second year, 3. DH/CT – disk harrowing alternated with conventional tillage every second year, 4. CP – loosening with a chisel plough at 15–20 cm depth, 5. DH – disk harrowing at 8–10 cm depth. Tillage treatments in the alternation (CT/DH, DH/CT) were present each year. The sub-plots, 3.5 m × 9 m in size, were subjected to treatments with a triasulfuron & chlortoluron mixture with three ascending dose rates up to the highest recommended commercial dose. Sub-plot treatments were: W0 – untreated control, W1 – one-quarter dose (2.8 & 297 g a.i./ha), W2 – one-half dose (5.6 & 593 g a.i./ha), and W3 – full recommended dose (11.3 & 1185 g a.i./ha) of triasulfuron & chlortoluron mixture. The post-emergence application of herbicide mixture was made when winter wheat and spring barley were at the tillering stage, corresponding to Zadok's scale 25–29. The time interval between spring barley sowing and herbicide spraying was 25 days. The herbicide mixture was applied by a knapsack-sprayer Solo (Lurmark AN 1.0 nozzle type) in 300 l/ha of water volume at a pressure of 300 kPa.

The data on weed plants in winter wheat are based on the second weed assessment made in June of each season. Weed samples in spring barley were collected 54 days after herbicide application as well as in June. Weed biomass was estimated in each sub-plot in four quadrants, each measuring 50 cm × 50 cm (16 replications totally). Weeds found in each quadrant were cut at the ground level, separated by the species, counted, oven-dried at 65°C and weighed. The efficacy of herbicide was measured as a relative reduction in weed biomass for each weed species compared to untreated plots within each tillage treatment. Weed biomass and statistical analyses are shown according to weed dry weight of weed life cycle groups of annual broad-leaved weeds and perennial weeds. Perennials included dicotyledons and cryptogams.

The analysis of variance was used for the testing of univariate differences between independent groups of observations. Dependent variables were: weed dry biomass of annual broad-leaved weeds, perennial weeds and total weeds. Years, tillage and weed control treatments as well as their interactions were groups in separate analyses of variance. Particular group-to-group differences were tested by Fisher's least significant difference test (Ott 1993) using the probability level of $P = 0.05$ (Fisher's protected *LSD* test). Linear regression analyses were performed to evaluate univariate correlations between total weed dry biomass and crop densities expressed in spike number per m^2. Correlated values were sub-plot averages of replications of the respective variable. Correlation analyses were performed for the total sample and for each tillage treatment and each weed control treatment separately.

RESULTS AND DISCUSSION

Effects of tillage and herbicide dose reduction on weed biomass in wheat

A total of thirty-seven weed species was recorded in the three-year study of winter wheat, out of them 68% were annual broad-leaved species, 27% perennials and 5% grass species. The weed flora was dominated by summer annual broad-leaved species. The weed species with

Table 1. Monthly average temperatures and total precipitation in the growing seasons for winter wheat (1996–1997, 1997–1998, 1999–2000) and spring barley (1999) at Čačinci locality

		Month										Total/Mean
		X.	XI.	XII.	I.	II.	III.	IV.	V.	VI.	VII.	
1996–1997	P	46	75	53	15	44	21	62	59	120	116	611
	T	12.1	8.5	–0.4	–1.3	4.9	6.6	8.9	17.0	20.4	21.1	9.8
1997–1998	P	79	53	96	106	2	49	65	122	39	73	684
	T	9.4	6.2	3.0	3.8	6.1	5.2	12.7	16.1	21.8	22.1	10.6
1998–1999	P	100	103	32	38	63	40	125	52	228	95	876
	T	12.5	3.9	–2.7	1.2	1.2	8.3	12.7	16.1	19.8	21.7	9.5
1999–2000	P	24	125	97	14	23	39	60	37	37	87	543
	T	14.4	4.6	2.1	–0.4	5.1	7.2	14.5	17.9	20.9	21.3	10.8

