PECULIARITIES OF WILLOW PRODUCTIVITY FORMATION IN THE FIRST YEAR OF GROWING UNDER MECHANICAL WEED CONTROL
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ОСОБЛИВОСТІ ФОРМУВАННЯ ПРОДУКТИВНОСТІ ВЕРБИ ЕНЕРГЕТИЧНОЇ ПЕРШОГО РОКУ ВЕГЕТАЦІЇ ЗА МЕХАНІЧНИХ ПРИЙОМІВ КОНТРОЛЮВАННЯ БУР'ЯНІВ

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ABSTRACT
The results of five-year field experiments using various mechanical techniques to protect annual plantings of energy willow from weeds in the central forest-steppe zone of Ukraine were given. The use of inter-row cultivation system (3 treatments every 15 days) reduced the value of forming a weeds mass to 2.9 times; using mounted chain harrow – *3.1 times, and the use of three consequent harrowing between rows – 3.4 times, compared with the case* without weed treatment – *3854 g/m^2. The lowest yield of dry energy willow biomass (1.15 t/ ha) was obtained without weed control, while the highest was obtained after six consequent hand weedings (3.14 t/ha). Successive hoeing of the space between rows ensured, on the average, 2.52 t/ha dry biomass in the first year of growing, while similar harrowing with chain harrow 2.55 t /ha, and cutting of weeds 2.60 t/ha.*

РЕЗЮМЕ
Наведено п'ятирічні результати проведених в Центральному Лісостепу України на чорноземно-лучному ґрунті досліджень ефективності застосування різних механічних прийомів для захисту однорічних посадок верби енергетичної від бур'янів. Використання системи міжрядних культивацій (3 догляди через кожні 15 днів) знижувало величину формування маси бур'янів у 2,9 раз; аналогічної система міжрядних боронувань сітчастими боронами – у 3,1 раз, а при застосуванні трьох послідовних зрізувань сходів у міжряддях – у 3,4 рази, порівняно з варіантом без проведення доглядів – 3854 г/м^2. Встановлено, що на варіанті забур'яненого контролю рослин верби енергетичної формували мінімальне значення урожайності сухої біомаси – 1,15 т/га, в той же час максимальний рівень урожайності був у варіанті з проведенням шести послідовних ручних просапувань – 3,14 т/га. За проведення системи послідовних міжрядних культивацій отримали середню урожайність верби енергетичної першого року вирощування на рівні 2,52 т/га, за послідовних міжрядних боронувань навісними сітчастими боронами – 2,55 т/га а за системи послідовних зрізувань сходів бур'янів рослини верби сформували 2,60 т/га сухої біомаси.

INTRODUCTION
The first energy willow plantations appeared in Sweden in the late 1980s as a reaction to the volatile fossil fuel market (*Gustafsson et al, 2009; Mola-Yudego B., 2010*). Given the high calorific value of the willow wood, which according to various estimates amounts to 17.0−17.5 MJ·kg^{-1} of absolutely dry matter (*Roik et al., 2015; Fuchylo Ya. D., 2011*) although it can reach 19.8 MJ·kg^{-1} (*Keoleian and Volk, 2005*)), willow biomass is mainly used for the production of chip fuel, pellets and briquettes for combustion in solid fuel boilers.

Dominating in energy-intensive plantations in Sweden were the clones and hybrids of the Salmonidae (Salix viminalis L.) derived from long-term dedicated breeding program for *Salix viminalis* cultivation carried out since 1987 (*Ahman and Larson, 1994*). Simultaneously, breeding was carried out over other species and their hybrids (*Willow Varietal Identification Guide, 2012*). Currently, the varieties of Swedish breeding, due to their high productivity and unpretentiousness to soil conditions, are common in most European countries, including Ukraine. One of the most productive varieties is 'Torah'. In Sweden, this cultivar achieves productivity up to 22 ton·ha^{-1} year^{-1} (*Volk et al., 2004*) and in the United Kingdom 11.3 ton·ha^{-1} year^{-1} (*Aylott et al., 2008*). In addition to studying general principles of the establishment of energy willow plantations (*Caslin et al., 2010*), much attention in the United Kingdom was being paid to improve the resistance of willow to harmful organisms (*McCracken et al,, 2011; Parfitt and Stott, 1987*).

