Evaluation of various mechanical measures on weed control efficacy

A. Simončič and G. Leskošek

Beurteilung verschiedener mechanischer Maßnahmen für eine effiziente Unkrautbekämpfung

1 Introduction

The basic principle in weed control is to provide better conditions for the development of the crop. This can be achieved most effectively by combining direct chemical measures and all the other indirect measures taken in the frame of production technique as well as direct non-chemical measures among which the mechanical measures are still the most important ones. Nevertheless, it is reported by numerous authors (RASMUSSEN, 1996) that most weed control techniques are still based upon various modified techniques which preferably include chemical products and do not attribute any major importance to mechanical measures due to their lower effectiveness. For numerous crops a very limited number of herbicides allowed to be applied in the weed control are available. This is especially so for the so called minor crops such as industrial plants, one of them being also hop. Under such conditions it is necessary to use

Zusammenfassung

Die vorliegende Arbeit beschreibt die Simulationsergebnisse von verschiedenen mechanischen Maßnahmen zur Unkrautbekämpfung, die aus Gefäßversuchen in Klimakammern zwischen den Jahren 2001 und 2002 gewonnen wurden. Unter Verwendung von 5 Unkrautarten mit unterschiedlichem Wuchshabitus und darauf basierendem Wiederwuchs-Verhalten simulierte man 9 verschiedene Systeme der mechanischen Unkrauftbekämpfung. Der Versuch wurde an 2 Terminen in Relation auf Wuchsverhalten und unter trockenen und feuchten Wachstumsbedingungen durchgeführt. Die Ergebnisse zeigten, dass die Effizienz dieser Maßnahmen vom Wuchsstadium und der Bodenfeuchtigkeit an den jeweiligen Behandlungsterminen abhängig waren. Die besten Ergebnisse wurden erzielt, wenn die mechanischen Behandlungsmethoden sehr früh, d.h. bei den breitblättrigen Unkräutern im 2–3 Blattpaarstadium und bei den Gräsern im 2–3 Blattstadium erfolgten. Dies war auch unter den Trockenbedingungen der Fall, wenn der Wiederwuchs der geschädigten Unkräuter gehemmt war.

Schlagworte: Unkräuter; Unkrautbekämpfung, mechanische Maßnahmen.

Summary

The current paper presents results from an investigation of simulation of various mechanical measures in weed control which was conducted in pot trials in a growth chamber between 2001 and 2002. Simulation of nine different systems of mechanical control with five weed species chosen for their different growth habits and subsequent regrowth capabilities was compared. The trial was conducted on two dates in relation to weed size and under wet and dry growth conditions. It could be found out that the effectiveness of mechanical measures depended on weed size and on soil moisture by the time of carried out measures. The best results were obtained when mechanical measures were taken earlier, i.e. when broad-leaved weeds had 2–3 pairs of true leaves and grasses had 2–3 leaf-blades, and under dry conditions which prevented the subsequent regrowth and development of damaged weeds.

Key words: Weeds; weed control, mechanical measures.

all the non-chemical methods as effectively as possible. Hop belongs to the group of perennial plants which are generally known for their weed damage threshold as being much higher than that of annual plants; certain weed species are even welcome in perennial plantations (SIMONČIČ et al., 1995). In spite of that CRAMER (1967) estimated that losses in hop yield due to weeds amounted to 5.9 % on the average. PARRISH and BAZZAZ (1982), among other authors, found that *Chenopodium album* L., which is one of the most widely spread weed species in field crops, vegetables and in hop plantations in Slovenia, contains a rather great share if nitrogen and potassium in its dry matter. Based on these results it can be estimated that one or two *Chenopodium album* plants can use at least half as much nitrogen per m^2 as it is used by hop during its growth period, i.e. approximately 140 kg of pure nitrogen per ha (KIŠGECI et al., 1984; MAJER, 2002). At the same time, weeds provide better conditions for the incidence and spreading of diseases; they allow development of certain hop pests or even act as their nutrient plants (RADIŠEK et al., 2003).

In order to ensure better growth conditions for crops under the conditions of restricted use of herbicides, mechanical weed control ought to gain greater importance in comparison with chemical measures or to complement them to a greater extent (BLAIR et al., 2002). This goal requires a much better information and knowledge on the ecology of weeds and the influence of weed control on the quantity and quality of yield of grown plants, better technical equipment for the mechanical weed control including technical innovations as well as more practical experience of producers (CAMPBELL and GRICE, 2000). Several authors published articles on the advantage of mechanical measures applied before and after germination of different crops and negative effects of these measures on yield quantity (RASMUSSEN and RASMUSSEN, 1995; HATCHER and MELANDER, 2003; NORREMARK and GRIEPENTROG, 2004).

JONES and BLAIR (1996) investigated the effectiveness of different types of mechanical control of certain weeds. They simulated mechanical measures in pot trials by cutting the weeds at different heights, pulling them and then leaving them on the ground or covering them with soil. The trial was carried out under dry and wet soil conditions. They found that weeds were differently susceptible to various mechanical measures. The effectiveness of measures in the control of grass weeds was also influenced by soil moisture since their regrowth in case of sufficiently moist soil was substantially stronger than that of broad-leaved weeds. On a similar basis we intended to find out the efficacy of individual mechanical weed damage by simulating different tools used for mechanical control of the most widely spread annual weeds in Slovenia, especially hop gardens.

2 Material and methods

The research on the efficacy of mechanical measures using different tools for cultivation and covering was carried out in pot trials in which we tried to simulate the work of the tools for weed control such as hoeing, harrowing, ridging, discing and hilling up. By that we tried to find out how effective the control of individual weed species was if different tools used in hop plantations were applied, taking into consideration the size of weeds and moisture of soil, i.e. the two factors on which the efficacy of mechanical measures in weed control strongly depends. The research included different weeds which are the most frequently present in hop plantations in Slovenia (CERJAK, 1991; SIMONCˇICˇ et al., 1995). They were classified in three groups for the form and growth habit of their above and below ground parts (Table 1).

