Chapter 4

Weed Seed Rain Dynamics and Ecological Control Ability in Agrophytocenosis

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Additional information is available at the end of the chapter

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1. Introduction

Evolving together with agricultural plants, weeds have adapted their growth and biological cycle of development. The dispersal of weed seeds in agriculture fields is increased by current grain harvesting technology after seed set [1, 2]. Herbicides are used to prevent new weed seed bank additions. Although herbicides cannot control all weeds, they may partially control them, thus weeds ripen fewer seed numbers. Therefore, infest soil, straws and awns by seeds [3]. Intensive use of herbicides following the traditional crop growing technologies, however, does not entirely solve the problem of weediness [4]. Surviving weeds after herbicide applications are able to produce new seeds [6], depending on species, significantly decreasing total seed production [5]. Even a few weed plants left undamaged by herbicides can produce considerable weed seed amounts [7]. Previous research of Leguizamon and Roberts (1982) revealed that after cultivation in early April of a sandy loam soil with 9500 apparently viable seeds m^2 in 0–10 cm, 295 seedlings m^2 emerged, of which about half survived to maturity in July. Seeds were dispersed from mid-June to November and 136,460 m^2 were returned to the soil, representing a 14-fold increase in the seed bank. Application of soil-active herbicides reduced the numbers of weeds and the total seed output, but that of tolerant species was increased. Maximum numbers of seeds were 59,980 m^2 for *Chenopodium album*, 39,430 m^2 for *Stellaria media* and 37,580 m^2 for *Veronica persica* [8]. Today more attention is given to ecological problems which arise through use of herbicides [9]. Pesticides are leaching through the soil and into groundwater far more commonly than the projected ones a decade ago. Point sources may be widespread but are not the sole cause; it is also clear that many pesticides are leaching to groundwater from routine, nonpoint source labeled use. Controlled plot studies show the intermittent, often rapid delivery of many pesticides to shallow groundwater. Generally, the concentrations of pesticides in groundwater are low, in the 0.1–5.0 μg L^{-1} range. Even at these concentrations there are concerns for long-term, chronic exposure to a large segment of the public through drinking-water supplies [10].

According to Seralini et al. (2012) agricultural edible GMOs and formulated pesticides must be evaluated very carefully by long term studies to measure their potential toxic effects. First long-term research study "Long term toxicity of a Roundup herbicide and a Roundup-tolerant genetically modified maize" showed worrying results in rat pathology (tumor development, liver congestions and necrosis, etc.). The experimental object in this study was Roundup-tolerant genetically modified maize (from 11% in the diet), cultivated with or without Round-up, and Roundup alone (from 0.1 ppb in water) [79]. In recent years ecological and economic factors provided a need and a necessity to decrease the use of herbicides or even to refuse them entirely [11]. Research and policies to resolve the problems of agricultural impacts on the environment will require a new focus on integrated farm-management systems that enhance efficiency and reduce off-site impacts [10]. The quality of weed control in today's agriculture depends on the ability to eliminate seeds, which are still in the soil and to limit the amount of additions [1, 12], as well integrating non-chemical – ecologically acceptable – weed control means.

The research hypothesis: most weed seeds ripened in the crop would be removed from the field together with spring barley harvested in the late milk-early dough growth stage of maturity. Accordingly in the late milk-early dough growth stage spring barley maturity, the highest dry matter yield and energy is accumulated. *The aim* of this work was to evaluate weed seed rain dynamics, and implications on ecological and economic management.

2. Evaluation of spring barley agrophytocenosis

Field experiment site and soil type. A field experiment was conducted at 54°52'N and 23°49'E. The soil of the experimental site is *Calcari-Epihypogleyic Luvisols – LVg-p-w-cc* drained clay loam on sandy light loam. The soil agrochemical characteristics: pH_{KCl} 7.08-7.25, humus 2.22-2.45%, mobile P_2O_5 – 245.0-251.3 mg kg^{-1} and mobile K_2O – 93.6-110.5 mg kg^{-1}. Agrochemical soil properties were established using the infrared ray system PSCCO/ISI IBM – PC 4250. Soil samples for agrochemical analysis were taken from 0–20 cm soil layer from 10 sites of all treatments and their replications, making combined samples.

Experimental design. The experiment was arranged as a randomized complete block design with treatments including the following harvest timing, which was made on the basis of spring barley maturity stages by Zadoks [13] and Meier [14].

Spring barley was harvested at the stages of maturity:

1. Stem elongation 39-41*, 37-39, 31
2. Heading 57-59, 55, 57-59
3. Early milk 71-73, 69-71, 69-71
4. Milk (medium milk) 75, 73-75, 73
5. Late milk-early dough 77-83, 77-83, 77-83
6. Dough 87, 85, 87
7. Hard 92, 91-92, 92

* - decimal code for spring barley development during experimental years: 1997, 1998 and 1999.

Experimental treatments were replicated four times. Total size of each experimental plot was 96 m^2 (4x24m) and results recording plot size – 66 m^2 (3x22m).

Spring barley growing conditions. The preceding crop for spring barley was winter wheat *Triticum aestivum* (1997), spring barley *Hordeum vulgare* (1998) and cultural amaranth *Amaranthus spp*. (1999) [1]. In every year of the experiment, double-row barley cv '*Roland*' was grown on different fields. Herbicides were not used in the experimental field for evaluation of alternative weed control. Complex phosphorus, potassium and nitrogen fertilizers (60 kg ha^{-1} of active compounds) "*Azofoska*" (N:P:K ratio 1:1:1 by 16%) were applied on spring barley in spring after sowing before sprouting. Soil tillage in every year of the trial was the same. Each year, mouldboard ploughing at approx. 24 cm depth was accomplished in September. Autumn and spring loosening at approx. 8 cm depth was performed in October and April respectively, while spring loosening with harrow at approx. 4 cm depth was accomplished in early May, just prior to crop sowing.

Spring barley productivity. At stem elongation, heading, early milk, milk (medium milk) and late milk-early dough growth stages of maturity spring barley was harvested by frontal reaper for biomass and at dough and hard stages by combine harvester for grain.

Whole-plant silage was prepared from spring barley biomass harvested at early milk, milk (medium milk), late milk-early dough and dough stages of maturity. Spring barley green biomass was chopped up with the grinding-mill and ensiled in 3 L volume glass jar taking into account method used by Wilson and Wilkins [15].

Laboratorial analyses of spring barley whole-plant biomass, grain and silage: dry matter, crude protein, crude fat, crude fibre, crude ash [16] and metabolizable energy for ruminants (cows) in MJ kg^{-1} of dry matter [17] were determined at each harvesting growth stage in prepared samples for analyses. Drying plant samples at 103°C for 4 hours, there was established the amount of dry matter and burning at 550°C for 3.5 hours in muffle-furnace, there was established the amount of crude ash. Crude protein was established by the *Kjeldahl* method and crude fat by direct extraction with petrol-ether for 6 hours in *Sokslet* device. The concentration of crude fibre was established by plant samples boiling with adequate concentration of sulphuric acid and potassium alkali, filtered, separated, washed, dried, weighed and burned at 500°C for 3 hours in muffle-furnace [16]. Metabolizable energy [MJ kg^{-1}] in dry matter of fodder for ruminants (cows) was established depending on gas production (CO_2 and CH_4) *in vitro* and fodder chemical composition, by the Hohenheim fodder value test. 200 mg of fodder sample with cow rumen fluid, micro- and macro-elements, buffer- and reduction-solutions is placed in the special test-tube and incubated in a rotary thermostat by 39 °C for 24 hours [17]. Silage fermentation analysis was made according to standard methods used in Agrochemical centre of Lithuanian institute of agriculture. It evaluated silage pH, concentrations of lactic, acetic and butyric acids.

Crop weediness. Weed samples were taken at the early milk stage of spring barley maturity. There were 10 samples taken from every experimental plot by wire frame of 20x30cm. Air-dried weeds were divided into species, counted and weighed.

Weed seed rain. Dynamics of weed seed rain in spring barley agrophytocenosis was established according to Rabotnov [18] method and other weed seed rain experiments [8, 19, 20]. Fifty troughs were laid out in each of four replications, in chess-order, in tens (Figure 1 and 2). In total, two hundred troughs were used. Weed seeds from the troughs were collected every 2-4 days. The collected seeds were divided into species and counted.

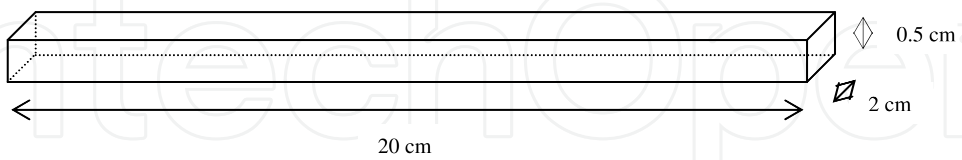


Figure 1. Schema of trough used for the weed seed rain establishment [1]

Figure 2.Troughs for collecting weed seeds in spring barley crop, photographs by Vytautas Pilipavičius

Meteorological conditions. The Lithuanian territory occupies intermediate geographical position between west Europe oceanic climate and Eurasian continental climate. The climate of the Lithuanian territory forms in different radiation and circulation conditions. Differences in these conditions hardly cross the boundaries of microclimatic differences; therefore, Lithuania belongs to the western region of the Atlantic Ocean continental climatic area [21]. Meteorological conditions during experimental years were established utilizing data of Kaunas (Noreikiškės) meteorological station situated in vicinity of the experimental fields. Meteorological factors taken included: average air temperatures, sum of active air temperatures (> 10°C), rainfall (mm) and sunlight duration in hours.

Economic treatment evaluation. In order to evaluate the economics of alternative and conventional harvest technologies the valuations of agricultural machinery were used [22-24]. The price of fodder spring barley is evaluated in 320 Lt t^{-1}, and the normative price of straws in 27

Lt t^{-1} [the ratio of national currency Litas (Lt) and Euro (€) is 1 € = 3.4528 Lt]. The value of spring barley biomass at the late milk-early dough growth stage of maturity was determined according to the energetic value of its grains and straws. Calculating the costs of spring barley harvested at the late milk-early dough growth stage of maturity includes autumn soil ploughing, autumn and spring continuous cultivation and cultivation with harrowing, sowing, green biomass pressing into rolls and their rolling with pellicle as well as transporting were evaluated. Calculating the costs of spring barley harvested at the hard stage of maturity includes autumn soil ploughing, autumn and spring continuous cultivation and cultivation with harrowing, sowing, as well as the cereal harvesting, grain and straw managing were evaluated. The tractor *MTZ-80/82*, the cereal harvester SK-5 „*Niva*“ as well as various agricultural machinery were used for these proceedings.

Statistical data assessment. The research data were statistically evaluated by dispersion analysis ANOVA method applying *Selekcija* [25, 26] and *SigmaStat* [27] software packages. Degrees of phenomena interdependence and their directions were established by correlation-regression analysis applying *SigmaPlot* software package [28]. Reliability of dependencies was evaluated by the *p* criterion.