Various aspects of creation, cultivation, exploitation, economic and ecological efficiency of energy willow plantations are also being explored in the United States *(Caputo et al, 2013; Volk et al., 2006; Volk et al., 2016; Wang et al. 201*5), Finland (*Hytonen J., 1995*), Canada (*Mosseler et al., 2014; Mosseler and Major, 2014; Nissim et al., 2013; Glavonjić, B., 2017*), the Czech Republic (*Weger et al., 2011*) and Ukraine (R*oik et al., 2015; Fuchylo, Ya. D., 2011*). Being a light-demanding plant, energy willow requires weed control in the first years of growing. It was found that weed infestation can reduce willow yield by 50 − 95% in the first years (*Sage R., 1999; Mitchell et al., 1999*). Besides light, weeds compete with willow for nutrients and water (*Weger et al., 2011*). It is clear that the longer the crop remains clear of weeds, the better it grows and forms a larger yield (*Hansen and Netzer, 1985*). Taking into account its low competitiveness, controlling weeds in willow plantations in the early stages of development should include a set of measures for mechanical and chemical weed control carried out, first of all, before the emergence of weeds, as post-emergence control is ineffective (*Davies R. J., 1985*). The most common ways of weed control in small plots include agrotechnical control and hand weeding but large energy willow plantation cannot be maintained without chemical weed control. At the same time, mechanical (agrotechnical) weed control methods also revealed some disadvantages: first of all, the intensive mixing of the upper soil layer when hoeing the space between rows. Such mixing promotes the emergence of the next wave of sprouting weeds. Reducing the level of mixing the soil (using chain harrow), and especially successive cuttings of weeds, reduced the intensity of weed emergence, but did not stop the process completely.

There are a number of registered commercial soil action formulas based on propyzamide, aclonifen, cycloxydim, clopyralid (*Gustafsson et al., 2009),* and glyphosate *(Gustafsson et al., 2009; Gustafsson L., 1987*) in Sweden. The latter is the most common herbicide for willow plantations in Europe and USA. It is introduced annually in the first three years during dormancy period, as glyphosate applied during the growth period suppresses willow plants. Romanian researchers reckon that introduction of herbicides does not inhibit the growth of willow plants (*Kondor et al. 2007*).

Agrotechnical weed control in willow plantations using multi-row cultivators and rotary ploughs was investigated in the early 1990s in different Sweden regions and on different soil types. A common problem of all these methods was to combat weeds between plants in a row, and in the case of using rake for this purpose willow seedlings were significantly damaged (*Albertsson J., 2012*). Three inter-row hoeing in the first half of the growing season practiced for willow in Ukraine almost completely destruct weed sprouts in the space between rows. However, weeds continue their growth in the rows and within buffer (protective) strips. Therefore, hand weeding is necessary for their destruction, which required significant labour costs (Roik *et al*., 2015). According to Polish researchers, the first 4−10 weeks following planting are critical for willow from the herbological point of view (*Sekutowski et al., 2007*); therefore, control of undesirable vegetation at this stage is considered one of the most important components of the growing technology (*Rola et al., 2006; Glavonjić, B., 2017*).

The volatility of energy willow plantations in the first year of vegetation in terms of quantitative and species weed composition usually reflects the weed infestation of the field in the previous years (*Baum et al., 2009*). Therefore it is important to define the groups of dominant and challenging weeds and to timely choose the methods of weed control. It was established that part of the common and challenging weed species survive and compete with willow plants during the first three years even when herbicides are introduced (*Wróbel et al., 2012*). Thus, weed species composition largely depends on the current land use, soil conditions, weed seed stock and other factors.

Consequently, as shown above, willow plants in the first year of vegetation are not very competitive with regard to weeds that spread in the free ecological niches of young energy willow plantations. That is why, the development of weed control practices, especially in the first year of vegetation, is a topical issue and requires a constructive solution.

High sensitivity of young plants to the action of majority of herbicides used against dicotyledonous weeds along with sanitary and environmental restrictions that are associated with planting near water bodies, in water protection and residential areas where the use of pesticides is forbidden, makes it difficult to introduce effective weed control technology for energy willow.