Table 1: Weed groups, names and properties of weeds used for the estimation of the efficacy of different mechanical treatments in pot trials conducted in growth chambers

Tabelle 1: Unkrautgruppen, Namen und Eigenschaften von Unkräutern zur Bestimmung der Effizienz verschiedener mechanischer Maßnahmen in den Gefäßversuchen in Klimakammern

Weed group	Weed species	Properties and the way of plant spreading	
		Above ground part	Below ground part
1	*Stellaria media* (L.)Vill. *Poa annua* L.	Low prostrate annual broad-leaved and grass weeds	Fibrous rooting system
2	*Chenopodium album* L. *Amaranthus retroflexus* L.	High, mostly one-stem plant, it may also spread at different stem nodes	Deep tap root plants
3	*Echinochloa crus-galli* (L.) P.B.	Development of above ground part allows its regrowth	Bundlelike roots

Table 2: Mechanical treatments for weed control used in pot trials conducted in a growth chamber in 2001 and 2002 and their characteristics
Tabelle 2: Erläuterung der mechanischen Maßnahmen zur Unkrautbekämpfung in Gefäßversuchen durchgeführt in den Jahren 2001 und 2002

Treatment	Mechanical treatment
0	Untreated plants
1	Carefully pulled out plants, with roots intact and left on soil surface
2	Stem or stems and leaves cut at soil surface using scissors
3	Plant cut 1 cm below surface using scissors and left on soil surface
4	Plant cut 1 cm above surface using scissors and left on soil surface
5	Whole plants pressed down and covered with 1 cm of compost
6	Partially buried plants (growing point of broad-leaved plants left visible as well as one leaf of the grasses) covered with 1 cm of compost
7	Carefully pulled out plants, with roots intact and left on the surface and re-buried roots with 1 cm of compost
8	Carefully pulled out plants, with undamaged roots and left on the surface and completely re-buried with 1 cm of compost
9	All leaves removed (leaf blades of grasses) by scissors, leaving stems intact

The trial included 10 treatments in 14 replications. The treatments differed in the method of simulation of mechanical measures. Treatment 0 stood for the untreated control. The different mechanical measures are presented in Table 2. Since we also studied the influence of soil moisture on the regeneration of weeds after mechanical treatment, in 7 replications of the trial the weeds were watered after the mechanical measures were taken (wet soil conditions) whereas in the remaining 7 replications the weeds were not watered until the evaluation of the trial (dry soil conditions).

The experiment was conducted in a walk-in growth chamber in 2001 and 2002. Each of the weed species was grown in 5 litre pots filled with clay enriched substrate containing sufficient organic matter to prevent water logging. In each pot approximately 50 seeds were sown and loosely covered with the substrate. The pots were then watered thoroughly and put into the growth chamber. They were watered every other day. As it was noticed that the soil in pots standing near the wall dried more quickly the pots in the chamber were moved several times. After the germination of weeds at first 6 plants and then 5 plants included in the evaluation were left in the pots.

Growth conditions:

- Day length: 14 hours; from 6.00 to 20.00 hours,
- Relative moisture at night: 75 %,
- Night temperature: 12 °C,
- Relative air moisture by day: 75 %,
- Day temperature: 20 °C.

The trial was carried out at the earlier and at the later phase of development. At the early phase of development *Chenopodium album* and *Amaranthus retroflexus* plants reached 4–6 true leaves, *Echinochloa crus-galli* and *Poa annua* had 2–3 leaves whereas *Stellaria media* was 4–6 cm tall (6–10 leaves). In the later phase of development *Chenopodium album* and *Amaranthus retroflexus* plants were left to grow until 10–12 true leaves, *Poa annua* until the beginning of tillering, *Echinochloa crus-galli* until the tillering and *Stellaria media* until 16–24 leaves. In both cases watering was stopped 7 days prior to treatment to allow the soil to dry out.

The evaluation of the trial started 14 days after the mechanical measures. First the length of above ground and below ground part of each *Chenopodium album*, *Amaranthus retroflexus* and *Echinochloa crus-galli* plant was measured, then the weeds were marked and dried for 2 days at 38 °C and for 1 day at 60 °C. The dry plants were then weighed each plant separately. As a result the weed mass reduction expressed in percentage among different treatments and compared to the control was taken. The data were subjected to three series of ANOVA, comparison among mechanical measures, growth stage of the weeds and between dry and wet conditions using LSD test at $P \leq 0.05$.

3 Results

The average values of dry matter masses and the percentage of mass reduction (efficacy) compared to untreated control in a pot trial on simulation of mechanical measures in weed control at earlier and later phase of development of weed species growing under dry and wet soil conditions are presented in Tables 3 to 12. The results of measurements are also shown in Figures 1 to 3.

4 Discussion

4.1 Efficacy of mechanical measures on the control of *Chenopodium album*

When studying the possibility of effective use of mechanical measures in *Chenopodium album*, the most frequent weed species in field crops and in hop plantations, it was found that by their use the weed could be kept effectively under the damage threshold. When *Chenopodium album* was in the stage of 2–3 pairs of leaves developed and when the soil contained sufficient moisture all the treatments were very effective with the exception of partially buried and pulled up and roots re-buried. The greatest mass reduction was obtained with the treatment in which the plants were cut or pressed down or pulled up and buried (Table 3).

The results were even better using mechanical control under dry conditions. Unsatisfactory effect, in this case too, was obtained when plants were partially buried, when they were pressed down and buried and when their leaves were completely stripped. That uprooting of different weeds including *Chenopodium quinoa* Wild. is far more efficient than covering with soil was found also by KURSTJENS and KROPFF (2001).