P = precipitation (mm), T = temperature (°C) average densities from nine to one plant per m^2 were: *Chenopodium album* L., *Ambrosia artemisiifolia* L., *Ch. polyspermum* L. and *Polygonum aviculare* L. These weed populations produced on average 83% of the total annual broad-leaved weed biomass in untreated crop. The most abundant perennial weed species with densities higher than one plant per m^2 were: *Equisetum arvense* L., *Plantago major* L. and *Calystegia sepium* (L.) R.Br. The only annual grasses that emerged later than the crop and were less competitive were *Apera spica-venti* (L.) PB. and *Echinochloa crus-galli* (L.) PB. Due to low biomass values, the botanical group of annual grasses was not subjected to statistical analyses, but their biomass is included into analyses of total weed biomass. Effects of year (Y), tillage (T) and herbicide dose reduction (W) and their interaction upon dry biomass of certain botanical weed groups based on the analysis of variance are shown in Table 2.

During the years of the study, the weed biomass of both weed groups varied considerably. For example, in 1997 annual broad-leaved weeds made up 75% of total weed biomass whereas perennial weeds constituted on average 24% of total weed biomass. On the contrary, in 1998 it was annual broad-leaved weed biomass that account-

Table 2. Testing of univariate differences between independent groups of observations by the analysis of variance for weed dry biomass in winter wheat (3-year average)

	Annual broad-leaved weeds (g/m^2)		Perennial weeds (g/m^2)		Total weeds (g/m^2)	
	mean	sorted & tested	mean	sorted & tested	mean	sorted & tested
T	N = 192, F = 1.52, P = 0.193		N = 192, F = 15.44*, P = 0.000		N = 192, F = 11.23*, P = 0.000	
CT	1.84	DH/CT	0.85	DH	3.25	DH
CT/DH	2.81	CP	1.85	CP	5.23	CP
DH/CT	4.46	DH	4.42	DH/CT	9.19	DH/CT
CP	3.35	CT/DH	5.60	CT/DH	9.35	CT/DH
DH	3.21	CT	15.02	CT	18.46	CT
W	N = 240, F = 70.79*, P = 0.000		N = 240, F = 7.87*, P = 0.000		N = 240, F = 885.37*, P = 0.000	
W0	11.75	W0	10.50	W0	23.50	W0
W1	0.47	W1	5.42	W1	6.25	W1
W2	0.30	W2	4.28	W2	4.58	W2
W3	0.03	W3	2.00	W3	2.05	W3
Y	N = 320, F = 8.00*, P = 0.000		N = 320, F = 22.72*, P = 0.000		N = 320, F = 114.21*, P = 0.000	
1997	4.51	1997	1.43	2000	5.98	2000
1998	1.28	2000	3.71	1998	4.96	1997
2000	3.63	1998	11.51	1997	16.35	1998
T × W	N = 48, F = 1.18, P = 0.292		N = 48, F = 2.03*, P = 0.019		N = 48, F = 5.42*, P = 0.000	
CT W0	6.83	DH/CT W0	1.50	DH W0	9.92	DH W0
CT W1	0.33	CP W0	1.08	DH W1	2.00	DH/CT W0
CT W2	0.25	DH W0	0.58	DH W2	0.83	CP W0
CT W3	0.00	CT/DH W0	0.25	DH/CT W0	0.25	CT/DH W0
CT/DH W0	10.75	CT W0	3.83	CP W0	16.50	DH W1
CT/DH W1	0.25	DH/CT W1	1.42	CP W1	2.00	DH W2
CT/DH W2	0.25	DH W1	1.58	CPW2	1.83	CT W0
CT/DH W3	0.00	DH/CT W2	0.58	DH W3	0.58	CP W1
DH/CT W0	16.08	CT W1	9.67	DH/CT W1	26.67	CP W2
DH/CT W1	1.00	DH W2	3.92	CT/DH W0	5.25	DH/CT W1
DH/CT W2	0.67	CT/DH W1	2.58	CP W3	3.25	DH W3
DH/CT W3	0.08	CT W2	1.50	DH/CT W2	1.58	CP W3
CP W0	13.33	CT/DH W2	7.92	CT/DH W2	22.25	DH/CT W2
CP W1	0.08	DH/CT W3	6.08	CT W0	6.67	CT/DH W1
CP W2	0.00	CP W1	5.25	DH/CT W3	5.25	CT W1
CP W3	0.00	DH W3	3.17	CT/DH W1	3.25	CT/DH W2
DH W0	11.75	CT W3	29.58	CT W1	42.17	DH/CT W3
DH W1	0.67	CT/DH W3	14.58	CT W2	15.33	CT W2
DH W2	0.33	CP W2	11.42	CT/DH W3	11.75	CT/DH W3
DH W3	0.08	CP W3	4.50	CT W3	4.58	CT W3