3. Weediness of spring barley agrophytocenosis

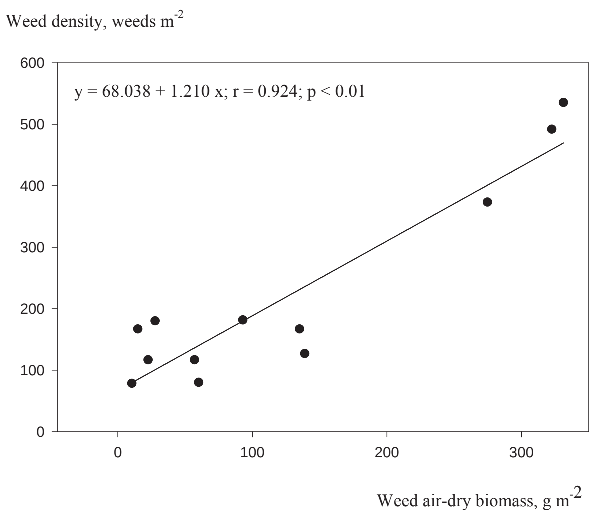
The field experiments were carried out in separate fields with different weed infestations (Table 1). The experiment initiated on a very weedy field. The second year of the experiment trial was moved to the field where weed density was established more than three times and weed air-dry biomass was 2.6 times less comparing with the spring barley agrophytocenosis of the first year experiment. During the experiment in 1999 weed density was 135 weeds m^{-2}, i.e. analogically as in 1998 but their air-dry biomass was more than 6 times less and weighed only 18.9 g m^{-2}. During the three year experiment in spring barley agrophytocenosis, annual weeds dominated accounting for 68-98% of crop air-dry weed biomass and 84-98% of the total weed number. Perennial weeds comprised 2-32% of total weed air-dry biomass and 2-16% of the total weed number in the crop. Our results are similar to previous research indicating in Lithuania prevailing weeds as short-lived annual dicotyledons that comprise 70-90% of total spread weeds [4, 29]. Consequently, in the experimental spring barley agrophytocenosis, annual weeds prevailed that are commonly spread by seeds while perennials commonly propagate by vegetative parts and spreading by seeds is less important except for infesting new soils. However, Zwerger [30] pays high attention to the perennial weed spreading by seeds analyzing potential danger of *Cirsium arvense* spreading. From annual weeds in the crop prevailed *Chenopodium album*, *Stellaria media* and *Sonchus asper* while from perennial ones - *Sonchus arvensis*. During all three years of experiment, 40 weed species, 32 annual and 8 perennial, were found. Twenty-six weed species were established in spring barley agrophytocenosis during the first year, 19 during the second and 21 during the third year of the experiment (Table 1).

Weeds	Weed density and air-dry biomass					
	1997		1998		1999	
	weeds m^{-2}	g m^{-2}	weeds m^{-2}	g m^{-2}	weeds m^{-2}	g m^{-2}
Amaranthus spp. L.	0	0.0	0	0.0	10.83	0.14
Anthemis arvensis L.	0	0.0	0	0.0	0	0.0
Anthemis tinctoria L.	0	0.0	0	0.0	0	0.0
Apera spica-venti (L.) P.Beauv.	0	0.0	0	0.0	0	0.0
Atriplex patula L.	0	0.0	0	0.0	0	0.0
Avena fatua L.	0	0.0	0	0.0	0	0.0
Capsella bursa-pastoris (L.) Medik.	17.1	1.37	2.50	0.44	13.33	1.40
Chaenorrhinum minus (L.) Lange	0.4	0.01	1.25	0.04	2.50	1.57
Chenopodium album L.	29.5	131.3	70.0	53.96	66.25	5.67
Cirsium arvense (L.) Scop.	2.9	5.58	2.08	3.43	0.83	0.25
Crepis tectorum L.	3.3	0.88	0	0.0	0	0.0
Elytrigia repens (L.) Nevski	0	0.0	0	0.0	2.5	2.3
Erysimum cheiranthoides L.	62.1	6.39	1.67	0.19	1.25	0.08
Euphorbia helioscopia L.	3.8	0.18	0.83	0.20	0.83	0.05
Fallopia convolvulus (L.) A. Löve	2.1	0.14	5.42	1.45	0	0.0
Galeopsis tetrahit L.	0	0.0	1.67	0.29	0	0.0
Galinsoga parviflora Cav.	0	0.0	0.83	0.17	0	0.0
Galium aparine L.	2.5	0.30	2.08	1.08	0	0.0
Lamium purpureum L.	1.2	0.05	0	0.0	0.83	0.18
Medicago lupulina L.	1.2	0.18	0	0.0	0	0.0
Mentha arvensis L.	0	0.0	0	0.0	1.67	0.28
Myosotis arvensis (L.) Hill.	1.7	0.13	0	0.0	0	0.0
Plantago major L.	2.5	0.13	0.42	0.81	2.92	0.06
Poa annua L.	7.5	0.50	0	0.0	5.0	0.10
Polygonum aviculare L.	0.4	0.07	0	0.0	0	0.0
Polygonum laphatifolium L.	8.3	0.91	3.75	0.56	0.42	0.01
Raphanus raphanistrum L.	0.4	0.17	0	0.0	0	0.0
Rumex crispus L.	0	0.0	0	0.0	0	0.0
Sinapis arvensis L.	147.9	69.23	1.67	1.05	0	0.0
Sonchus asper (L.) Hill.	16.4	8.98	3.33	5.21	0.87	0.44
Sonchus arvensis L.	0.3	0.17	15.84	24.77	6.21	3.14

Weeds	Weed density and air-dry biomass					
	1997		1998		1999	
	weeds m^{-2}	g m^{-2}	weeds m^{-2}	g m^{-2}	weeds m^{-2}	g m^{-2}
Spergula arvensis L.	0	0.0	0.42	0.25	0	0.0
Stellaria graminea L.	0	0.0	0	0.0	0.42	0.01
Stellaria media (L.) Vill.	37.9	17.13	7.08	3.79	9.17	2.73
Thlaspi arvense L.	4.6	0.49	0	0.0	0.42	0.08
Tripleurospermum inodorum (L.) Sch. Bip.	34.2	10.92	0	0.0	2.92	0.22
Trifolium pratense L.	1.2	0.02	0	0.0	0	0.0
Tussilago farfara L.	0	0.0	1.25	0.12	0	0.0
Veronica arvensis L.	2.5	0.08	0	0.0	4.17	0.09
Viola arvensis Murray	3.3	0.18	0.42	0.04	1.67	0.05
Annual	388.3	249.54	102.92	68.72	120.46	12.81
Perennial	7.0	5.90	19.59	29.13	14.55	6.13
All weeds	395.3	255.4	122.5	97.8	135.0	18.9

Table 1. Composition, density and air-dry biomass of weed species in agrophytocenosis of spring barley on separate fields [1, 31]

Weed density linearly depended on weed air-dry biomass. With increase of air-dry weed biomass by 1 gram per square meter weed density enlarges by 1.21 weed plants. There was established opposite dependence of weed air-dry biomass on weed density. It showed change of weed air-dry biomass by 0.7 g m^{-2} with change of weed density by 1 plant (Figure 3).



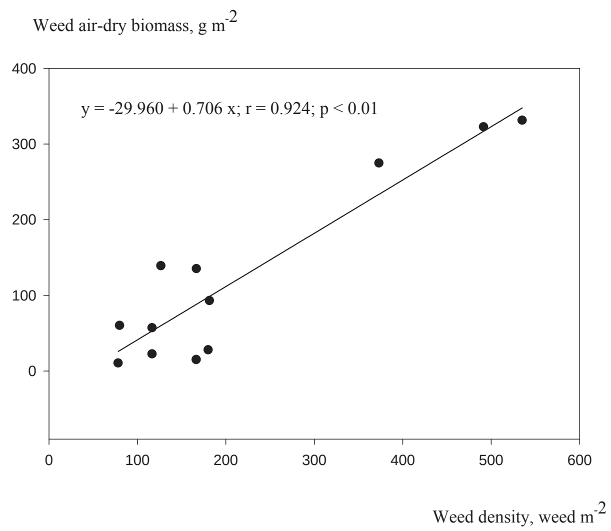


Figure 3. Relationship between weed density and weed air-dry biomass [1, 31]

4. Weed seed rain

4.1. Weed seed rain initiation

Dispersed weed seeds in spring barley agrophytocenosis during three years of the experiment belonged to 29 weed species from 12 families (Table 2). Weed seed rain in spring barley begins when spring barley is at stem elongation stage and increases to the hard stage of maturity. Ephemeral weeds of short vegetation *Stellaria media* and *Poa annua* as well the early summer weed *Chenopodium album* matured and began to disperse their seeds at the stem elongation of spring barley.

Winter annual weeds such as *Capsella bursa-pastoris* ripened and dispersed seeds at heading growth stage of spring barley, usually in the third ten-day period of June. Spring barley changing into early milk stage of maturity, *Lamium purpureum*, *Apera spica-venti*, *Atriplex patula*, *Veronica arvensis*, *Sonchus asper* and *Myosotis arvensis* ripened and began to pour seeds. At milk (medium milk) stage of spring barley maturity, *Thlaspi arvensis*, *Raphanus raphanistrum*, *Spergula arvensis*, *Galium aparine*, *Fallopia convolvulus* and *Polygonum laphatifolium* ripened and began to pour seeds. Spring barley changing from milk into dough stage of maturity, *Sinapis arvensis*, *Sonchus arvensis*, *Erysimum cheiranthoides* and *Cirsium arvense* ripened and began to disperse seeds. At dough stage of spring barley maturity, *Avena fatua*, *Crepis tectorum*, *Anthemis arvensis* and *Anthemis tinctoria* ripened their seeds. At dough stage of spring barley maturity, all weed species of agrophytocenosis which seeds were ripened except in 1998 when *Crepis tectorum* seeds matured and began to disperse only at hard stage of spring barley maturity [2].

The experimental data showed that *Crepis tectorum*, *Cirsium arvense* and *Sonchus arvensis* ripened and began to disperse seeds the latest. However, during separate experimental years the beginning of seed ripeness and start of seed rain for some weed species lasted more than presented the first growth stages of spring barley through the uneven meteorological conditions during separate years of field experiment. As example can serve, *Chenopodium album* seeds began to disperse at stem elongation stage of spring barley in 1997, at heading growth stage in 1999 and at milk (medium milk) maturity in 1998. Mainly it depended on the year climatic conditions (see subchapter 4.3) and on general crop stand weediness (Figure 4).