The purpose of the research was to evaluate the effectiveness of the various environmentally friendly mechanical weed control practices for one-year-old energy willow plantations.

MATERIALS AND METHODS

The experiment was carried out from 2012 to 2016 in the fields of the State Enterprise Experimental Farm 'Salyvinky' (Ksaverivka, Vasylkiv district, Kiev region). The weather conditions are typical for the zone of unstable humidification of the Central Forest-Steppe of Ukraine. The soil for the experiment was meadow chernozem or molisols (*Kravchenko et al., 2012*). The experiment was established in energy plantations of *Salix viminalis* in its first growing season according to the following design: (a) without weed treatment; (b) three consequent cultivations between rows at an interval of 15 days; (c) three consequent harrowing between rows using mounted chain harrow at an interval of 15 days; (d) three consequent manual weed cutting (cut height 1.5−3.0 cm at an interval of 15 days); (e) six consequent hand weedings (to total destruction of weeds).

The planting of ligneous cuttings of willow was carried out after the start of field work in early or mid-April. Before planting cuttings continuous tillage was carried out. Pre-planting tillage was made to kill existing sprouts of wintering and early spring weed species such as *Matricaria inodora L., Gallium aparine L., Descurainia Sophia L. Schur., Sisymbrium altissimum L., Thlaspi arvense L., Sinapis arvensis L.* and others. Experimental plot area was 36 m^2 and the registration area was 25 m^2. The plots were randomised with 4-times replication. Weeds observation was carried out using fixed frames measured 1.25 m x 0.20 m = 0.25 m^2 that were permanently set in four places diagonally in each treatment (*Tsyliuryk et al, 2017*). The first and second registration of weeds was made in early May and second decade of August accordingly.

The yield of the above-ground part of plants was determined by the method of cutting the above-ground parts at the experimental sites and expressed in either g/m^2 or t/ha.

RESULTS

The appearance of weed sprouts in the willow plantations occurred simultaneously with the start of opening buds on willow seedlings. The weed composition of energy willow plantation in the first year of vegetation is shown **in f**igure 1.