Table 2. (to be continued)

	Annual broad-leaved weeds (g/m²)		Perennial weeds (g/m²)		Total weeds (g/m²)	
	mean	sorted & tested	mean	sorted & tested	mean	sorted & tested
T × Y	*N* = 64, *F* = 3.01*, *P* = 0.002		*N* = 64, *F* = 11.86*, *P* = 0.000		*N* = 64, *F* = 10.44*, *P* = 0.000	
CT 1997	3.44	DH/CT 1997	1.06	DH 2000	4.50	DH 2000
CT 1998	1.50	CT/DH 1997	1.13	CP 2000	2.69	CP 2000
CT 2000	0.63	CP 2000	0.38	DH/CT 1998	2.56	DH/CT 2000
CT/DH 1997	6.88	DH 2000	1.00	DH/CT 2000	8.00	DH/CT 1998
CT/DH 1998	0.88	DH/CT 2000	1.13	CP 1998	1.69	CT/DH 1997
CT/DH 2000	0.69	CT 1997	3.44	DH 1998	6.00	DH/CT 1997
DH/CT 1997	7.00	DH 1997	0.88	CT/DH 2000	7.88	CP 1998
DH/CT 1998	1.44	CP 1997	6.69	DH 1997	8.19	CT/DH 2000
DH/CT 2000	4.94	CP 1998	5.69	CP 1997	11.50	DH 1997
CP 1997	1.81	CT 1998	1.88	CT 1998	3.69	DH 1998
CP 1998	1.75	DH/CT 1998	5.06	CT/DH 1998	6.88	CT 1997
CP 2000	6.50	CT/DH 1998	9.88	CT 1997	17.50	CP 1997
DH 1997	3.44	DH 1998	2.31	CT/DH 1997	5.81	CT 1998
DH 1998	0.81	CT/DH 2000	4.56	DH/CT 1997	5.38	CT 2000
DH 2000	5.38	CT 2000	38.19	CT 2000	44.19	CT/DH 1998
W × Y	*N* = 80, *F* = 5.96*, *P* = 0.000		*N* = 80, *F* = 2.08, *P* = 0.053		*N* = 80, *F* = 84.45*, *P* = 0.000	
W0 1997	16.15	W0 1997	2.40	W0 2000	18.65	W0 2000
W0 1998	4.95	W0 2000	7.85	W1 2000	12.65	W0 1997
W0 2000	14.15	W0 1998	21.25	W2 2000	39.20	W0 1998
W1 1997	1.20	W1 1997	1.80	W0 1998	3.05	W1 2000
W1 1998	0.10	W2 1997	3.15	W3 2000	3.25	W2 2000
W1 2000	0.10	W2 2000	11.30	W1 1998	12.45	W3 2000
W2 1997	0.70	W1 2000	1.40	W2 1998	2.10	W1 1998
W2 1998	0.05	W1 1998	2.45	W0 1997	2.50	W1 1997
W2 2000	0.15	W3 2000	9.00	W1 1997	9.15	W2 1998
W3 1997	0.00	W2 1998	0.10	W2 1997	0.10	W2 1997
W3 1998	0.00	W3 1997	1.40	W3 1998	1.45	W3 1998
W3 2000	0.10	W3 1998	4.50	W3 1997	4.60	W3 1997
T × W × Y	*N* = 16, *F* = 2.87*, *P* = 0.000		*N* = 16, *F* = 1.85*, *P* = 0.008		*N* = 16, *F* = 7.95*, *P* = 0.000	

Groups = tillage (T), weed control level (W), year (Y), combination of tillage and weed control (T × W), tillage and year (T × Y), weed control and year (W × Y) and tillage, weed control and year (T × W × Y); *N* = number of observations in the group, *F* = proportion of between-group and within-group variance and *P* = respective probability. *F* = designated by * where $P < 0.05$; particular group-to-group differences were tested by Fisher's *LSD* test; vertical lines comprise groups that are not significantly different at $P = 0.05$

ed for 26%, and perennials that made up 75% of total weed biomass. However, when the experiment ended in 2000, the proportion of annual weed biomass decreased by 20% and perennial weed biomass increased 8 times compared to the four years before.