A much higher variability was obtained using mechanical measures with larger plants. If these plants were pulled up

Table 3: Mean dry mass, percentage of reduction in dry mass and percentage of survived plants of Chenopodium album in the early stage (4–6 leaves) compared to untreated plants grown under wet and dry moisture conditions

Tabelle 3: Mittelwert der Trockenmasse, Prozentsaz der überlebenden Pflanzen und Prozentsatz der Reduktion der Trockenmasse von *Chenopodium album* im Frühstadium (4–6 Blätter) im Vergleich zu unbehandelten Pflanzen unter feuchten und trockenen Wuchsbedingungen

Treatment		Dry mass (g)		Efficacy (%)		Survived plants (%)	
		wet	dry	wet	dry	wet	Dry
1	Pulled out and left on surface	0,66	0,00	90,6	100,0	28,6	0,0
2	Cut at surface	0,00	0,00	100,0	100,0	0,0	0,0
3	Cut 1 cm below surface	0,16	0,07	97,7	98,5	17,1	8,6
4	Cut 1 cm above surface	0,22	0,12	96,9	97,5	20,0	20,0
5	Pressed down and completely buried	0,09	0,94	98,7	80,1	8,6	42,9
6	Pressed down and partly buried	5,29	4,42	24,6	6,4	97,1	97,1
7	Pulled up and roots buried	2,07	0,08	70,5	98,3	65,7	22,9
8	Pulled up and completely buried	0,23	0,00	96,7	100,0	8,6	0,0
9	Leaves stripped or cut	1,22	0,93	82,6	80,3	94,3	88,6
0	Untreated plants	7,02	4,72	–	–	100,0	100,0

Table 4: Mean dry mass, percentage of reduction in dry mass and percentage of survived plants of Chenopodium album in the later stage (10–12 leaves) compared to untreated plants grown under wet and dry moisture conditions

Tabelle 4: Mittelwert der Trockenmasse, Prozentsatz der überlebenden Pflanzen und Prozentsatz der Reduktion der Trockenmasse von *Chenopodium album* im Spätstadium (10–12 Blätter) im Vergleich zu unbehandelten Pflanzen unter feuchten und trockenen Wuchsbedingungen.

Treatment		Dry mass (g)		Efficacy (%)		Survived plants (%)	
		wet	dry	wet	dry	wet	Dry
1	Pulled out and left on surface	11,27	0,00	69,7	100,0	88,6	0,0
2	Cut at surface	0,14	0,00	99,6	100,0	5,7	0,0
3	Cut 1 cm below surface	1,40	0,00	96,2	100,0	37,1	0,0
4	Cut 1 cm above surface	0,00	0,00	100,0	100,0	0,0	0,0
5	Pressed down and completely buried	3,87	6,83	89,6	66,2	62,9	97,1
6	Pressed down and partly buried	16,60	14,4	55,4	28,6	100,0	100,0
7	Pulled up and roots buried	12,07	0,23	67,6	98,9	97,1	5,7
8	Pulled up and completely buried	5,92	1,91	84,1	90,5	82,9	37,1
9	Leaves stripped or cut	2,73	3,61	93,5	82,1	100,0	91,4
0	Untreated plants	37,22	20,18	–	–	100,0	100,0

under sufficiently wet conditions, they managed to re-grow to a great extent whereas the lowest reduction percentage of weed mass was reached with partially buried plants (55.4 % reduction) and pulled up plants and roots re-buried (67.6 % reduction). Similar results were obtained also by KURSTJENS et al. (2000). They found that the sensitivity of investigated weeds above to uprooting decreased rapidly after plant emergence. With larger plants it is more difficult to achieve an even cover with soil which in practice means that plants may grow up to the surface and towards the light and continue developing. Under dry conditions the plants that were cut did not recover regardless of how high they were cut which led to their complete decay. It can be therefore understood that even under dry conditions the weed species can not be controlled by poor covering with cultivators i.e. a situation frequently met in hop plantations. Partly buried or entire pulled up and then re-buried plants can re-grow to a great extent (Table 4).

If to all this fertilizers are added, which in most cases is done at that time, the vigorous growth of *Chenopodium album* up to more than 2 m and the excessive weediness of hop plantations with this weed species can easily be explained.

4.2 Efficacy of mechanical measures on the control of *Amaranthus retroflexus*

When the susceptibility of *Amaranthus retroflexus* to mechanical damage was studied many similarities with *Chenopodium album* were found. In this case, too, the plants did not recover after they were pulled up, cut at the surface or below the surface (Table 5).

A few more plants survived only when they were cut 1 cm above the surface, however, an 89.2 % mass reduction was obtained in this case, too. With *Amaranthus retroflexus* the treatment of partially buried plants (55.3 % mass reduction) and pulled up plants whose root system was re-buried (49.4 % reduction) was only halfway successful. The results were similar under dry conditions, only the effectiveness of measures in which plants were cut at the surface or partially buried was a bit poorer (81.7 % and 34 % mass reduction compared to undamaged plants).

In the trial with larger plants the results were even a little worse on the average (Table 6). In our opinion the soil layer with which the weeds were covered was too thin. Irrespective of soil moisture it became evident that *Amaranthus retroflexus* had to be covered thoroughly. In the case of larger plants under dry conditions an unexpectedly lesser effectiveness of measures was observed when the plants were buried partially or when they were carefully pulled up and their roots were re-buried. Similar results were obtained when plants were pressed down and buried completely. According to our opinion, the reason for that may be found in the decay (rotting) of leaf mass of weed due to the moist soil. In treatments in which plants were cut above the surface, at the surface and below it extremely good effectiveness was reached since only a small percentage of plants managed to survive and even those did not recover during the research. A little worse effectiveness was reached when plants were cut 1 cm above the surface since a lot of plants succeeded in regrowing. In contrast to the first date it was estab-

Table 5: Mean dry mass, percentage of survived plants and percentage of reduction in dry mass of *Amaranthus retroflexus* in the early stage (4–6 leaves) compared to untreated plants grown under wet and dry moisture conditions

Tabelle 5: Mittelwert der Trockenmasse, Prozentsatz der überlebenden Pflanzen und Prozentsatz der Reduktion der Trockenmasse von *Amaranthus retroflexus* im Frühstadium (4–6 Blätter) im Vergleich zu unbehandelten Pflanzen unter feuchten und trockenen Wuchsbedingungen