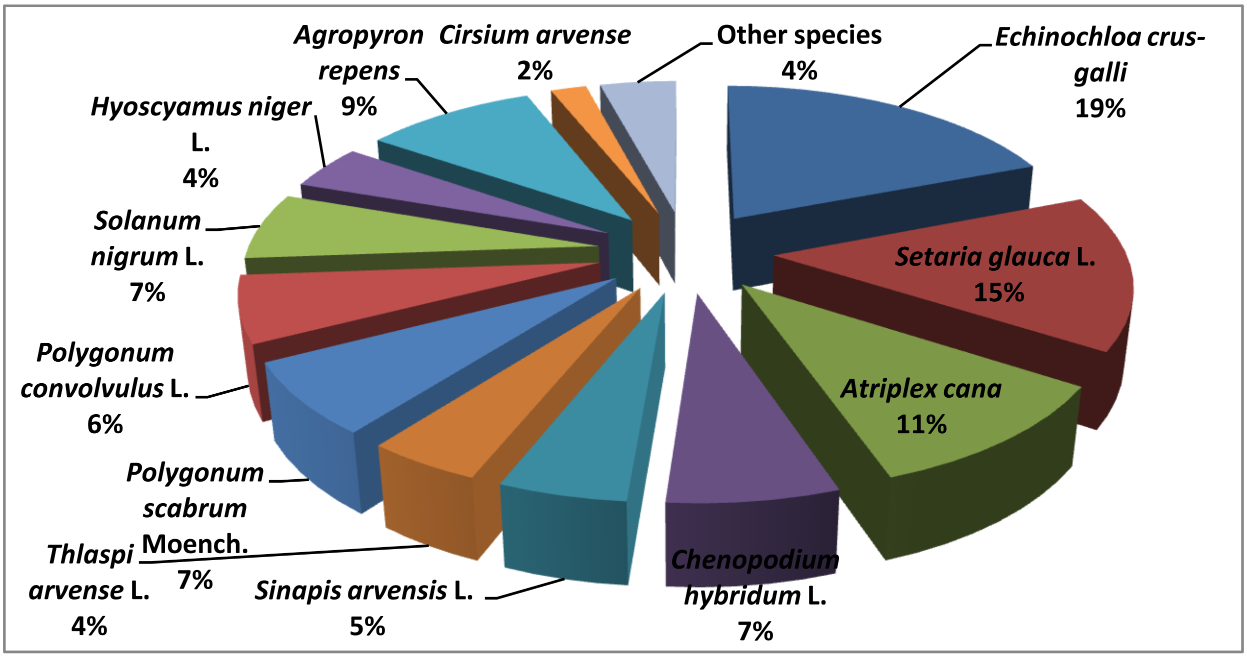

Fig. 1 - Weed composition of energy willow plantation in the first year of vegetation (average of 2012/2016)

Sufficient stock of moisture in soil, available mineral nutrients, a long growing season, access to photosynthetic active radiation (PAR) and favourable temperature regime along with the stock of weed seeds and developed vegetative reproduction organs in the control trial A gave weed plants the opportunity of successful growth, development and formation of the underground mass (Table 1). During five years, the mass of weeds at the second time of the weed observations (mid-August) amounted to an average of 3854 g/m^2. The largest share of the weed species in the willow plantations had Solanum nigrum L. (833 g/m^2 or

21.6%), *Atriplex cana* (18 g/m^2 or 21.2%), *Echinochloa crus-galli* (434 g/m^2 or 11.3%), *Setaria glauca L*. (316 g/m^2 or 8.2%), *Sinapis arvensis L*. (280 g/m^2 or 7.3%) and others. The application of mechanical weed control reduced the ability of weeds for growing and development. The weight of weeds in the trial B amounted to an average of 1312 g/m^2. It was 2.9 times lower than in trial A. The largest share of weed mass after the application of successive hoeing system was formed by *Solanum nigrum L*. (315 g/m^2 or 24.0%), *Atriplex cana* (286 g/m^2 or 21.8%), *Echinochloa crus-galli* (132 g/m^2 or 10.1%), Setaria glauca L. (97 g/m^2 or 7.4%), *Sinapis arvensis L*. (85 g/m^2), and *Polygonum scabrum Moench*. (72 g/m^2 or 5.5%). Plants of such species as *Hyoscyamus niger L*., *Chenopodium hybridum L*., and *Polygonum convolvulus L*., after successive hoeing of the space between rows formed the overweight mass slowly and in small quantities.

Table 1

Effect of mechanical weed control practices on the weed mass accumulation [g/m^2], average of 2012/2016

Weed species	Trials				
	A	B	C	D	E
Echinochloa crus-galli	434	132	106	128	-
Setaria glauca L.	316	97	110	93	-
Atriplex cana	818	286	191	245	-
Chenopodium hybridum L.	102	39	44	36	-
Sinapis arvensis L.	280	85	63	81	-
Thlaspi arvense L.	183	54	37	49	-
Polygonum scabrum Moench.	191	72	86	63	-
Polygonum convolvulus L.	135	38	29	40	-
Solanum nigrum L.	833	315	362	253	-
Hyoscyamus niger L.	108	31	42	35	-
Agropyron repens	109	44	63	26	-
Cirsium arvense	134	52	75	34	-
Other weeds	211	67	36	58	-
Total weeds	3854	1312	1244	1141	-
$LSD_{0.05}$	1.3				-