In respect of tillage, the total dry biomass on untreated plots was significantly influenced by tillage and it was lowest in CT tillage (99 kg/ha), medium and similar in CT/DH, DH/CT and CP (218 kg/ha) whereas the biomass was highest in DH tillage (422 kg/ha). Thereby the proportions of annual broad-leaved weed biomass were 70, 63, and 28%, respectively.

Most annual broad-leaved species were not associated with any tillage practice in the last 4 years of the experiments. *Ch. album* and *P. aviculare*, the characteristic species in mouldboard ploughing (Froud-Williams et al. 1981), occurred in our trials in the DH/CT and CT/DH tillage treatments with densities of 15 plants per m² that were 3 times higher than those found in mouldboard ploughing (CT). The abundance of these weed populations probably reflected the effect of tillage on the seedbank size and seedling distribution in the soil layer as well wheat competitiveness.

Perennial species such as *E. arvense, P. major, C. sepium* and *Rumex obtusifolius* L. responded more to DH and CP than to CT tillage while *Cirsium arvense* (L.) Scop. was associated only with DH in the final year of the trial when on these tilled plots it produced 19% of the total dry weight of 382 kg/ha perennial biomass. The tendency of these species to increase with time in less intensive tillage systems was reported previously by Légère et al. (1990). Yet, the time interval was still relatively short for

Table 3. Plant density and dry biomass of main annual broad-leaved weed species on untreated plots in winter wheat and herbicide dose efficacy of triasulfuron & chlortoluron mixture (mean of 5 tillage treatments according to assessments in June, 1997–1998, 1998–1999, 1999–2000)

Weed species	Weed density (plant/m^2)	Weed biomass (DW g/m^2)	Herbicide dose rates		
			25%	50%	100%
			weed control efficacy (%)		
Chenopodium album L.	9.2	3.25	95.8	97.6	100.0
Ambrosia artemisiifolia L.	4.7	1.24	85.4	93.2	97.8
Chenopodium polyspermum L.	2.6	0.21	93.8	94.2	98.3
Polygonum aviculare L.	1.2	0.71	80.8	91.2	95.4

the registration of directional shifts and the selective effects of tillage on weed composition in wheat.

The analysis of variance shows no tillage effect in total weed biomass in the first two years. In 2000 significant interaction (T × Y) in total weed biomass was recorded in the continuous DH tillage treatment with the highest weed biomass level of 442 kg/ha.

Neglecting the effect of tillage, the average biomass of total weeds was 235 kg/ha in untreated and 43 kg/ha in treated plots, respectively. Thus, the average control efficacy with triasulfuron & chlortoluron mixture was 82%. The best herbicide efficacy was achieved with the highest recommended herbicide dose, which corresponded to 91% of relative dry biomass reduction on average compared to untreated plots. One-half and one-quarter of the recommended dose decreased efficacy on average by 12% and 19%, respectively, compared to the highest dose, but they still provided very good control of the most abundant annual broad-leaved weeds (Table 3). *Ch. album* showed the highest susceptibility to one-quarter dose of this herbicide mixture with 96% of control. The same species turned out to be receptive to low doses of MCPA/Mecoprop or MCPA/Fluroxypyr herbicide mixture under Finnish conditions as well (Salonen 1992).