4.2. Weed seed rain dynamics

Weed seed rain is more intensive in weedier cereal crop, considering weed density and especially weed air-dry weight. It was confirmed by the correlation-regression analysis. Weed seed rain linearly and positively depended on weed dry weight $r = 0.842^{**}$ and on weed density $r = 0.686^{*}$. Weed air-dry biomass increase of 1 g m^{-2} induced increase of weed seed rain by 11.7 seeds m^{-2} while increase in weed density by one plant enhanced weed seed rain by 7.3 seeds m^{-2}. Hence, total weed seed rain was more dependent on the weed air-dry biomass than on weed density (Figure 4).

Family	Species	The beginning of seed rain		
		97	98	99
Boraginaceae Juss.	*Myosotis arvensis* (L.) Hill.	M.	N.	M.e.
Chenopodiaceae Less.	*Atriplex patula* L.	M.	M.	M.e.
	Chenopodium album L.	S.e.	M.e.	He.
Cruciferae B. Juss.	*Capsella bursa-pastoris* (L.) Medik.	M.	M.	He.
	Erysimum cheiranthoides L.	M.l.-D.e.	D.	N.
	Raphanus raphanistrum L.	M.	M.l.-D.e.	N.
	Sinapis arvensis L.	M.l.-D.e.	M.l.-D.e.	M.l.-D.e.
	Thlaspi arvense L.	M.	N.	M.
Compositae Giseke	*Anthemis arvensis* L.	D.	N.	N.
	Anthemis tinctoria L.	D.	N.	N.
	Cirsium arvense (L.) Scop.	D.	M.l.-D.e.	D.
	Crepis tectorum L.	D.	H.	N.
	Sonchus asper (L.) Hill.	M.l.-D.e.	M.	M.e.
	Sonchus arvensis L.	D.	M.l.-D.e.	D.
	Tripleurospermum inodorum (L.) Sch. Bip.	D.	N.	D.
Caryophyllaceae Juss.	*Stellaria media* (L.) Hill.	S.e.	M.e.	He.
	Spergula arvensis L.	N.	M.l.-D.e.	N.
Euphorbiaceae J. St. Hill.	*Euphorbia helioscopia* L.	N.	N.	M.
Labiatae Juss.	*Lamium purpureum* L.	M.e.	M.	N.
Poaceae Bernhart	*Apera spica-venti* (L.) P. Beauv.	N.	M.e.	N.
	Avena fatua L.	N.	M.	N.
	Poa annua L.	S.e.	N.	N.
Polygonaceae Lindl.	*Fallopia convolvulus* L.	D.	M.	M.
	Polygonum lapathifolium L.	M.	M.l.-D.e.	M.
	Polygonum aviculare L.	M.	N.	N.
	Rumex crispus L.	D.	N.	N.
Rubiaceae Juss.	*Galium aparine* L.	M.l.-D.e.	M.l.-D.e.	N.
Scrophulariaceae Juss.	*Veronica arvensis* L.	M.	M.e.	M.
Violaceae Juss.	*Viola arvensis* Murr.	N.	M.l.-D.e.	N.

Note. Spring barley growth stages of maturity: S.e. – stem elongation, He. – heading, M.e. – early milk, M. – milk, M.l.-D.e. – late milk-early dough, D. – dough, H. – hard, N. – weed seed rain was not established.

Table 2. Weed seed rain initiation in spring barley agrophytocenosis [1, 2]

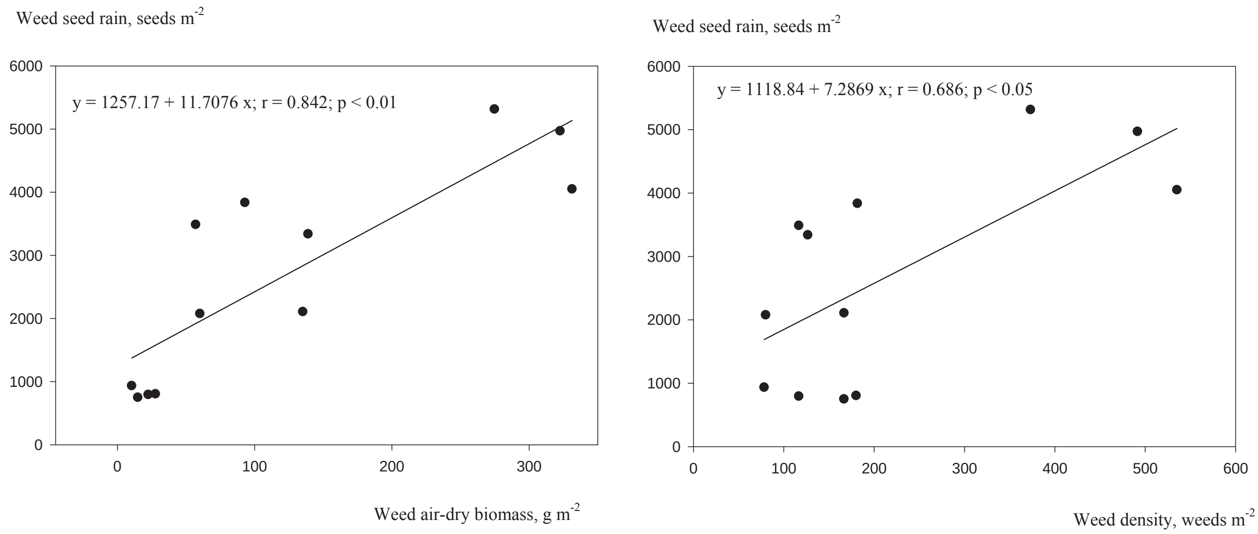


Figure 4. Weed seed rain dependence on weed air-dry biomass and density [1, 31]

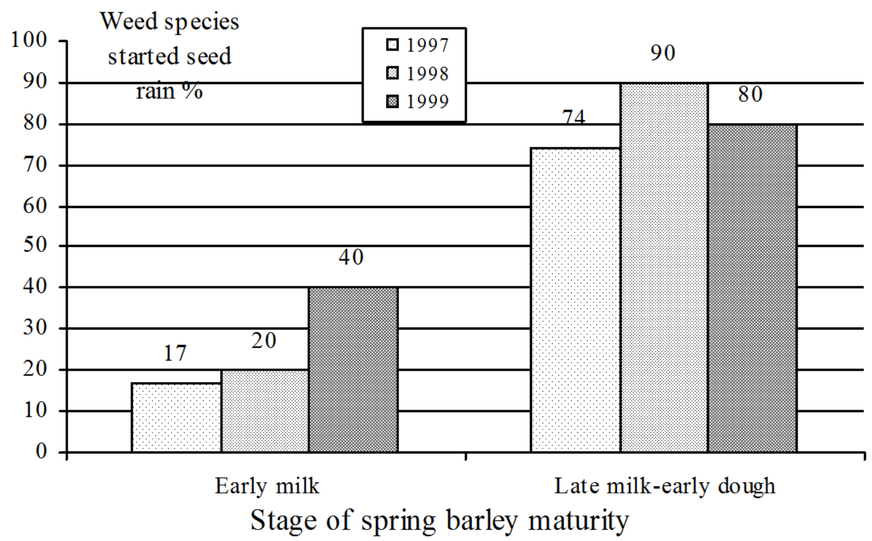


Figure 5. Weed species [%] started seed rain depending on spring barley crop maturity

It was established that seed rain depended directly on plant density of *Stellaria media* r = 0.711*, *Sonchus asper* r = 0.918*** and *Capsella bursa-pastoris* r = 0.474. Accumulated *Stellaria media, Sonchus asper* and *Capsella bursa-pastoris* air-dry biomass in the crop had adequate influence on their seed rain, respectively r = 0.833**, r = 0.786* and r = 0.766* [32]. When spring barley was ripening, weed seed rain was more intensive (Figure 5 and 6). It is in conformity with data of other researchers indicating that, until cereal harvesting, some weed species are able to pour out all their ripened seeds [33].

Weed seed rain during separate years of the experiment varied in accordance with the spring barley crop weediness. However, seeds matured and dispersed 29 (Figure 7) of 40 weed species (Table 1) grown in spring barley agrophytocenosis. Presumptively it was influenced by the low density of some weed species and limiting solar light to others by successful smothering

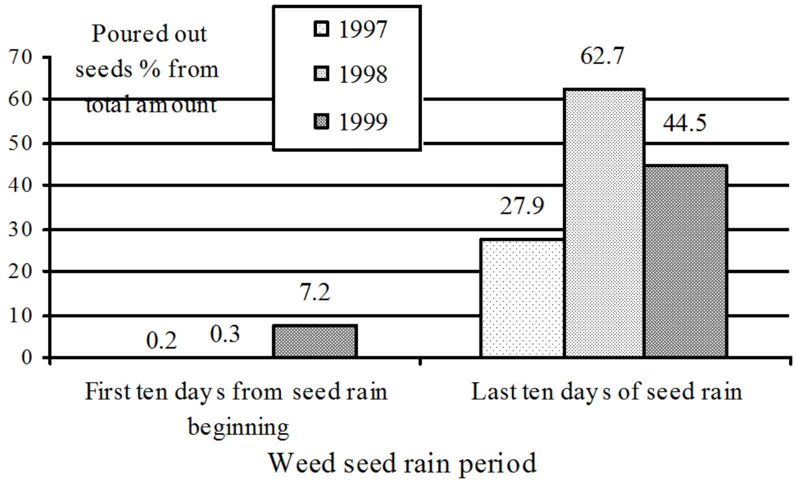
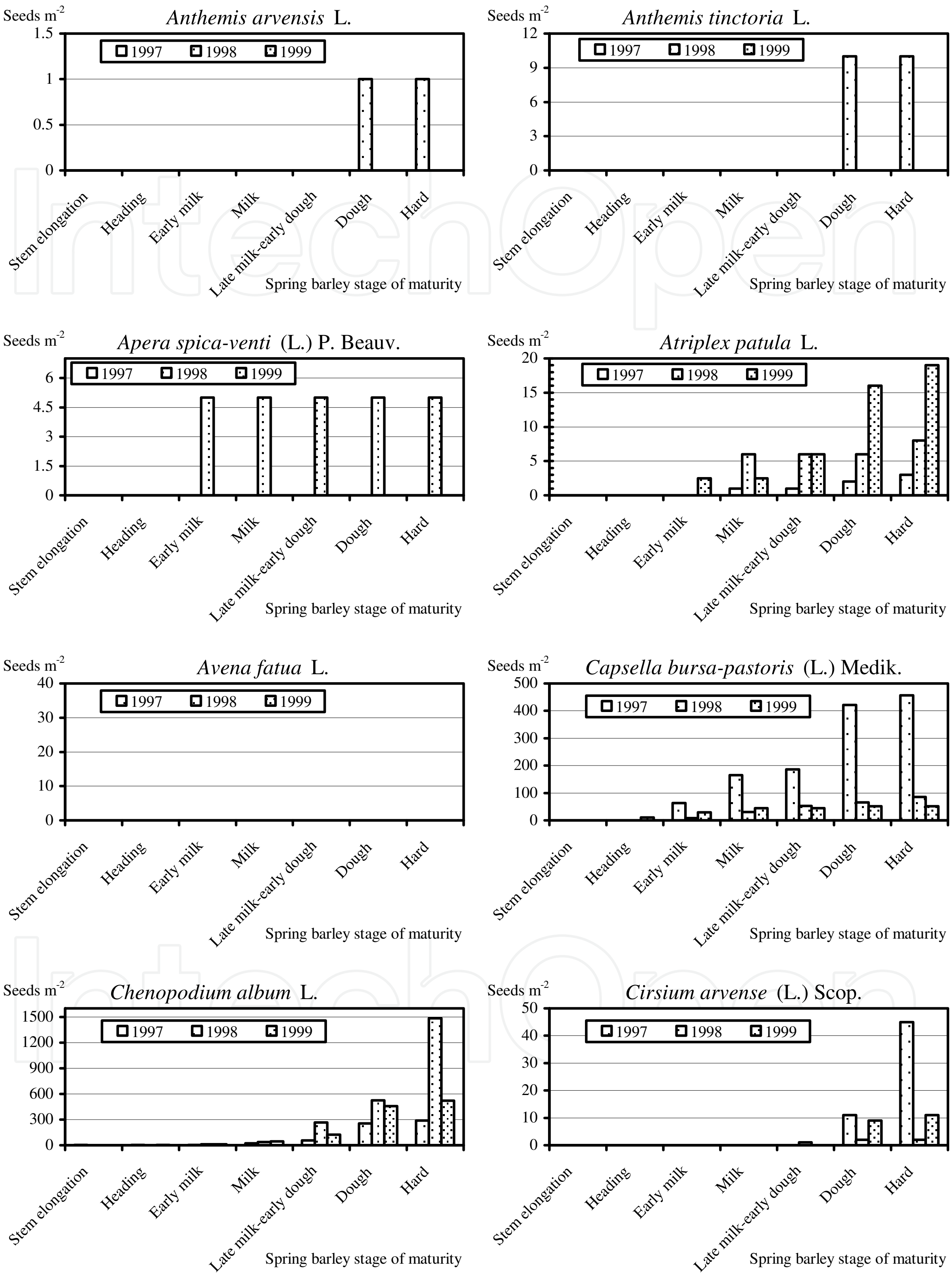