Treatment		Dry mass (g)		Efficacy (%)		Survived plants (%)	
		wet	dry	wet	dry	wet	Dry
1	Pulled out and left on surface	0,38	0,01	94,4	99,7	28,6	2,9
2	Cut at surface	0,04	0,03	99,4	99,2	8,6	5,7
3	Cut 1 cm below surface	0,15	0,00	97,8	100,0	14,3	0,0
4	Cut 1 cm above surface	1,15	0,30	83,0	91,6	34,3	37,1
5	Pressed down and completely buried	0,21	0,13	96,9	96,4	20,0	17,1
6	Pressed down and partly buried	2,71	1,74	59,9	51,1	94,3	88,6
7	Pulled up and roots buried	2,92	1,21	56,8	66,0	88,6	77,1
8	Pulled up and completely buried	0,01	0,01	99,9	99,7	2,9	2,9
9	Leaves stripped or cut	1,98	0,71	70,7	80,1	94,3	48,6
0	Untreated plants	6,76	3,56	–	–	100,0	100,0

Table 6: Mean dry mass, percentage of reduction in dry mass and percentage of survived plants of *Amaranthus retroflexus* in the later stage (10–12 leaves) compared to untreated plants grown under wet and dry moisture conditions
Tabelle 6: Mittelwert der Trockenmasse, Prozentsatz der überlebenden Pflanzen und Prozentsatz der Reduktion der Trockenmasse von *Amaranthus retroflexus* im Spätstadium (10–12 Blätter) im Vergleich zu unbehandelten Pflanzen unter feuchten und trockenen Wuchsbedingungen

Treatment		Dry mass (g)		Efficacy (%)		Survived plants (%)	
		wet	dry	wet	dry	wet	Dry
1	Pulled out and left on surface	1,62	0,59	94,3	96,3	14,3	11,4
2	Cut at surface	0,00	0,03	100	99,8	0,0	8,6
3	Cut 1 cm below surface	0,71	0,34	97,5	97,8	17,1	5,7
4	Cut 1 cm above surface	0,97	1,92	96,6	87,8	40,0	60,0
5	Pressed down and completely buried	1,11	1,97	96,1	87,5	22,9	11,4
6	Pressed down and partly buried	18,52	8,70	34,8	44,8	88,6	94,3
7	Pulled up and roots buried	13,86	4,54	51,2	71,2	85,7	45,7
8	Pulled up and completely buried	0,30	0,29	98,9	98,2	5,7	5,7
9	Leaves stripped or cut	14,73	7,52	51,6	52,3	88,6	94,3
0	Untreated plants	28,39	15,76	–	–	100,0	97,1

Table 7: Mean dry mass, percentage of reduction in dry mass and percentage of survived plants of *Stellaria media* in the early stage (6–10 leaves) compared to untreated plants grown under wet and dry moisture conditions
Tabelle 7: Mittelwert der Trockenmasse, Prozentsatz der überlebenden Pflanzen und Prozentsatz der Reduktion der Trockenmasse von *Stellaria media* im Frühstadium (4–6 Blätter) im Vergleich zu unbehandelten Pflanzen unter feuchten und trockenen Wuchsbedingungen

Treatment		Dry mass (g)		Efficacy (%)		Survived plants (%)	
		wet	dry	wet	dry	wet	Dry
1	Pulled out and left on surface	0,036	0,002	89,4	99,1	22,9	2,9
2	Cut at surface	0,003	0,005	99,1	97,7	2,9	8,6
3	Cut 1 cm below surface	0,024	0,010	92,9	95,5	22,9	17,1
4	Cut 1 cm above surface	0,020	0,009	94,1	95,9	28,6	22,9
5	Pressed down and completely buried	0,039	0,010	88,5	95,5	37,1	34,3
6	Pressed down and partly buried	0,117	0,050	65,6	77,3	80,0	68,6
7	Pulled up and roots buried	0,099	0,028	70,9	87,3	65,7	37,1
8	Pulled up and completely buried	0,009	0,000	97,4	100,0	8,6	0,0
9	Leaves stripped or cut	0,154	0,030	54,7	86,4	88,6	88,6
0	Untreated plants	0,340	0,220	–	–	100,0	100,0

lished that larger *Amaranthus retroflexus* plants which were entirely stripped of their leaves recovered well under dry conditions (27.7 % mass reduction) whereas under wet conditions their response to defoliation was unexpectedly poor.

4.3 Efficacy of mechanical measures on the control of *Stellaria media*

Investigation of effectiveness of mechanical measures in the control of *Stellaria media* indicated that *Stellaria media* needed a lot of moisture to develop. The comparison of results helped establish, similarly to Jones and Blair (1996), considerable differences in the mass of undamaged plants as a consequence of moist or dry conditions. Among mechanical measures pulling up of plants and cutting them at the surface and above the surface were the most effective (Table 7).

Somewhat poorer were the results at cutting 1 cm below surface since the plants managed to regrow relatively well. Results were even poorer if plants were covered and pulled up and their roots re-buried. The lowest effectiveness was obtained at partially buried plants since at the measurement of mass 82.4 % effectiveness was reported. It was no better under dry conditions with the effects being even much worse. A satisfactory effectiveness was observed only in the case of pulled up plants cut at the surface and 1 cm below it. Pulling up of plants and then re-burying their roots was

Table 8: Mean dry mass, percentage of survived plants and percentage of reduction in dry mass of *Stellaria media* in the later stage (16–24 leaves) compared to untreated plants grown under wet and dry moisture conditions

Tabelle 8: Mittelwert der Trockenmasse, Prozentsatz der überlebenden Pflanzen und Prozentsatz der Reduktion der Trockenmasse von *Stellaria media* im Frühstadium (10–12 Blätter) im Vergleich zu unbehandelten Pflanzen unter feuchten und trockenen Wuchsbedingungen

Treatment		Dry mass (g)		Efficacy (%)		Survived plants (%)	
		wet	dry	wet	dry	wet	Dry
1	Pulled out and left on surface	0,140	0,012	86,3	98,5	31,4	5,7
2	Cut at surface	0,039	0,023	96,2	97,1	20,0	17,1
3	Cut 1 cm below surface	0,083	0,039	91,9	95,0	25,7	17,1
4	Cut 1 cm above surface	0,137	0,147	86,6	81,3	48,6	71,4
5	Pressed down and completely buried	0,142	0,099	86,1	87,4	60,0	45,7
6	Pressed down and partly buried	0,380	0,245	62,8	68,8	85,7	85,7
7	Pulled up and roots buried	0,248	0,171	75,7	78,2	65,7	60,0
8	Pulled up and completely buried	0,046	0,011	95,5	98,6	20,0	8,6
9	Leaves stripped or cut	0,312	0,277	69,4	64,7	91,4	94,3
0	Untreated plants	1,021	0,784	–	–	100,0	100,0

also satisfactory. All the remaining measures proved to be much worse and unsatisfactory.