Our results did not confirm any increase in the biomass proportion of annual broad-leaved weed infestation after three years of continuous use of one-quarter dose. At the same time, the proportion of perennial weed biomass increased in the one-quarter and also in the half dose of herbicide with average control efficacy of only 28–50%. In the first three years of the trials (which included the barley trial in 1999) the infestation with perennial weeds was relatively low for all tillage treatments and effectively reduced by both reduced doses in all reduced tillage treatments. However, in the last year of the wheat trial, in 2000 a dose reduction to one-quarter in the disk harrowing tillage decreased the control efficacy by 41% compared to the highest herbicide dose, with significant interaction (T × W). This was due to a higher residual infestation with *C. arvense* on these tilled plots. Consequently, the weed biomass at one-quarter dose in DH in 2000 was higher than on the untreated plots in CT. These results suggest that differential susceptibility of weed species in wheat stands by the long-term lowered dose of this herbicide mixture could favour more tolerant perennial weeds in continuous DH tillage with negative effects on future weed infestation. Due to this failure it must be complemented with a special herbicide in the third or fourth year.

Some significant interactions (T × W, T × Y, W × Y) were identified by the ANOVA with continuous disk harrowing tillage and one-quarter dose treatment both in 2000. The lower herbicide efficacy in DH probably reflects lower crop competition in 2000. The season of 2000 was dry, with 181 mm less precipitation than the average of 724 mm, October to July, in 1996–1999 (Table 1). These unfavourable weather conditions influenced the wheat spike number in DH that was significantly reduced to 474 spikes per m^2 compared to an average of 521 spikes per m^2 in CT. In these conditions, the weak competition of wheat stands had a major impact in the suppression of weed growth and efficiency of the lowest herbicide dose. Courtney (1991) and Christensen (1994) suggest that an increase in crop density increased the effectiveness of reduced doses. In many cases, weed growth in competitive cereal stands can be suppressed by only a quarter of the recommended dose almost as successfully as by a full dose in less competitive cereal stands, as reported by Pallutt (1999).

Our results show that the correlation between crop density and total weed biomass is strong, significantly negative only in DH (r^2 = –0.6339*). In all other tillage and herbicide treatments the mentioned correlation is low (Table 5). The lower competitive ability of wheat stands in DH affected wheat yields in 2000 with a decrease by 11% compared to CT with an average yield of 5.9 t/ha (Knežević et al. unpublished data).

Effects of tillage and herbicide dose reduction on weed populations in spring barley

In the barley weed community a total of twenty weed species was recorded, out of them 58% were annual broad-leaved weed species, 37% perennials and 5% grass species. The predominant annual broad-leaved weed

Table 4. Testing of univariate differences between independent groups of observations by the analysis of variance for weed dry biomass in spring barley in 1999

	Annual broad-leaved weeds (g/m^2)		Perennial weeds (g/m^2)		Total weeds (g/m^2)	
	mean	sorted & tested	mean	sorted & tested	mean	sorted & tested
T	N = 64, F = 2.93, P = 0.021		N = 64, F = 2.67*, P = 0.032		N = 64, F = 2.53*, P = 0.041	
CT	2.20	DH/CT	0.08	DH	2.28	DH
CT/DH	1.72	CT	0.56	CP	2.28	DH/CT
DH/CT	2.80	DH	1.44	DH/CT	4.24	CP
CP	2.08	CP	1.64	CT/DH	3.72	CT
DH	2.20	CT/DH	3.48	CT	5.68	CT/DH
W	N = 80, F = 41.14*, P = 0.000		N = 80, F = 2.30, P = 0.077		N = 80, F = 30.09* P = 0.000	
W0	7.88	W0	2.88	W0	10.76	W0
W1	0.48	W1	1.64	W1	2.08	W1
W2	0.40	W2	0.76	W2	1.16	W2
W3	0.04	W3	0.48	W3	0.56	W3
T × W	N = 16, F = 3.06*, P = 0.000		N = 16, F = 0.77, P = 0.685		N = 16, F = 0.59, P = 0.848	
CT W0	8.20	DH/CT W0	0.12	DH W0	8.32	DH W0
CT W1	0.24	CP W0	0.04	CP W0	0.28	CP W0
CT W2	0.52	CT W0	0.12	DH W1	0.64	DH/CT W0
CT W3	0.00	DH W0	0.08	DH/CT W1	0.08	CT W0
CT/DH W0	6.56	CT/DH W0	1.72	CT/DH W0	8.28	CT/DH W0
CT/DH W1	0.12	CT W2	0.32	DH W2	0.44	DH W1
CT/DH W2	0.12	DH/CT W2	0.16	DH/CT W0	0.28	DH/CT W1
CT/DH W3	0.08	DH/CT W1	0.00	CP W2	0.08	DH W2
DH/CT W0	10.32	DH W2	1.20	DH W3	11.52	CP W2
DH/CT W1	0.36	CT W1	2.92	DH/CT W3	3.28	DH/CT W2
DH/CT W2	0.40	CT/DH W1	0.72	DH/CT W2	1.16	DH W3
DH/CT W3	0.04	CT/DH W2	1.00	CP W3	1.04	DH/CT W3
CP W0	8.16	CT/DH W3	4.96	CT/DH W1	13.16	CT W2
CP W1	0.08	CP W1	0.00	CT/DH W2	0.08	CT/DH W1
CP W2	0.08	CP W2	1.16	CT W2	1.24	CP W3
CP W3	0.00	DH W3	0.40	CT W0	0.40	CT W1
DH W0	7.00	DH/CT W3	6.48	CT W3	13.48	CT/DH W2
DH W1	1.52	CT W3	4.88	CT W1	6.40	CT W3
DH W2	0.24	DH/CT W0	1.52	CT/DH W3	1.76	CT/DH W3
DH W3	0.08	CP W3	1.04	CP W1	1.12	CP W1