Figure 6. Weed seed rain intensity during vegetation in agrophytocenosis of spring barley

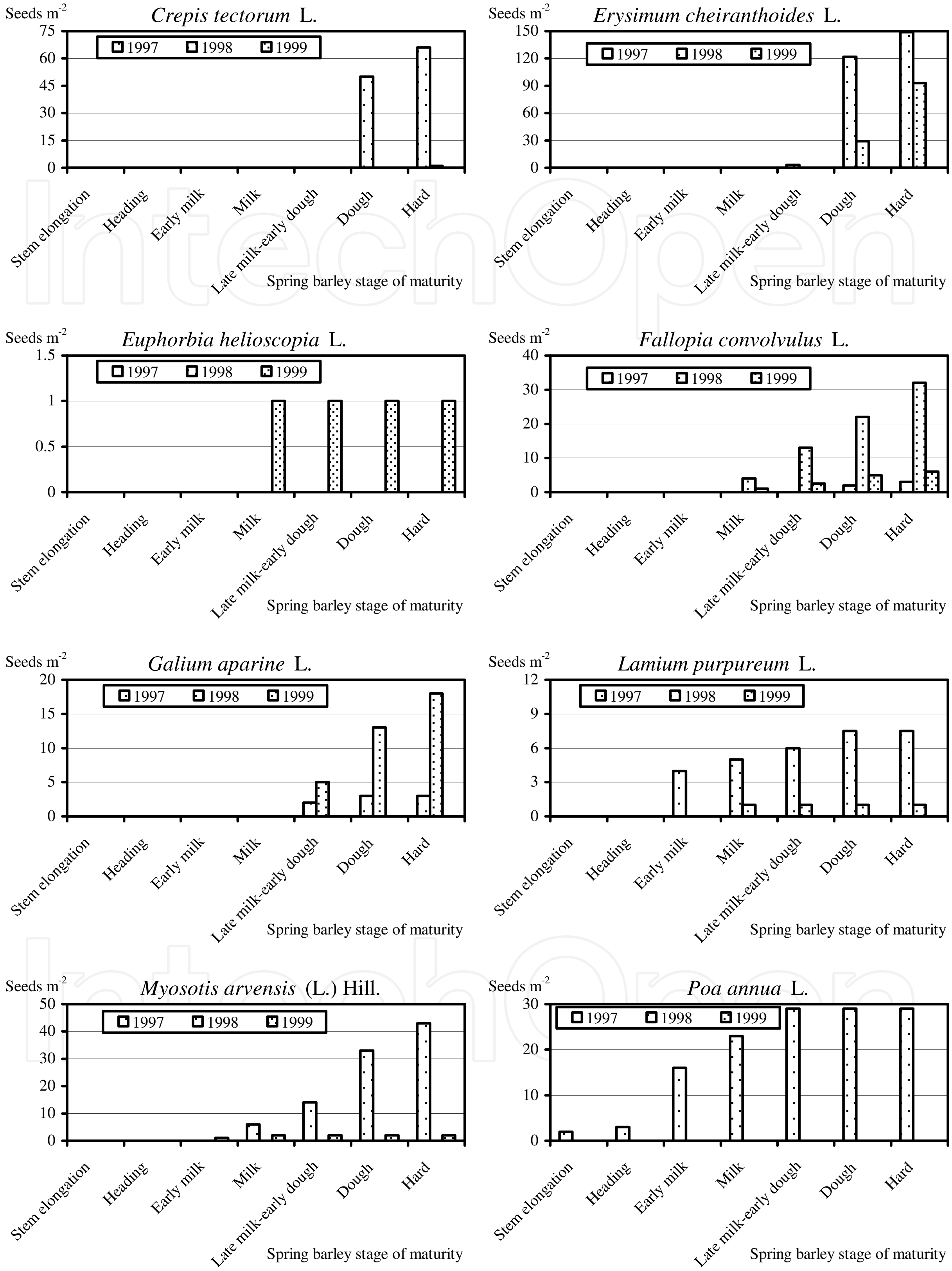
by spring barley. The most important weed species in weed seed rain dynamics biologically belonged to annual weeds. Dispersed seeds of *Stellaria media* in spring barley agrophytocenosis composed 19-29% from total seed rain during experimental years. Seed rain of *Chenopodium album* covered from 6% to 63% of total weed seed rain while *Capsella bursa-pastoris* 6%-10%. Seed rain of *Sonchus asper* and *Sinapis arvensis* was essential only during the first year of experiment with 26% and 11% of seeds from total number of dispersed ones, accordingly. From perennial weeds only *Sonchus arvensis* showed significant seed rain covering 4.8% of total dispersed weed seed number during the second year of experiment. Seed rain of all other weeds in spring barley agrophytocenosis jointly consisted from 11% to 19% from total number of dispersed weed seeds (Figure 7).

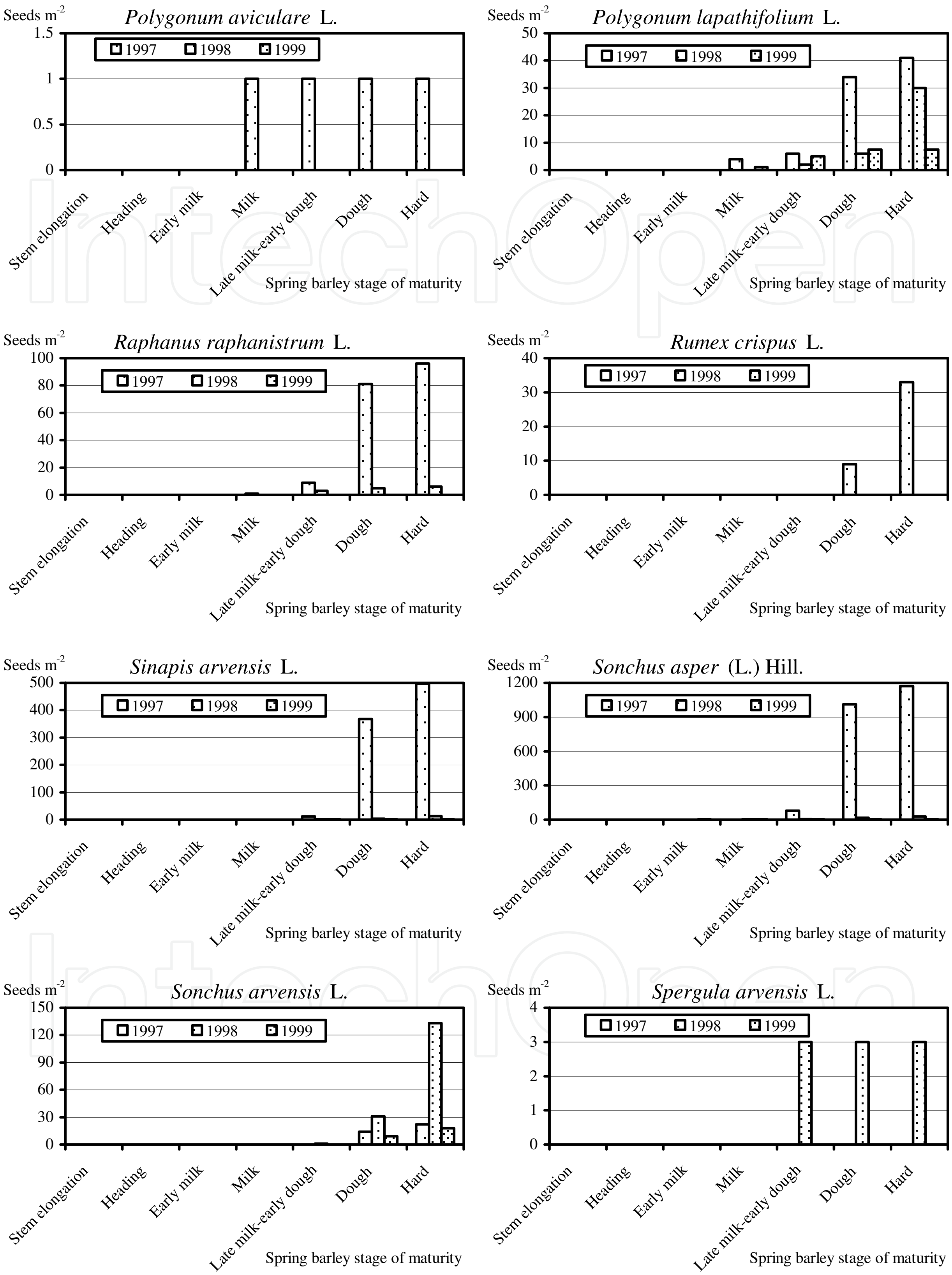
The data of the field trial proved that weeds ripened regularly. Analyzing seed rain of all weed species of spring barley agrophytocenosis were established 4543 seeds m^{-2} in 1997, 2753 seeds m^{-2} in 1998 and 821 seeds m^{-2} in 1999 (Table 3).