At the verification of effectiveness of mechanical measures on larger *Stellaria media* plants no essential changes were noticed in comparison with the control of smaller plants (Table 8). Under dry conditions the results of mechanical measures were much better which also speaks in favour of taking into consideration the weather conditions if the mechanical measures are being applied.

4.4 Efficacy of mechanical measures on the control of *Poa annua*

Due to the specific structure and development of grasses their mechanical control differs a great deal from that of weeds such as *Chenopodium album* or *Amaranthus retroflexus*. The grasses such as *Echinochloa crus-galli* and *Poa annua* do not have a distinctive stem like the two broad-leaved species mentioned above. At certain simulations of mechanical measures it was extremely difficult to evenly carry out the measures. At cutting of plants 1 cm above surface in small plants it was very important whether the shoot tip was affected as it was situated on the cutting height at that time. According to our opinion, smaller differences in the size of plants and cutting height could have had a decisive influence on the effectiveness of measures or subsequent regrowth of plats. Similar happened at the stripping of leaves from entire plants when the leaves of grasses were cut similarly to cutting treatment, only at the height of 2 cm.

The specificity of grasses in comparison with *Chenopodium album* or *Amaranthus retroflexus* may also be observed in their roots. While the two broad-leaved species, *Chenopodium album* and *Amaranthus retroflexus*, have a strong main root on which their development depends, the grasses included in the research have a fibrous and tufted root system which is divided in relation to depth in the upper and lower root system, depending mainly on moisture available in soil (Blair et al., 2002). Performing of mechanical measures of weed cutting below surface gave rather poorer and unequal results (Tables 9 and 10).

In *Poa annua* small plants and optimal soil moisture unsatisfactory effects were obtained at the majority of simulations of mechanical measures (Table 9). The poorest results were obtained in the treatment of plants cut 1 cm below surface (44.6 % weed mass reduction); similar results were obtained with partial burying of plants (44.2 %). Not very much better was cutting of weeds 1 cm above surface (54 %). *Poa annua* recovered a great deal in the case of pulling since with this treatment only 59 % reduction of its mass compared to undamaged plants was obtained. The best effectiveness in the control of *Poa annua* was reached when it was cut at the surface and when it was entirely buried in soil.

Under dry conditions the results of the control were much better; the only measure that was outstanding in the negative sense was the partial burial of plants. At the use of mechanical measures for the control of grasses it is important – more than with broad-leaved weeds – to choose beside adequate tools also the appropriate time of cultivation, i.e. when the soil is dry enough thus contribu-

Table 9: Mean dry mass, percentage of survived plants and percentage of reduction in dry mass of *Poa annua* in the early stage (2–3 leaves) compared to untreated plants grown under wet and dry moisture conditions
Tabelle 9: Mittelwert der Trockenmasse, Prozentsatz der überlebenden Pflanzen und Prozentsatz der Reduktion der Trockenmasse von *Poa annua* im Frühstadium (2–3 Blätter) im Vergleich zu unbehandelten Pflanzen unter feuchten und trockenen Wuchsbedingungen

Treatment		Dry mass (g)		Efficacy (%)		Survived plants (%)	
		wet	dry	wet	dry	wet	Dry
1	Pulled out and left on surface	0,128	0,004	59,0	98,7	60,0	5,7
2	Cut at surface	0,023	0,007	92,6	97,7	14,3	11,4
3	Cut 1 cm below surface	0,173	0,068	44,6	78,2	77,1	60,0
4	Cut 1 cm above surface	0,141	0,074	54,8	76,3	80,0	82,6
5	Pressed down and completely buried	0,041	0,011	86,9	96,4	22,9	11,4
6	Pressed down and partly buried	0,174	0,102	44,2	66,5	88,6	85,7
7	Pulled up and roots buried	0,125	0,022	60,0	92,8	74,3	22,9
8	Pulled up and completely buried	0,041	0,002	86,9	99,3	25,7	2,9
9	Leaves stripped or cut	0,142	0,044	54,5	85,5	88,6	45,7
0	Untreated plants	0,312	0,304	–	–	100,0	100,0

Table 10: Mean dry mass, percentage of survived plants and percentage of reduction in dry mass of *Poa annua* in the later stage (beginning of tillering) compared to untreated plants grown under wet and dry moisture conditions
Tabelle 10: Mittelwert der Trockenmasse, Prozentsatz der überlebenden Pflanzen und Prozentsatz der Reduktion der Trockenmasse von *Poa annua* im Spätstadium (Beginn der Bestockung) im Vergleich zu unbehandelten Pflanzen unter feuchten und trockenen Wuchsbedingungen

Treatment		Dry mass (g)		Efficacy (%)		Survived plants (%)	
		wet	dry	wet	dry	wet	Dry
1	Pulled out and left on surface	0,38	0,10	83,9	95,4	34,3	11,4
2	Cut at surface	0,12	0,11	94,9	95,0	17,1	11,4
3	Cut 1 cm below surface	1,53	0,53	35,2	75,7	88,6	42,9
4	Cut 1 cm above surface	1,12	0,89	52,5	59,2	82,9	85,7
5	Pressed down and completely buried	0,33	0,35	86,0	83,9	20,0	28,6
6	Pressed down and partly buried	1,68	1,31	28,8	39,9	88,6	88,6
7	Pulled up and roots buried	0,90	0,40	61,9	81,7	74,3	37,1
8	Pulled up and completely buried	0,22	0,11	90,7	95,0	20,0	11,4
9	Leaves stripped or cut	1,22	0,90	48,3	58,7	88,6	88,6
0	Untreated plants	2,36	2,18	–	–	100,0	100,0

ting additionally to the enhancement of control effectiveness.