Successive hoeing of the space between rows (trial C) not only effectively reduced the number of weeds, but also restrained the processes of their mass formation. On average, at the time of the recordings, even taking into account the buffer zones, the mass of weeds was 1244 g/m^2, which made up only 32.3% of the maximum mass of trial A. Among the weed species, the largest share had *Solanum nigrum L*. (362 g/m^2 or 29.1%), *Atriplex cana* (191 g/m^2 or 15.4%), *Setaria glauca L*. (110 g/m^2 or 8.8%), *Echinochloa crus-galli* (106 g/m^2 or 8.5%), *Polygonum scabrum Moench*.(86 g/m^2), and *Cirsium arvense* (75 g/m^2 or 6.0%). Other species formed a smaller mass. In the trial D, to control weeds we used a system of consistent mechanical cutting of above-ground part of weed plants. Partly survived weeds formed a small biomass. The bulk of the mass was formed by young plants that sprouted after successive cuttings. The weight of the weeds in trial D averaged to 1141 g/m^2, which was 3.4 times lower than the maximum accumulation of weeds in trial A. The analysis of the field experiment data proved that all mechanical weed control methods were sufficiently effective. The decrease in the number of weeds during the years of the experiment ranged from 84.3% to 89.1%, i.e. it was close to the level of efficiency adopted for the evaluation of herbicides (above 95%). Noteworthy, application of various options of mechanical weed control in willow plantations in the first year of vegetation significantly influenced the peculiarities of leaf area formation in both willow plants and weeds (Table 2). The leaf area of energy willow plants in the trial A was 5 66 m^2/ha and correlated with the habit of plants of the first year of life. Meantime, the total leaf area of weeds was 106120 m^2/ha. This means that even among the weed plants there was a sharp competitiveness.

The maximum leaf area (m^2/ha) was developed by the following weed species: *Atriplex cana* (28700), *Chenopodium hybridum L*. (17550) and *Thlaspi arvense L*. (1656).

The leaf area of willow plants in the mechanical weed control treatments was 6850−7000 m^2/ha. Meantime maximum values in trial E treatment amounted to 8520 m^2/ha. The largest leaf area of the weed species was developed *for Atriplex cana*, *Chenopodium hybridum L*. and *Thlaspi arvense L*.

The field experiment conducted in 2012/2016 enabled evaluating interaction of weed plants and young willow plants (cuttings) in the first year of vegetation.

Table 2

Effect of mechanical weed control practices on the leaf area of energy willow [1000 m^2/ha], average of 2012/2016

Weed species	Trials				
	A	B	C	D	E
Energy willow	5.66	6.85	6.81	7.00	8.52
Echinochloa crus-galli	8.48	0.95	0.57	0.70	-
Setaria glauca L.	6.15	0.70	0.50	0.55	-
Atriplex cana	28.70	2.62	3.77	2.79	-
Chenopodium hybridum L.	17.55	2.30	1.64	1.31	-
Sinapis arvensis L.	1.76	0.24	0.22	0.22	-
Thlaspi arvense L.	16.56	4.14	2.07	1.84	-
Polygonum scabrum Moench.	3.31	0.41	0.35	0.26	-
Polygonum convolvulus L.	3.05	0.32	0.32	0.26	-
Solanum nigrum L.	5.30	0.45	0.55	0.40	-
Hyoscyamus niger L.	3.55	0.40	0.60	0.35	-
Agropyron repens	2.18	0.34	0.24	0.16	-
Cirsium arvense	1.18	0.18	0.15	0.11	-
Other weeds	8.36	1.11	0.86	0.86	-
Total weeds	106.12	14.15	11.84	9.81	-
Leaf area	111.78	21.00	18.65	16.81	8.5
$LSD_{0.05}$	0.02				-

Availability of free ecological niches and favourable conditions for growth and development along with the low competitiveness of young willow plants contributed to the intensive occupation of willow plantation by weed species. On the areas where weeds had the opportunity to grow and develop freely (trial A), they formed the largest above-ground biomass, absorbed significant amounts of mineral nutrients from soil and made willow plants compete for life factors. Intensive vegetation of weeds limited the capacity of young willow plants and reduced their biological potential. Willow plants gradually established and formed shoots. Their annual increment over the years of research amounted to 63 cm (Table 3).

Table 3

Energy willow productivity under different weed control practices (average of 2012/2016)

Indicator	Trials					
	A	B	C	D	E	$LSD_{0.05}$
Shoot length [cm]	63.0	121.8	123.2	125.6	152.0	5.3
Biomass yield [t/ha]	2.08	4.58	4.63	4.72	5.72	0.14
Dry biomass yield [t/ha]	1.15	2.52	2.55	2.60	3.14	0.10
Solid biofuel yield [t/ha]	1.26	2.77	2.80	2.86	3.46	0.11
Energy yield [GJ/ha]	23.3	51.3	51.9	52.9	64.0	1.2

Application of mechanical (agrotechnical) systems of weed control implemented through three successive hoeing of the space between rows provided for the reduction of the biological potential of weed plants that survived in the buffer zones. Weed control measures provided for a more complete implementation of the biological potential of young willow plants. The length of their annual shoots averaged 121.8 cm that exceeded weeded control (trial A) 1.9 times. Application of successive inter-row harrowing with chain harrows showed similar to the previous method efficiency towards weeds and contributed to the formation of annual shoots of willow plants with an average length of 123.2 cm.