Different number of dispersed weed seeds depended on crop and meteorological conditions. Initially, weed seed rain every year of the experiment was slow with low numbers of weed species and low numbers of dispersed seeds. At medium milk stage of spring barley maturity, dispersed seed covered just 6%-23% of total seeds. At late milk-early dough stage of spring barley maturity, it already covered 27%-42% of total dispersed weed seed number. Usually, weed seeds which were left in the crop could be taken from the field together with harvest (biomass of spring barley for silage) and would not infest the soil. Harvesting spring barley for biomass or silage at medium milk stage of maturity, 77%-94% of weed seeds would be removed from the field while harvesting at late milk-early dough stage of maturity, 58%-73% of weed seeds could be removed from the field. When harvesting cereal at hard stage of maturity, most of the weed seeds already are dispersed on the soil and naturally increase weed infestation in the following crop of the crop rotation.



Anthemis arvensis L.
Anthemis tinctoria L.
Apera spica-venti (L.) P. Beauv.
Atriplex patula L.
Avena fatua L.
Capsella bursa-pastoris (L.) Medik.
Chenopodium album L.
Cirsium arvense (L.) Scop.
Seeds m-2
1997
1998
1999
Stem elongation
Heading
Early milk
Milk
Late milk-early dough
Dough
Hard
Spring barley stage of maturity


Crepis tectorum L.
Erysimum cheiranthoides L.
Euphorbia helioscopia L.
Fallopia convolvulus L.
Galium aparine L.
Lamium purpureum L.
Myosotis arvensis (L.) Hill.
Poa annua L.
Seeds m-2
1997
1998
1999
Stem elongation
Heading
Early milk
Milk
Late milk-early dough
Dough
Hard
Spring barley stage of maturity


Polygonum aviculare L.
Polygonum lapathifolium L.
Raphanus raphanistrum L.
Rumex crispus L.
Sinapis arvensis L.
Sonchus asper (L.) Hill.
Sonchus arvensis L.
Spergula arvensis L.
Seeds m-2
1997 1998 1999
Stem elongation
Heading
Early milk
Milk
Late milk-early dough
Dough
Hard
Spring barley stage of maturity

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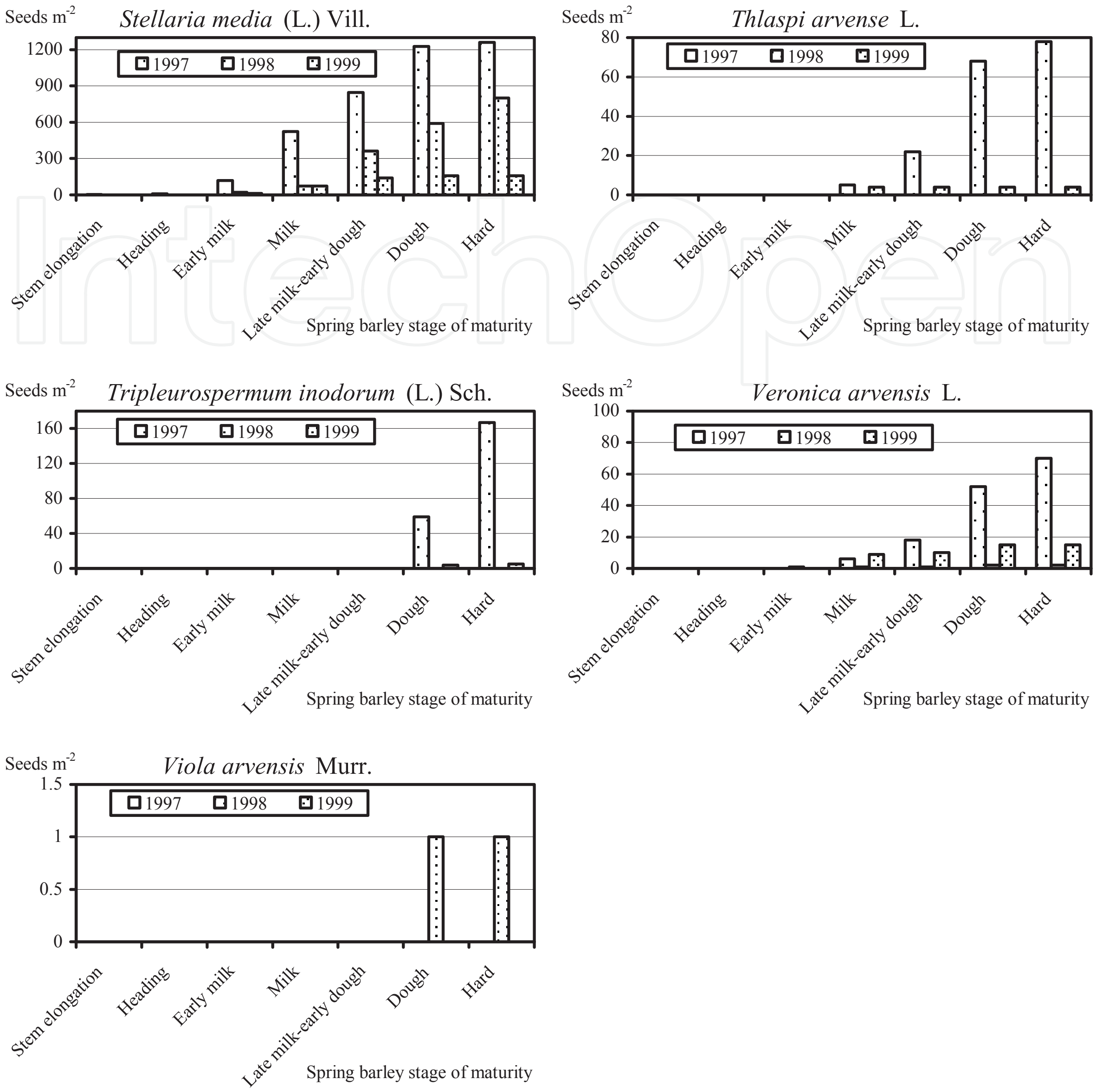

Figure 7. Weed species seed rain dynamics in spring barley agrophytocenosis [1, 2]

Moreover, most weed seeds which, together with crop biomass, get in silage [35-38], in manure [36, 37, 39], in sewage [40] in compost [41], or going through alimentary canal of cattle [35, 42], lost their germinating power and would not infest the crop in the future.

4.3. Weed seed rain and meteorological conditions

Weed seed rain increases during the time of cereal ripening (Figure 4, 6, Table 3) but it decreases in separate vegetation periods depending on change of meteorological conditions. Growth and development of all plants are influenced by environmental factors from which meteorological ones are highly important [43].

Stages of spring barley maturity	Weed seed rain					
	1997		1998		1999	
	seed m^{-2}	%	seed m^{-2}	%	seed m^{-2}	%
Stem elongation	8**	0.17	0**	0.0	0**	0.0
Heading	16**	0.35	0**	0.0	12**	1.5
Early milk	207**	4.6	47**	1.7	60**	7.3
Milk (medium milk)	764**	16.8	161**	5.8	189**	23.0
Late milk-early dough	1289**	28.4	731**	26.6	343**	41.8
Dough	3871	85.2	1331**	48.3	744*	90.6
Hard	4543	100	2753	100	821	100
LSD_{05}	707.0	-	417.7	-	71.5	-
LSD_{01}	968.4	-	572.1	-	97.9	-

Table 3. Total weed seed rain in the crop of spring barley [1, 9, 34]; * $p < 0.05$; ** $p < 0.01$

Meteorological conditions such as temperature, rainfall, and sunlight at sprouting and germination stage influenced vegetation and can determine plant density in the crop. For example, germination of *Solanum elaeagnifolium* [44] and *Matricaria perforata* [45] depends on temperature, germination of *Rumex obtusifolius* depends on temperature and light [46], germination of *Ranunculus repens* depends on soil humidity and temperature [47]. Growth and biomass accumulation of *Chenopodium album* [48], *Bromus tectotum* and *Taeniatherum asperum* [49] also depends on meteorological conditions. In our experiments there was determined linear relationship between weed biomass and weed seed rain (Figure 4). Logically, weed seed rain could be influenced by the meteorological factors such as air temperature, rainfall and sunlight duration. According to the sum of active air temperature and precipitation, the vegetation period during the first and the second experimental years was wet and during the third experimental year – not humid enough (Figure 8).

Weed seed rain changed dynamically, increasing and decreasing during vegetation regardless of total seed number dispersed during separate years of experiment (Figure 7). In our experiment, established weed seed rain fluctuations significantly depended on active air temperature (> 10^{o}C), rainfall and sunlight duration (Figures 9-11). Weed seed rain regularly intensified with increase of sum of active air temperature (Figure 9) as well as with increase of sunlight duration (Figure 11). This phenomenon is based on plant physiological processes such as development and water circulation in plant tissues that are significantly dependent on sunlight and environmental temperature. In contrast to the sum of active air temperature and sunlight duration, rainfall inhibited weed seed rain (Figure 10). Jointly, during rainy periods, active air temperatures decreased and shortened sunlight duration which leads to an increase of humidity accumulation in plants. Excess humidity amounts reaching weed seeds managed to slow physiological maturation and as well inhibited seed rain. Statistically reliable non-linear dependencies of total weed seed rain on active air-temperatures r^2=0.528**, r^2=0.538**, r^2=0.119*, rainfall r^2=0.567**, r^2=0.608**, r^2=0.155* and sunlight duration r^2=0.512**, r^2=0.418**, r^2=0.136* are presented in figures 9-11.