The effectiveness at the control of larger plants and sufficient moisture was very similar to that of the smaller plants (Table 10). An exception was observed only at the pulling up of plants when more than 30 % better effectiveness was obtained with larger plants compared to the first date (83 % mass reduction). In this case the root system was probably unable to regain the contact with soil on time to preserve at life the pretty much developed plants. The poorest results with larger plants were reached in the case of partially buried plants in which there was only by 28.8 % less weed mass on the average compared to undamaged plants. Even greater was the deviation of this mechanical measure under dry conditions. It was more than twice as ineffective as all the other measures (Table 10). With all the remaining measures much better results were obtained under dry conditions than at sufficient moisture but, at the same time, results were a little poorer compared to the control of weed under dry conditions in the first date.

4.5 Efficacy of mechanical measures on the control of *Echinochloa crus-galli*

Echinochloa crus-galli, distinguishing in its development from *Poa annua* by its upright growth, does not differ very much in its susceptibility to various mechanical measures from *Poa annua* (Tables 11 in 12). Treatments used in the case of *Echinochloa crus-galli* with regard to effectiveness in the first date irrespective of soil moisture showed deviations when plants were cut at the surface (87 % under moist conditions and 96.7 % under dry conditions), when plants were pressed down and buried completely (92.5 % under moist conditions and 97.2 % under dry conditions), when they were pulled up and buried (90.4 % under moist conditions and 100 % under dry conditions). A substantial difference in the effectiveness in the first date was observed at the treatment of pulled up plants and then left on the ground. While the effectiveness at sufficient moisture in soil was only 61.5 %, under dry conditions this treatment was one of the best (99 % effectiveness). If we want to control *Echinochloa crus-galli* effectively it is very important to bury it completely since the results of investigation have shown that it can stand very well the partial burial in soil (24.2 % effectiveness under moist conditions and 51.9 % under dry conditions). Even if it is cut 1 cm below the surface, 1 cm or 2 cm above the surface the research has shown that very good results are not to be expected. Especially under sufficiently moist conditions not more than 60 % effectiveness can be expected on the average (Table 11). Somewhat better are the results under dry conditions, especially when plants are cut 1 cm below the surface (80.7 % effectiveness).

At the comparison of individual treatments for all the five

Table 11: Mean dry mass, percentage of survived plants and percentage of reduction in dry mass of *Echinochloa crus-galli* in the early stage (2–3 leaves) compared to untreated plants grown under wet and dry moisture conditions

Tabelle 11: Mittelwert der Trockenmasse, Prozentsatz der überlebenden Pflanzen und Prozentsatz der Reduktion der Trockenmasse von *Echinochloa crus-galli* im Frühstadium (2–3 Blätter) im Vergleich zu unbehandelten Pflanzen unter feuchten und trockenen Wuchsbedingungen

Treatment		Dry mass (g)		Efficacy (%)		Survived plants (%)	
		wet	dry	wet	dry	wet	Dry
1	Pulled out and left on surface	0,164	0,004	61,5	99,0	60,0	2,9
2	Cut at surface	0,055	0,013	87,1	96,7	31,4	11,4
3	Cut 1 cm below surface	0,172	0,077	59,6	80,7	68,6	37,1
4	Cut 1 cm above surface	0,224	0,127	47,4	68,2	85,7	88,6
5	Pressed down and completely buried	0,032	0,011	92,5	97,2	14,3	8,6
6	Pressed down and partly buried	0,323	0,192	24,2	51,9	85,7	80,0
7	Pulled up and roots buried	0,152	0,052	64,3	87,0	62,9	28,6
8	Pulled up and completely buried	0,041	0,000	90,4	100,0	20,0	0,0
9	Leaves stripped or cut	0,168	0,096	60,6	76	77,1	60,0
0	Untreated plants	0,426	0,399	–	–	97,1	100,0

Table 12: Mean dry mass, percentage of survived plants and percentage of reduction in dry mass of *Echinochloa crus-galli* in the later stage (beginning of tillering) compared to untreated plants grown under wet and dry moisture conditions

Tabelle 12: Mittelwert der Trockenmasse, Prozentsatz der überlebenden Pflanzen und Prozentsatz der Reduktion der Trockenmasse von *Echinochloa crus-galli* im Spätstadium (Beginn der Bestockung) im Vergleich zu unbehandelten Pflanzen unter feuchten und trockenen Wuchsbedingungen

Treatment		Dry mass (g)		Efficacy (%)		Survived plants (%)	
		wet	dry	wet	dry	wet	Dry
1	Pulled out and left on surface	13,83	0,68	84,5	98,8	57,1	14,3
2	Cut at surface	4,27	0,82	95,2	98,5	65,7	20,0
3	Cut 1 cm below surface	26,74	9,36	70,0	82,8	60,0	54,3
4	Cut 1 cm above surface	14,41	14,31	83,8	73,7	80,0	88,6
5	Pressed down and completely buried	2,02	1,07	97,7	98,0	5,7	20,0
6	Pressed down and partly buried	33,69	22,37	62,2	58,9	80,0	88,6
7	Pulled up and roots buried	49,4	17,12	44,6	68,5	77,1	48,6
8	Pulled up and completely buried	0,61	1,87	99,3	96,6	5,7	11,4
9	Leaves stripped or cut	35,66	24,54	60,0	54,9	82,9	85,7
0	Untreated plants	89,09	54,39	–	–	94,3	91,4