Groups = tillage (T), weed control level (W), combination of tillage and weed control (T × W); N = number of observations in the group, F = proportion of between-group and within-group variance and P is respective probability, F = designated by * where $P < 0.05$; particular group-to-group differences were tested by Fisher's *LSD* test; vertical lines comprise groups that are not significantly different at $P = 0.05$

species of *A. artemisiifolia*, *Ch. album* and *P. lapathifolium* occurred in all barley stands. Their average total biomass made up 89% of total annual broad-leaved weed biomass. The effects of tillage and herbicide doses and their interaction (T × W) on weed biomass of botanical weed groups are shown in Table 4.

In the third-year of the trial, 1999, tillage effect on weed biomass was significant only for perennial weed groups in DH. The dynamics of perennial weeds in barley stands depended on the biomass of two main species *Convolvulus arvensis* L. and *Sonchus arvensis* L. with a proportion of 67% in total perennial weed biomass. Compared to CT tillage, which produced the lowest perennial weed biomass (0.8 kg/ha), the continuous DH tillage increased perennial biomass by 43%.

In all tillage practices, the reduced doses of triasulfuron & chlortoluron mixture provided 94–99% control of biomass of the main annual broad-leaved weeds. In this trial, the efficacy of one-quarter dose failed to control perennial weed biomass in the disk harrowing tillage with a significant interaction (T × W). Nevertheless, the average total weed biomass reduction in the treatment of one-quarter dose obtained an acceptable control level of 81% in terms of barley yield. Tillage and herbicide doses had no significant effects on barley yields that ranged between 4.5 and 4.9 t/ha. Barley density was mostly poorly

Table 5. Univariate linear correlations between sub-plot means of the spike number and total weed biomass

	Total	Tillage treatment					Weed control treatment			
		CT	CT/DH	DH/CT	CP	DH	W0	W1	W2	W3
N	60	12	12	12	12	12	15	15	15	15
Winter wheat	–0.4213***	–0.0857	–0.2985	–0.2346	–0.5601	–0.6339*	–0.6319*	–0.4061	–0.3294	–0.4143
N	20	4	4	4	4	4	5	5	5	5
Spring barley	–0.0134	0.7704	0.5194	–0.7034	–0.3301	–0.1978	–0.1966	–0.0964	–0.0689	–0.2200

Significant correlation coefficients are designated by $*P = 0.05$, $**P = 0.01$, $***P = 0.001$

correlated with total weed biomass between the tillage and weed control treatments (Table 5).