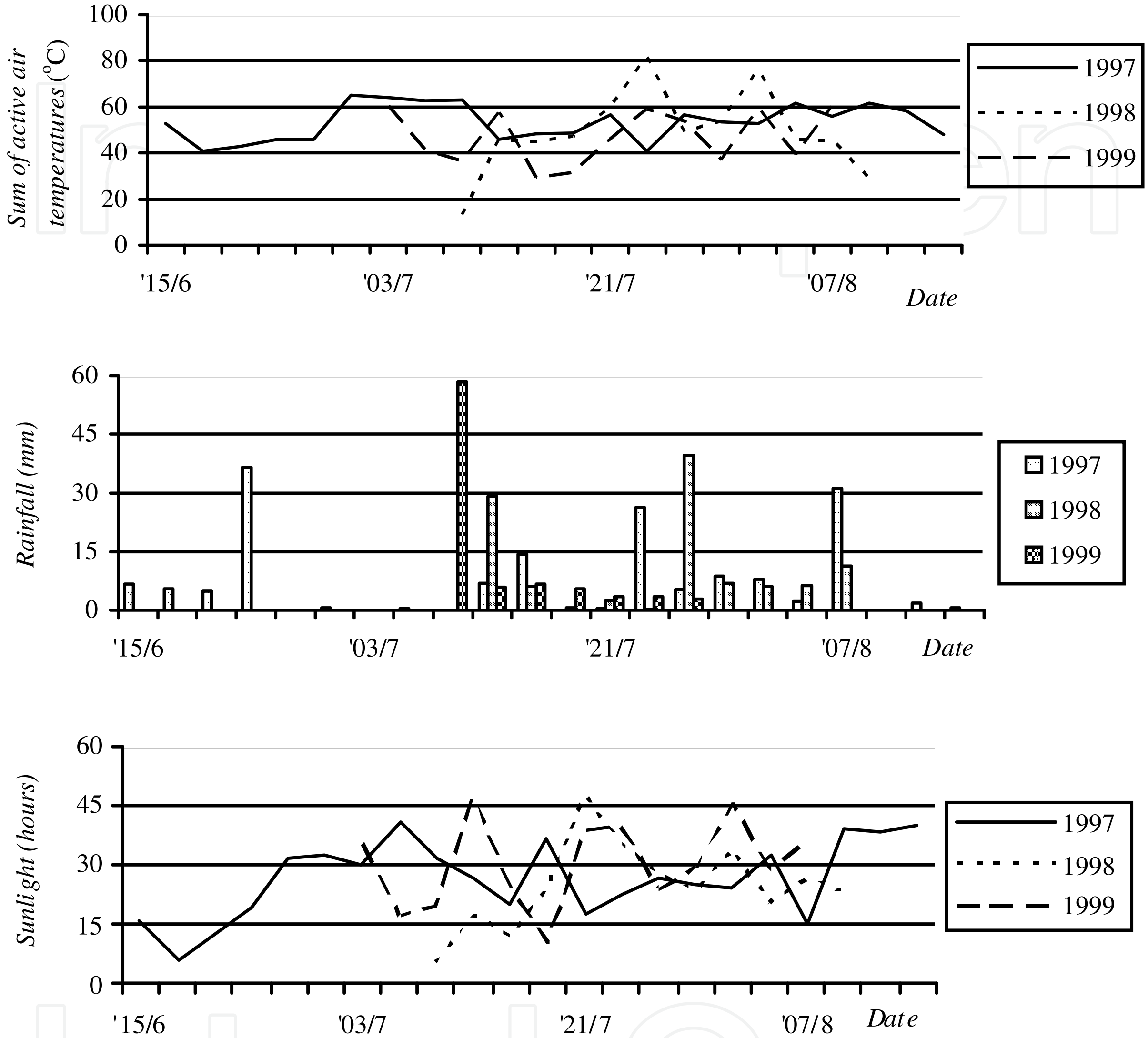

Figure 8. Meteorological conditions: active air temperatures, rainfall and sunlight dynamics during experimental years, Kaunas (Noreikiškės) Meteorological station [43]

4.4. Weed seeds in grains

The later the cereal harvest, the fewer amounts of weed seeds get into grain, but the more of them infested the soil [12]. In cereal grain yield of hard maturity (in the sample of 100 g), on average, are found less weed seeds by 820 when comparing with grain yield of dough maturity. Such decrease makes up to 21 million (12–39 million) fewer weed seeds in crop yield from 1 ha with a biomass of approximately 38 kg (13–53 kg). This regularity motivates the necessity of earlier spring barley harvesting not only because of frequently experienced grain losses but also because of weed seed spreading limitation [50].

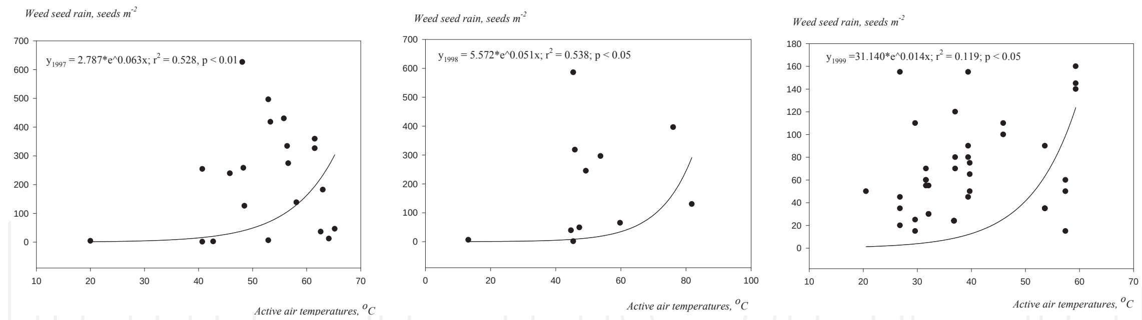

Figure 9. Weed seed rain dependence on active air temperatures [43]

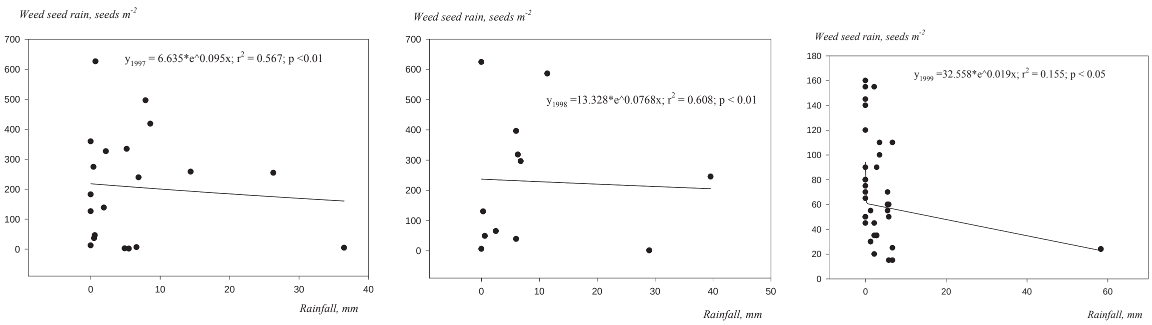

Figure 10. Weed seed rain dependence on rainfall [43]

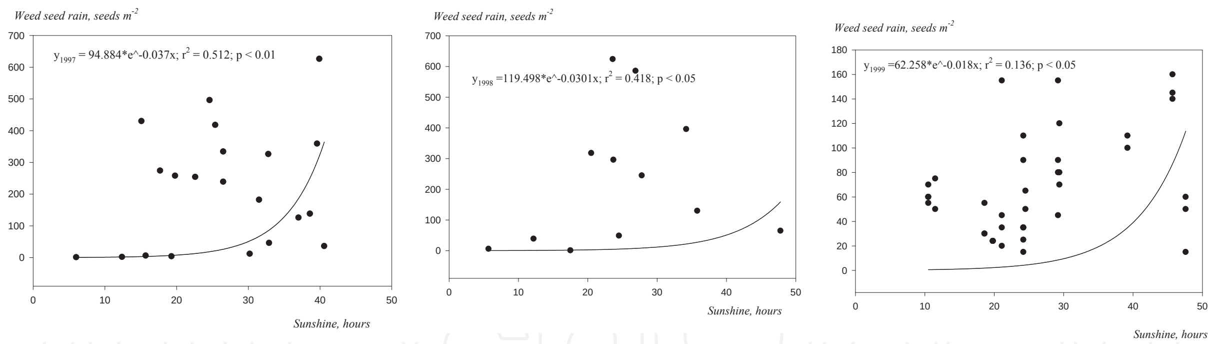

Figure 11. Weed seed rain dependence on sunshine duration [43]

4.5. Spring barley crop productivity

Spring barley dry matter yield increased significantly while cereal matured from stem elongation to late milk-early dough growth stages. In the further growth stages of spring barley - dough and hard – total above-ground dry matter yield decreased significantly (Figure 12). The yield of dry matter begins to decrease at anthesis complete growth stage of spring barley [51]. The optimal period for gathering cereal is considered 4 weeks after heading [52] or 2-3 weeks before hard growth stage, when dry matter yield reaches maximum and begins to decrease [53]. The maximum increase of dry matter in cereal is characteristic from heading till milk stage but the biggest yield accumulates in milk-dough and dough stages of maturity [54], thereafter it decreased slightly for the two-row cultivars [55]. Dynamics of dry matter in cereal can be influenced by meteorological conditions, soil, fertilization and other factors [56]. However, dynamics of dry matter accumulation in cereals depends on decrease of assimilation surface when leaves decline and on allocation and transformation of assimilation products [51, 53, 57]. The general decrease of dry matter yield is influenced by decrease of vegetative biomass [58]. Growth stages of spring barley and other cereals can be theoretically divided into three groups according accumulation dynamics of harvest: increase, reach of maximum, and decrease. The logical solution is to limit yield losses, i.e. to refuse the third group. By cutting cereal at milk-dough stages of maturity, it would be possible to achieve that. Of course, then it would be necessary to refuse conventional harvesting of cereal for grain applying an alternative use of all above-ground biomass for forage at such stage of maturity when maximum yield of dry matter and metabolizable energy is reached [1, 59].

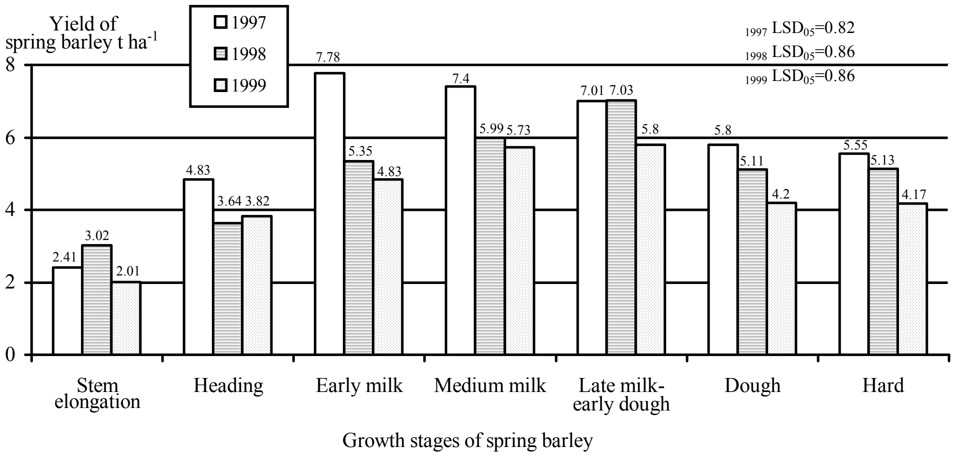

Figure 12. Spring barley dry matter yield at seven stages of growth and maturity [1, 59, 60]

The concentration of crude protein, crude fibre, crude fat and crude ash variation of each year of the experiment preserved analogical tendency (Table 4). The concentration of crude protein and crude ash was the greatest at stem elongation growth stage and as the spring barley matured the concentration of crude protein and crude ash decreased. However, in the grain of dough and hard growth stages, concentration of these components increased but in the straw it decreased. Therefore, total yield of crude protein and crude ash decreased significantly at dough and hard growth stages compared with milk and late milk-early dough stages of spring barley maturity. The concentration of crude fibre and crude fat tended to increase or decrease as the spring barley matured. However, the yield of crude fibre and crude fat at dough and hard growth stages decreased significantly (Table 4).