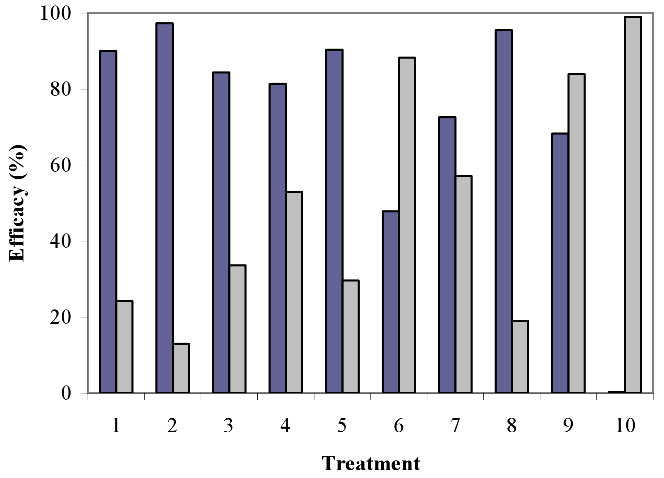

Figure 1: The efficacy of treatments and the percentage of survived weed species compared to untreated plants in pot trials with simulated mechanical measures for weed control independent of plant size and soil moisture

Abbildung 1: Effizienz der Behandlungen und Prozentsatz der überlebenden Unkrautpflanzen im Vergleich zur Kontrolle im Gefäßversuch mit simulierten mechanischen Maßnahmen, unabhängig von der Pflanzenentwicklung und der Bodenfeuchte

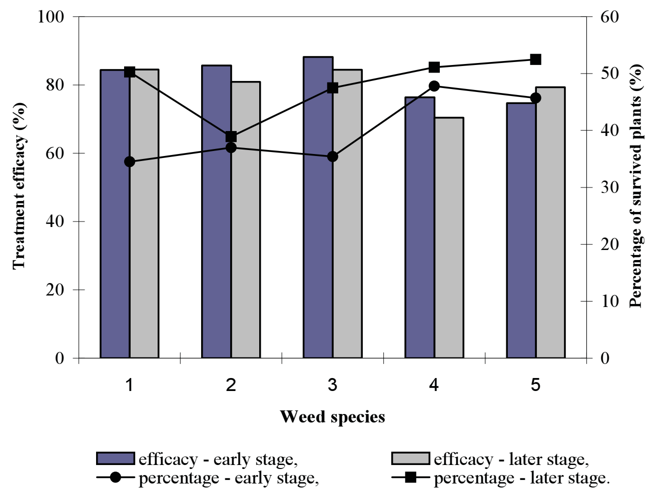

Figure 2: The efficacy of treatments and the percentage of survived weed species compared to untreated plants in pot trials with simulated mechanical measures for weed control dependent on plant size. Weeds: 1 – *Chenopodium album*, 2 – *Amaranthus retroflexus*, 3 – *Stellaria media*, 4 – *Poa annua*, 5 – *Echinochloa crus-galli*

Abbildung 2: Effizienz der Behandlungen und Prozentsatz der überlebenden Unkrautpflanzen im Vergleich zur Kontrolle im Gefäßversuch mit simulierten mechanischen Maßnahmen in Abhängigkeit von der Pflanzenentwicklung. Unkräuter: 1 – *Chenopodium album*, 2 – *Amaranthus retroflexus*, 3 – *Stellaria media*, 4 – *Poa annua*, 5 – *Echinochloa crus-galli*

weed species it was found that more than 90 % weed mass reduction can be obtained on the average if weeds are pulled up, pulled up and buried completely or partially. A very effective measure is the lowest possible cut of weeds preventing their subsequent regrowth. With the partial burial of plants or pulling and partial burial a greater success is not to be expected (Fig. 1). Poor results were also obtained with the simulation of mulching and harrowing in which more than 80 % of plants survived and continued to grow and develop.

With mechanical control worse results can be expected on the average if the treatment is carried out under the conditions of sufficient soil moisture. With all the five weed species studied the effectiveness in the use of mechanical measures is greater in the case of drier conditions during and after the treatment (Fig. 3).

The mechanically affected plants are thus prevented from their subsequent regrowth and development. Average differences in the effectiveness of mechanical measures as a consequence of different soil moisture were not as obvious as at the analysis of particular weed species. From the analysis of data it was found that the differences were statistically significant which is confirmed by Fig. 3 in which differences in the effectiveness in favour of treatments performed under less moist soil conditions may be seen distinctly. Differences are even more obvious if the share of survived plants is compared since between the plants which had sur-

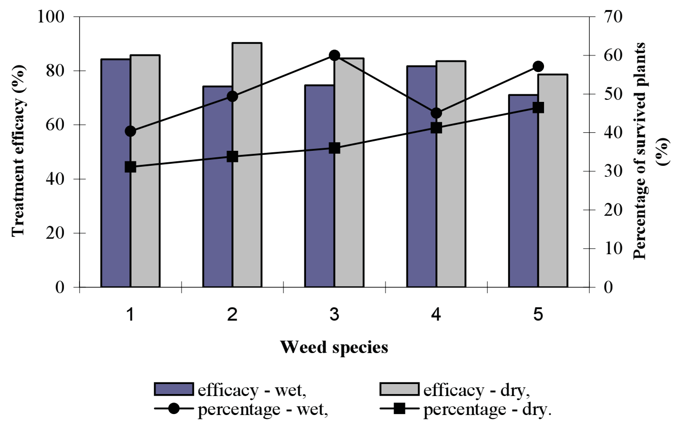

Figure 3: The efficacy of treatments and the percentage of survived weed species compared to untreated plants in pot trials with simulated mechanical measures for weed control dependent on soil moisture. Weeds: 1 – *Chenopodium album*, 2 – *Amaranthus retroflexus*, 3 – *Stellaria media*, 4 – *Poa annua*, 5 – *Echinochloa crus-galli*

Abbildung 3: Effizienz der Behandlungen und Prozentsatz der überlebenden Unkrautpflanzen im Vergleich zur Kontrolle im Gefäßversuch mit simulierten mechanischen Maßnahmen in Abhängigkeit von der Bodenfeuchte. Unkräuter: 1 – *Chenopodium album*, 2 – *Amaranthus retroflexus*, 3 – *Stellaria media*, 4 – *Poa annua*, 5 – *Echinochloa crus-galli* vived under moist and those survived under dry conditions they are even greater. Lesser differences in the effectiveness between the two treatments can be explained by a still sufficiently moist soil which allowed growth and development of partly affected weeds in individual weeds and treatments.