Only one year of the spring barley trial showed the effects of tillage and reduction of herbicide dose on weed spectrum similar to the wheat trial. Numerous results from Danish, Finnish and Scottish trials show that a reduction of herbicide dose is feasible and successful in winter and spring cereals with considerable economic and environmental impacts (Kudsk 1989, Salonen 1992, Fischer et al. 1993).

CONCLUSION

Four years of tillage experiments showed that total weed biomass production was significantly influenced by tillage and it was lowest in continuous mouldboard ploughing, medium and similar in alternating mouldboard ploughing/disk harrowing and in chisel ploughing, whereas the biomass was highest in continuous disk harrowing. *Ch. album, A. artemisiifolia*, *Ch. polyspermum* and *P. aviculare* are the most abundant summer annual broad-leaved weed species recorded in all tillage variants during the experiments.

Across tillage treatments the triasulfuron & chlortoluron mixture provided the best average total weed control at the highest herbicide rate (91–95%) and it ensured an efficient control of dominant annual broad-leaved weeds even with one-quarter of the recommended herbicide dose (94–96%) in both crops. The efficacy of reduced herbicide doses in the control of these weeds did not vary significantly between tillage treatments and growing seasons. The level of weed biomass on treated plots was affected by crop competitiveness in certain tillage treatments, and by the weed spectrum with differential sensitivity of species to the herbicide doses as well as to the herbicide mixture.

Significant differences in control efficacy and a risk of the failure of one-quarter dose were observable in the final year of wheat trials when perennial weeds on DH tilled plots increased their biomass proportion 8 times compared to the four years before.

The results suggested that the substitution of mouldboard ploughing by all reduced tillage treatments in these trials and use of low rates of triasulfuron & chlortoluron mixture would not result in an increase of annual broad-leaved weed biomass after the 4 year trial period, but could increase the perennial weed biomass especially after DH tillage. Therefore it is necessary to include an additional special herbicide against perennial species in the third or fourth year.

The continued research of other environmental factors that could cause a failure at applications of reduced herbicide doses in cereals on lessive pseudogley soil is required.

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ABSTRAKT

Vliv zpracování půdy a snížených dávek herbicidů na produkci biomasy plevelů v ozimých a jarních obilninách

V severovýchodních oblastech Chorvatska byl na pseudoglejových půdách v letech 1997–2000 sledován vliv rozdílného zpracování půdy a snížených dávek postemergentních kombinací herbicidů triasulfuron a chlortoluron na jednoleté širokolisté plevele v ozimé pšenici a jarním ječmeni. Celková suchá hmotnost plevelů na neošetřených parcelách byla průkazně ovlivněna orbou, přičemž nejnižší byla po opakované orbě klasickým pluhem s odhrnovačkou (99 kg/ha), střední a obdobná při klasické orbě, resp. zpracování diskovými branami, které se střídaly každý druhý rok, a při zpracování půdy dlátovým kypřičem (218 kg/ha), zatímco nejvyšší biomasa byla zaznamenána při opakovaném diskování (422 kg/ha). V tomto pořadí byl zjištěn podíl jednoletých širokolistých plevelů, který činil 70, 63 a 28 %. Nejrozšířenějšími jednoletými plevely při všech způsobech zpracování půdy byly *Chenopodium album* L., *Ambrosia artemisiifolia* L., *Ch. polyspermum* L. a *Polygonum aviculare* L. Poloviční a čtvrtinové dávky herbicidů snižovaly působení na biomasu plevelů o 12 a 19 %, u ječmene ve srovnání s nejvyšší dávkou poskytly velmi dobrý účinek na jednoleté plevele (94–96 %). Vliv snížených dávek herbicidů na širokolisté jednoleté plevele se nelišil prokazatelně v závislosti na zpracování půdy a ročním obdobím. Průkazná interakce opakovaného diskování a čtvrtinových dávek herbicidů byla zjištěna v posledním roce pokusu u pšenice, kdy výskyt vytrvalých plevelů stoupl osmkrát ve srovnání s obdobím před čtyřmi lety.

Klíčová slova: ozimá pšenice; jarní ječmen; zpracování půdy; herbicidy; suchá biomasa plevelů; účinek herbicidů

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