Likewise, as in our experiment, the greatest concentration of nutrition at stem elongation growth stage of spring barley and other cereals was determined. The concentration of nutrition essentially decreased to minimum at the end of vegetation [61] and remained constant near maturity [55, 62]. At the end of cereal vegetation, growth of DM is zero and biological yield does not increase but even begins to decrease [63]. Losses of DM in spring barley yield can be decreased additionally using nitrogen fertilizers. However, spring barley loses a part of whole-plant DM yield before reaching hard stage in variables of the trials fertilized and non-fertilized by nitrogen [64]. That is because the index of green plant surface area decreases to zero when respiration occurs in plant ears, which requires energy. So, if photosynthesis does not occur, spring barley matures about 3 weeks before harvesting using non-replenished energetic resources. Moreover, development of DM in plant organs fully influences not only the product (grain) but also the growth of a plant and biological yield [59]. Usually the differences between agricultural plants and their varieties are seen in differences of speed usage of DM of assimilation tissues. In some cases, when general biomass of cereal increases, grain yield does not increase because of the development of some assimilation products in vegetative organs [53]. The metabolizable energy (ME) in spring barley yield for ruminants (cows) is given in Table 5. Metabolizable energy is energy directly intaken and used in an animal's organs. Total forage energetic losses are rejected beforehand, which are experienced in an animal's organs for various reasons (energetic losses with feces, urine and intestine gas and energy necessary for digestion processes) [16, 65].

The ME (MJ kg^{-1} DM) was similar to the chemical composition dynamics. In contrast to the ME content (MJ kg^{-1} DM), the amount of ME per hectare increased significantly as the spring barley matured to the late milk-early dough growth stage, and likewise, DM, digestible organic matter in the dry matter, crude protein and crude ash yield decreased significantly at dough and hard growth stages.

Growth stage	In dry matter							
	Crude protein		Crude fibre		Crude fat		Crude ash	
	%	t ha^{-1}	%	t ha^{-1}	%	t ha^{-1}	%	t ha^{-1}
			1997					
Stem elongation	12.98	0.31	27.32	0.66	2.42	0.06	10.76	0.26
Heading	9.60	0.46	32.13	1.55	1.69	0.08	7.99	0.39
Early milk	6.61	0.51	31.61	2.45	2.30	0.18	9.46	0.74
Milk (medium milk)	7.16	0.53	28.44	2.10	2.20	0.16	7.40	0.55
Late milk-early dough	7.71	0.54	25.27	1.77	2.11	0.15	5.34	0.37
Dough	-	0.32#	-	1.64#	-	0.12#	-	0.25#
Grain	7.91	0.186	6.42	0.15	2.37	0.06	2.63	0.06
Straw	3.94	0.136	43.31	1.49	1.81	0.06	5.86	0.19
Hard	-	0.31#	-	1.62#	-	0.10#	-	0.21#
Grain	8.55	0.213	6.69	0.17	2.63	0.06	2.46	0.06
Straw	3.07	0.094	47.48	1.45	1.23	0.04	4.91	0.15

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Growth stage	In dry matter							
	Crude protein		Crude fibre		Crude fat		Crude ash	
	%	$t\ ha^{-1}$	%	$t\ ha^{-1}$	%	$t\ ha^{-1}$	%	$t\ ha^{-1}$
LSD_{05}		0.05		0.28		0.02		0.06
				1998				
Stem elongation	16.60	0.50	28.57	0.86	1.74	0.05	11.30	0.34
Heading	9.66	0.35	28.90	1.05	2.73	0.10	8.49	0.31
Early milk	8.70	0.47	26.68	1.43	2.33	0.12	6.64	0.36
Milk (medium milk)	8.23	0.49	25.84	1.55	2.04	0.12	6.01	0.36
Late milk-early dough	6.88	0.48	22.10	1.55	2.39	0.17	5.21	0.37
Dough		0.32#	-	1.37#	-	0.09#	-	0.28#
Grain	-	0.20	5.32	0.116	2.65	0.058	2.89	0.06
Straw	9.20	0.12	42.85	1.251	1.25	0.036	7.54	0.22
Hard	4.04	0.39#	-	1.17#	-	0.10#	-	0.18#
Grain	-	0.30	5.08	0.146	2.75	0.08	2.47	0.07
Straw	10.54	0.09	45.73	1.028	1.03	0.02	5.05	0.11
LSD_{05}		0.05		0.24		0.02		0.05
				1999				
Stem elongation	14.26	0.29	23.93	0.48	2.31	0.05	10.97	0.22
Heading	9.95	0.38	28.44	1.09	2.18	0.08	6.04	0.23
Early milk	7.60	0.37	21.70	1.05	2.16	0.10	6.75	0.33
Milk (medium milk)	7.98	0.46	25.05	1.43	2.64	0.15	5.87	0.34
Late milk-early dough	7.13	0.41	23.17	1.34	2.18	0.13	4.38	0.25
Dough	-	0.33#	-	1.00#	-	0.10#	-	0.19#
Grain	11.59	0.25	5.56	0.12	3.15	0.07	2.70	0.06
Straw	3.60	0.07	43.42	0.88	1.51	0.03	6.70	0.13
Hard	-	0.34#	-	0.93#	-	0.09#	-	0.19#
Grain	11.93	0.27	5.79	0.13	2.89	0.07	2.89	0.06
Straw	3.78	0.07	42.48	0.79	1.45	0.03	6.84	0.13
LSD_{05}		0.07		0.21		0.02		0.06

LSD_{05}, the least significant difference; # - total yield (grain + straw)

Table 4. Effect of spring barley growth stage at harvesting on yield chemical composition [1, 59, 60]

When spring barley grain matures at hard growth stage compared with dough stage, the yield of DM, crude protein, crude fibre and ME increases. The yield of crude fat and crude ash almost does not differ. However, when the quality of straw becomes worse, the general value of yield remains fewer than at milk-dough stage. Martin and Seibold [66] determined comparable results: ME of 9.56 MJ kg^{-1} DM at heading stage of maturity and ME of grain 12.93 MJ kg^{-1} DM and 6.80 MJ kg^{-1} DM of straw at hard stage of spring barley maturity.

Growth stage	ME, MJ kg^{-1} DM			ME, GJ ha^{-1}		
	1997	1998	1999	1997	1998	1999
Stem elongation	10.80	9.24	9.97	26.03	27.91	20.04
Heading	10.00	9.02	8.61	48.30	32.83	32.89
Early milk	8.38	9.54	8.01	65.20	51.04	38.69
Milk (medium milk)	8.49	9.45	8.56	62.74	56.61	49.05
Late milk-early dough	8.60	9.67	8.64	60.29	67.98	50.11
Dough	-	-	-	51.76#	42.18#	38.94#
Grain	11.97	11.30	11.84	28.13	24.75	25.93
Straw	6.85	5.97	6.47	23.63	17.43	13.01
Hard	-	-	-	50.69#	46.80#	36.02#
Grain	12.44	12.50	11.01	30.98	36.00	25.32
Straw	6.44	4.80	5.72	19.71	10.80	10.70
LSD_{05}	-	-	-	**6.78**	**7.66**	**7.70**

ME, metabolizable energy; DM, dry matter; # - total yield (grain + straw)

Table 5. Energetic value of spring barley over-ground biomass (whole-plant) at seven stages of growth and maturity [1, 59, 60]

Positive, statistically reliable, linear dependence of spring barley crude protein [t ha^{-1}] r_{1997}=0.736***, r_{1998}=0.317, r_{1999}=0.858***, crude fibre [t ha^{-1}] r_{1997}=0.964***, r_{1998}=0,937***, r_{1999}=0.961***, crude fat [t ha^{-1}] r_{1997}=0.960***, r_{1998}=0.911***, r_{1999}=0.957*** and crude ash [t ha^{-1}] r_{1997}=0.689***, r_{1998}=0.335, r_{1999}=0.646*** on dry matter yield [t ha^{-1}] and linear dependence of metabolizable energy [Gj ha^{-1}] on spring barley dry mass [t ha^{-1}], r_{1997}=0.992***, r_{1998}=0.985***, r_{1999}=0.983***, crude protein [t ha^{-1}] r_{1997}=0.750***, r_{1998}=0.420*, r_{1999}=0.844***, crude fibre [t ha^{-1}] r_{1997}=0.967***, r_{1998}=0.900***, r_{1999}=0.948***, crude fat [t ha^{-1}] r_{1997}=0.926***, r_{1998}=0.931***, r_{1999}=0.953*** and crude ash yields [t ha^{-1}] r_{1997}=0.671***, r_{1998}=0.385*, r_{1999}=0.576** were established [59].

Digestibility *in vitro* of spring barley organic matter in the dry matter depended on spring barley stage of maturity. The highest digestibility *in vitro* was established at growth stage of stem elongation 73–78% (except 1998) and at later growth stages it decreased. Digestibility of spring barley whole-plant biomass at stem elongation was less compared with barley grain digestibility at dough and hard stages of maturity (digestibility *in vitro* to 89%). Spring barley metabolizable energy directly depended on barley growth stages and fodder digestible organic matter in the dry matter digestibility *in vitro*, $r = 0.995\text{-}0.998$ at $P < 0.0001$ [67]. Ensiling spring barley biomass harvested at early milk, milk, late milk-early dough and dough stages of maturity, silage chemical composition directly depended on cereal stage of maturity. Whole plant silage produced from cereals of later stages of maturity, late milk-early dough and dough stages of maturity, has less crude protein and crude ash concentration, lower digestibility *in vitro* by ruminants and fewer accumulated metabolizable energy MJ kg^{-1} of silage dry biomass [68]. Nykänen et al. [69] reported the highest organic matter digestibility in peas (710–800 g kg^{-1}), vetches and spring barley had an organic matter digestibility of 670 g kg^{-1}, while the other spring cereals had the lowest values (550–610 g kg^{-1}). The highest organic matter digestibility of spring barley silage was found processing silage from biomass of earlier stage (milk) of spring barley maturity [68].