At the establishment of influence of time and performance of mechanical measures in relation to weed size on the effectiveness of the measures, the latter are more effective in smaller weeds on the average (Fig. 2). The exception is only *Echinochloa crus-galli* in which the mechanical measures were a little more effective in larger plants on the average. The differences in the effectiveness of measures as a consequence of control date were as great as reported by KOCH (1970) and BAUMANN (1992) in their investigations. This was also confirmed by the statistical analysis which, opposite to expectations, did not confirm a statistically significant difference in the effectiveness between both control dates. If comparing the average share of surviving plants in the first and the second date it is much more obvious that the number of surviving plants was much greater in the second date than in the first date which was also confirmed by statistically significant differences.

5 Conclusion

On the basis of the current investigation it can be concluded that using mechanical measures for the control of weeds it is very important what measure or what tool can be used for individual weed species as well as when it should be applied with regard to the size of weeds and in what growth and especially weather conditions it should be used. With the right choice of cultivators for the maintenance of fine structure of soil, which allows a more even germination of weed seeds, the soil for hoeing, harrowing and covering is prepared more adequately. Both hoeing, harrowing as well as covering depended on soil structure in the first place. Consequently, the efficacy of different mechanical measures applied in weed control depends on that, too.

Acknowledgements

The investigation was carried out at the Plant Protection Department of the Slovenian Institute for Hop Research and Brewing in frame of dissertation thesis. We would like to extend our sincere thanks to the colleagues for the help offered in the investigation.

References

BAUMANN, D. T. (1992): Mechanical weed control with spring tine harrows (weed harrows) in row crops. In: Proceeding of the IXth International Symposium on the Biology of Weeds. IXth International Symposium on the Biology of Weeds, Dijon, 18–21 jun., Dijon, EWRS: 123–128.

BLAIR A. M., P.A. JONES, R. H. INGLE, N. D. TILLET and T. HAGUE (2002): The integration of herbicides with mechanical weeding for weed control in winter wheat. Journal of Agricultural Science, 139: 385–395.

CAMPBELL A. D. and A. C. GRICE (2000): Weed biology: a foundation for weed management. Tropical Grasslands, 34: 271–279.

CERJAK, M. (1991): Plevelna flora v hmeljiščih v Spodnji Savinjski dolini. Diplomsko delo. Ljubljana, Univerza v Ljubljani, BTF VTOZD za agronomijo: 1–105.

CRAMER, H. H. (1967): Pflanzenschutz und Welternte. Pflanzenschutznachrichten Bayer, 20: 5.

HATCHER, P. E. and B. MELANDER (2003): Combining physical, cultural and biological methods: prospects for integrated non-chemical weed management strategies. Weed Research, 43: 303–322.

JONES, P. A. and A. M. BLAIR (1996): Mechanical damage to kill weeds. V: Proceedings of the Second International Weed Control Congress. Second International Weed Control Congress, Copenhagen, 25–28 June 1996. In: H. BROWN et al. (ed.). Slagelse, Department of Weed Control and Pesticide Ecology Flakkebjerg: 949–954.

KIŠGECI, J., A. MIJAVEC, M. AĆIMOVIĆ, P. SPEVAK and N. VUČIĆ (1984): Hmeljarstvo. Novi Sad, Poljoprivredni fakultet – Institut za ratarstvo i povrtarstvo Novi Sad, 1–374.

KURSTJENS, D. A. G. and M. J. KROPFF (2001): The impact of uprooting and soil-covering on the effectiviness of weed harrowing. Weed Research, 41: 211–228.

KURSTJENS, D. A. G., U. D. PERDOK and D. GOENSE (2000): Selective uprooting by weed harrowing on sandy soils. Weed Research, 40: 431–447.

KOCH, W. (1970): Unkrautbekämpfung. Stuttgart, Ulmer, 1–374.

MAJER, D. (2002): Prehrana hmeljnih rastlin. In: Priročnik za hmeljarje. In: D. MAJER (ed.). Žalec, Inštitut za hmeljarstvo in pivovarstvo Žalec, 103–135.

NORREMARK, M. and H. W. GRIEPENTROG (2004): Analysis and definition of the close-to-crop area in relation to robotic weeding. Proceedings of 6th EWRS Workshop on

Physical and Cultural Weed Control, Lillehamer, Norway, 127–140.

PARRISH, J. A. D. and F. A. BAZZAZ (1982): Responses of plants from three successional communities to a nutrient gradient. Journal of Ecology, 70: 233–248.

RADIŠEK, S., J. JAKŠE, A. SIMONČIČ and B. JAVORNIK (2003): Characterization of *Verticillium albo-atrum* field isolates using pathogenicity data and AFLP analysis. Plant dis., vol. 87, no. 6, 633–638.

RASMUSSEN, J. (1996): Mechanical Weed Management. V: Proceedings of the Second International Weed Control Congress. Second International Weed Control Congress, Copenhagen, 25–28 June 1996. In: H. BROWN et al. (ed.). Slagelse, Department of Weed Control and Pesticide Ecology Flakkebjerg, 943–948.

RASMUSSEN, J. and K. RASMUSSEN (1995): A strategy for mechanical weed control in spring barley. V: Challenges for Weed Science in a Changing Europe. 9th EWRS Symposium, Budapest, 10–12 July 1995. In: L. DARICS (ed.). Budapest, EWRS, 557–564.

SIMONČIČ, A., M. VERONEK and M. SVET (1995): Zatiranje plevela v hmeljiščih v razmerah omejene rabe herbicidov. Hmeljarski bilten, 4: 66–72.

Address of authors

Assist. Prof. Dr. Andrej Simončič, Agricultural Institute of Slovenia, Hacquetova 17, 1001 Ljubljana, Slovenia; E-Mail: Andrej.simoncic@kis.si

Gregor Leskošek, B.Sc., Slovenian Institute for Hop Research and Brewing, C. Žalskega tabora 2, 3311 Žalec, Slovenia; E-Mail: Gregor.leskosek@guest.arnes.si

Eingelangt am 5. November 2004
Angenommen am 27. September 2005