Successive cuttings weeds in the space between rows revealed the positive effect of such measures on young willow plants, primarily due to the weakening potential green competitors for life factors. Vegetation of plants was in sufficiently comfortable conditions, therefore, the annual increments of shoots averaged to 125.6 cm, i.e. 2.0 times exceeded the length of shoots of willow plants in control treatment.

The maintenance of willow plantations clear of the negative influence of weeds during the whole vegetation period (trial E) created the most favourable conditions for the growth and development of young plants. Average annual increment of willow shoots made up 152.0 cm over the experiment years.

The research results of many years demonstrated that in the weeded control treatment, the yield of energy willow biomass in the first year of cultivation was the lowest in the experiment and amounted to 2.08 t/ha.

The willow yield was 2.20 times higher after third consecutive hoeing of the space between rows (trial B, compared to trial A).

On the contrary, successive harrowing of the space between rows with chain harrows (trial C) did not differ significantly from trial B with the yield of 4.66 t/ha that exceeded 2.22 times the yield in the trial A.

Successive cutting of weeds in the space between rows improved the yield of willow plants (4.72 t/ha) 2.27 times exceeding the yield in weeded control treatment of the experiment.

The application of mechanical (agrotechnical) weed control methods for protecting plants from weeds by means of three successive hoeing of the space between rows contributed to the dry matter yield of 2.52 t/ha obtained from willow plantation in the first year of growing. The application of successive harrowing of the space between rows with chain harrow ensured the formation of 3.2% more willow biomass. At the same time, in the treatment with successive cutting of weeds in the space between rows, the productivity of willow plants was 2.60 t/ha.

Noteworthy, all the treatment under research did not differ significantly in terms of dry matter yield in the first year of vegetation and their deviations were within the bounds of the experimental error.

In the trial B of mechanical weed control implemented through successive hoeing of the space between rows, on the average of 2012/2016, the yield of solid biofuel was 2.77 t/ha. Successive harrowing of the space between rows resulted in biofuel yield of 2.80 t/ha. Successive cutting of weeds in the space between rows (trial D) ensured biofuel yield of 2.86 t/ha.

Energy yield is a generalizing measure of the efficiency of the technologies we offer for the mechanical weed control in willow stands of the first year of growing.

In the weeded control treatment, on the average over the years of the experiment, the energy yield was 23.3 GJ/ha, while the treatment with three consecutive hoeing of the space between rows ensured twice larger energy yield equalling 51.3 GJ/ha.

On the sites where the system of successive harrowing of the space between rows using chain harrow was applied, energy yield was 51.9 GJ/ha, while the system of successive cutting of weeds ensured 52.9 GJ/ha.

CONCLUSIONS

Mechanical weed control in energy willow stands in the first year of vegetation is quite effective when it was made timely and systematically. Taking into account the weeds in the buffer zones of the rows, the decline in the number of weed vegetation varied from 84.4% (successive hoeing of the space between rows) to 89.1% (successive cutting of weeds in the space between rows).

The accumulation of vegetative mass of weeds in energy willow plantations was affected by the system of mechanical weed control applied. Hoeing the space between rows reduced weed mass 2.9 times, harrowing the space between rows with chain harrow 3.1 times, successive cutting of weeds in the space between rows 3.4 times compared to the highest accumulation value of 3854 g/m^2.

The lowest yield of dry energy willow biomass (1.15 t/ha) was obtained without weed control, while the highest was obtained after six consequent hand weedings (3.14 t/ha).

Successive hoeing of the space between rows ensured, on the average, 2.52 t/ha dry biomass in the first year of growing, while successive harrowing with chain harrow ensured 2.55 t/ha and successive cutting of weeds 2.60 t/ha.

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