4.6. Economic evaluation of technology

Cereals in Lithuania are some of the most important agricultural crops. In 2011, cereal crop area comprised 51.7% of all crops [70] while conventionally they cover 60-64 % of crop area [71]. The biggest part of grain (approx. 70 %) is used for forage [72]. With the increasing intensity of agricultural production, spring barley is becoming one of the most important cereals in Lithuania [73, 74]. Spring barley covers more than 23% of total cereal crop area in the country [70]. Edwards et al. [75] proposed that it would be more purposeful to use the whole plant for forage than to feed animals with separate processed grain and straw. Silage significantly decreases cereal processing costs; expensive combining, straw processing, grain transport, grain cleaning and grain drying can be omitted. Moreover, inevitable grain losses, especially due to unfavourable meteorological conditions during the harvest can be avoided. When preparing whole plant silage from late milk-early dough and dough stages of spring barley maturity, higher nutritive value was achieved when evaluating total metabolizable energy received from plot area compared with earlier harvested for biomass or harvested at hard maturity for grains spring barley whole plant above-ground plant part energetic value as fodder for ruminants [68]. Of special interest is, whether in technology can be reduced unnecessary input use [77]. Therefore, the aim of this research was to determine economical efficiency of different spring barley growing and yield harvesting [at late milk-early dough suitable for silage and hay making and hard (grains and straws are obtained) stages of maturity] technologies as well as the economical background.

Due to the maturing process of spring barley, dry matter yield is gradually accumulated by reaching maximum at the late milk-early dough growth stages. The dry matter yield decreased significantly as the spring barley matured from late milk-early dough to hard growth stage (see subchapter 4.5). When harvesting spring barley at two different growth stages, the costs during separate years varied from 604.7 to 869.1 Lt ha^{-1} and depended on the different yields and proceedings. The costs associated with harvesting spring barley at the late milk-early

Growth stage of harvesting and operation	Costs [Lt ha^{-1}]*		
	Year		
	1997	1998	1999
Late milk-early dough	**659.24**	**674.40**	**604.73**
Autumn plough	76.09	76.09	76.09
Autumn loosening	26.03	26.03	26.03
Spring loosening	26.03	26.03	26.03
Spring loosening with harrow	24.82	24.82	24.82
Sow	106.75	106.75	106.75
Harvest	16.50	16.50	16.50
Press to rolls	199.50	214.13	176.67
Rolls involve in film	126.04	126.40	104.28
Transport	57.48	57.65	47.56
Hard	**840.52**	**869.13**	**749.94**
Autumn plough	76.09	76.09	76.09
Autumn loosening	26.03	26.03	26.03
Spring loosening	26.03	26.03	26.03
Spring loosening with harrow	24.82	24.82	24.82
Sow	106.75	106.75	106.75
Harvest	350.52	405.42	323.77
Press straw to rolls	125.74	92.45	76.84
Grain transport	25.02	28.94	23.12
Straw transport	22.25	16.36	13.59
Grain clean	7.47	8.64	6.90
Grain dry	49.80	57.60	46.00

Table 6. Cost structure of spring barley harvested at two growth stages [76]; * 1 € = 3.4528 Lt

dough stage decreased by 19-22% (Table 6), when compared with the control treatment, i.e. hard stage maturity.

When harvesting at the hard stage of maturity, the value of spring barley yield mainly depended on the grain value (91-94% of the spring barley yield value). The grain value at the late milk-early dough stage of maturity was much lower and made 71-77% of the spring barley biomass value. Comparing spring barley biomass yield value at the late milk-early dough stage of maturity with grain and straw yield value at the hard stage of maturity, it was determined that it was by 12-19% lower (Table 7).

Growth stage	Production	Yield value [Lt ha^{-1}]*		
		Year		
		1997	1998	1999
Late milk-early dough	Biomass for silage	707.00	857.65	663.91
Hard	Grain + straw	879.42	982.35	786.49
	Grain	796.80	921.60	736.00
	Straw	82.62	60.75	50.49

Table 7. Value of spring barley yield at two growth stages [76]; * 1 € = 3.4528 Lt

Analyzing the economical effect of different technologies, it was determined that the profit increased when harvesting spring barley at the late milk-early dough stage of maturity compared to the hard stage of maturity. In 1997 the profit increased by 22.7 %, in 1998 by 61.8 % and in 1999 by 61.9 %, respectively (Table 8). The larger profit and smaller costs influenced the larger productive profitability, which increased 1.6 times in 1997, 2.1 times in 1998 and 2.0 times in 1999 while harvesting spring barley at the late milk-early dough stage of maturity [76].

Growth stage	Profit [Lt ha^{-1}]*			Profitability [%]		
	Year					
	1997	1998	1999	1997	1998	1999
Late milk-early dough	47.75	183.25	59.18	7.2	27.2	9.8
Hard	38.91	113.22	36.55	4.6	13.0	4.9

Table 8. Profit and profitability of spring barley harvested at two growth stages [76]; * 1 € = 3.4528 Lt

Economical calculations show that costs on the average were 819.9 Lt ha^{-1} and production value was 882.8 Lt ha^{-1}, when spring barley were grown according to conventional farming technology. Therefore, the average profit was 61.9 Lt ha^{-1}, and profitability 7.7 %. When spring barley was grown according to alternative technology, the costs were 646.1 Lt ha^{-1}, while yield value, profit and profitability were 742.9 Lt ha^{-1}, 96.7 Lt ha^{-1} and 15.0 % respectively. Other authors [78] determined analogous value of spring barley yield 771-846 Lt ha^{-1} according to economical evaluation of crop technologies. Economical evaluation of technologies for spring barley growth and harvest determined that the alternative farming technology – harvesting spring barley at the late milk-early dough stage of maturity –is more effective. Compared with the conventional farming technology, costs decreased by 21.2 %, profit and profitability increased 1.5 and 1.9 times, respectively. The economical efficiency of the spring barley growth technologies directly depended on the dry matter yield. Linear relationships between spring barley yield and costs and between the yield and received profit were recognized (Figure 13). With the increase of the dry biomass yield of spring barley by 1 t ha^{-1}, growing costs decreased on the average by 50 Lt ha^{-1} and the received profit increased by 24 Lt ha^{-1} [76]. Additionally, the alternative technology of spring barley growth and harvest reduces weed seed spreading and weediness of the future crop.

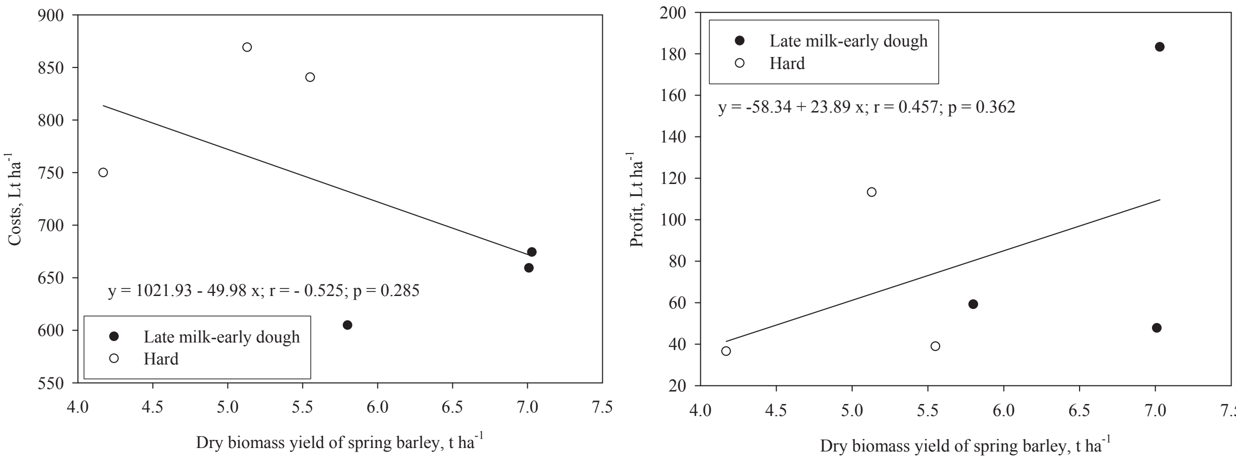

Figure 13. Costs and profit of spring barley technology depending on dry biomass yield (1 € = 3.4528 Lt) [76]

5. Conclusion

Spring barley agrophytocenosis on separate experimental plots was distinguished for different weed infestation: 395 weeds m^{-2} and 255 g m^{-2} air-dry biomass of weeds in 1997, 122 weeds m^{-2} and 98 g m^{-2} in 1998 and 135 weeds m^{-2} and 19 g m^{-2} in 1999.

Analyzing seed rain of all weed species in spring barley agrophytocenosis, there were established 4543 seeds m^{-2} in 1997, 2753 seeds m^{-2} in 1998 and 821 seeds m^{-2} in 1999. Weed seed rain was dependent on weed dry weight r=0.842** and on weed density r=0.686*. Consequently, it is very important to minimize accumulated weed biomass in the crop by weed control means before ripening and dispersal; new weed seeds build the soil weed seedbank and further field weediness.

Weed seed rain during vegetation non-linearly depended on active air temperature sum r^2= 0.528**, 0.538*, 0.119*; on rainfall r^2= 0.512**, 0.418*, 0.136* and on sunlight duration r^2= 0.567**, 0.608**, 0.155*. Increasing sum of active air-temperatures and sunlight duration increased weed seed rain by 12-54% and 14-51%, respectively. In contrast to the air temperatures and sunlight, rainfall inhibited weed seed rain by 16-57%.

Weed seed rain in spring barley agrophytocenosis began at the stem elongation stage and gradually increased until hard stage of maturity. At medium milk stage of maturity, 6-23% weed seeds were dispersed out and at late milk-early dough stage of maturity, 27-42% of weed seeds were dispersed. When harvesting cereal at milk or late milk-early dough stage of maturity, non-mature weed seeds are taken from the field together with crop yield and did not infest the soil. When harvesting cereals at medium milk stage of maturity and at late milk-early dough stage of maturity, 77-94% and 58-73%, of new weed seeds are removed from the field, respectively. Accordingly, it helped to control weed seed dispersal and potential weediness of future crops.

Growing and developing spring barley gradually accumulated dry biomass and metabolizable energy that reached the largest amount at milk and late milk-early dough stages. At later stages of spring barley maturity, yield and amount of metabolizable energy in spring barley decreased. Spring barley whole-plant dry matter yield at late milk-early dough maturity stage reached 7.03 t ha^{-1} and 5.80 t ha^{-1} accumulating 68.0 Gj ha^{-1} and 50.1 Gj ha^{-1} of metabolizable energy, respectively.

Alternative cereal harvesting (late milk-early dough stage of maturity, when grain humidity is 38-45 %) is promising. Harvesting of the largest crop yield could make it be possible to reduce the price of concentrated forage as well as to decrease weediness. By making whole-plant silage or haylage from cereals at late milk-early dough stage of maturity, more than 20% greater dry matter yield could be harvested.

Harvesting spring barley at the late milk-early dough growth stage helps to avoid expensive combining, grain and straw managing. Comparing these alternative and conventional technologies economically, it was established that using alternative technology, costs decreased by 21%, profit increased 1.5 times and profitability increased 1.9 times.

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