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THE INFLUENCE OF COVER CROPS AND VARIED TILLAGE ON YIELDS AND NUTRITIONAL VALUE OF CHICORY ROOTS (*Cichorium intybus* var. *sativum* Bisch.)

Mirosław Konopiński
University of Life Sciences in Lublin

Abstract. The method of tillage is one of the major factors determining the yield of root plants. Today we witness the degradation of soil on large cultivated lands. It is a result i.a. of more frequent tillage practices, and the omission of cover crops. The destruction of aggregate structures of the soil and the lowering of its organic matter content cause that conditions for growth and yields of the main crops are becoming worse. Field experiments were conducted in the years 2006–2008 on grey-brown podzolic soil with impermanent structure. The test plant was the rooted chicory (*Cichorium intybus* var. *sativum* Bisch.) of the 'Polanowicka' cultivar. This species has an important economical meaning, providing precious raw materials for inulin production. The experiments included: two kinds of pre-sowing tillage: a) a complex of pre-sowing tillage and sowing of cover crops (2nd decade of August) and pre-winter ploughing and mixing the green mass with soil, b) a complex of pre-sowing tillage and sowing of cover crops (2nd decade of August), leave them in the field during the winter and ploughing the plant mass in spring; two types of plant growing: in ridges or in flat soil; three cover crops: common vetch, tansy phacelia and oats. Beneficial influence of mulching the soil with tansy phacelia on the total chicory root yield, compared with unmulched plots was observed. The highest content of inulin was found in chicory roots collected from plots mulched with common vetch. It was significantly higher than its content in roots coming from the plots mulched with oats. When the productivity of inulin per unit of area is taken into account, the most beneficial tillage combination was the tillage of chicory in ridges, after spring ploughing, mixing the mulch of common vetch with the soil. Both the cultivation of the plant in ridges and ploughed vetch affected the yield significantly. The factors of the experiment had no significant influence on the content of dry matter and protein in the roots of chicory.

Key words: tillage, ridges, chicory, inulin, protein

Corresponding author: Mirosław Konopiński, Departament of Cultivation and Fertilization of Horticultural Plants, University of Life Sciences in Lublin, Leszczyńskiego 58, 20-068 Lublin, Poland, e-mail: miroslaw.konopinski@up.lublin.pl

INTRODUCTION

Plants rich in dietetic and therapeutic ingredients have an important meaning in the market of plant materials. These are, inter alia, the plants which are rich in carbohydrates with probiotic properties. The rooted chicory is one of the most important of them, as it stores inulin polysaccharide in its root. The roots of chicory are widely used in Europe for production of inulin, oligosaccharides, fructose syrups and crystalline fructose [Gałązka and Czarnecki 2002]. Inulin is also a good culture for beneficial bifidobacteria of the human digestive tract, which, by developing their populations, limit the occurrence of harmful putrid bacteria [Cieślik et al. 2001; Koo et al. 2003]. Inulin also bonds cholesterol and digestive acids, lowers the triglyceride levels in blood serum and prevents arterial sclerosis [Delzenne et al. 2002; Gałązka 2002; Monti et al. 2005]. It also stimulates the acquisition of calcium, magnesium, iron and phosphorus [Labell 1999; Niness 1999; Tungland 2000; Scholz-Ahrens and Schrezenmeir 2002] and prevents osteoporosis [Roberfroid 2002; Skowronek and Fiedurek 2003].

The pre-sowing tillage has an important, crop-shaping meaning in the process of cultivation of rooted plants. These plants require a well aerated soil, that is rich in nutrients. They also require a site abundant in organic matter. The question of presence of organic matter in soil is particularly important when it comes to appearance of its degradation, with intensification of cultivation efforts, chemicalization of crops and use of improper crop rotation. Modern agricultural technology places an ever growing importance on the need of constant replenishment of organic matter in soil, through the cultivation of ploughable cover crops, as well as the simplification of tillage. Ploughing the fresh or aerated dry matter of the cover crops allows to slow down the soil degradation processes and improve the growth conditions for the cultivated crops. This results in the improvement of physical, chemical and biological properties of the soil, as well as the decrease of soil erosion caused by wind and water [Dzienia et al. 1995; Konopiński et al. 2001, Konopiński 2009, 2011; Pięta and Kęsik 2007].

The aim of the studies was to assess the influence of cover crops: common vetch, tansy phacelia and oats, as well as pre-winter and spring ploughing and type of planting: in ridges or in flat soil on the volume and biological value of crops of chicory root.

MATERIAL AND METHODS

The field experiments for the root chicory (*Cichorium intybus* var. *sativum* Bisch.) of the ‘Polanowicka’ cultivar, were conducted in years 2006–2008 in Felin Experimental Station belonging to the University of Life Sciences in Lublin, district of Lublin (22º56’E, 51º23’N, Central Eastern Poland, 200 m a.s.l.), on a grey-brown podzolic soil. Completely randomized blocks method at four replications was used in the experiment.The experiments included: two kinds of pre-sowing tillage: a) a complex of pre-sowing practices and sowing of cover crops (2nd decade of August) and pre-winter ploughing the green mass with soil, b) a complex of pre-sowing practices and sowing of cover crops (2nd decade of August), leave them in the field during the winter and ploughing the plant mass in the spring; two types of planting: in ridges and in flat soil, and three species of cover crops (common vetch, tansy phacelia and oats). Total area of field experiment was 400 m^2, and the plot size for harvest was 4 m^2. Following an analysis of the soil, the following rates of nutrients were used: 100 kg N ha^{-1}, 44 kg P ha^{-1} and 166 kg K ha^{-1}. The nitrogenous fertilizer (ammonium nitrate) was applied in two rates: ½ before sowing and ½ after the emergence, the phosphorus (triple superphosphate) and potassium (potassium salt) fertilizer were both applied in one rate, before sowing. The chicory seeds were sown on: May 9th, 2006, May 14th, 2007 and May 12th, 2008 in the quantity of 5 kg ha^{-1}, in rows spaced at intervals of 50 cm and at the depth of 1.5 cm. All of the agrotechnical practices, as recommended for proper cultivation of root chicory were applied during the vegetative period of the plants. Weather conditions in years 2006–2008 were favourable for growing of chicory root. In the period from April to October, the average temperature amounted to 14,5ºC and was higher by 1,2ºC than the average long-term temperature. The total rainfall during that period amounted to 429,7 mm and was higher by 24.9 mm than the average of long-term rainfall.

During the experiment the following features were taken: the yield of the chicory roots, biological value of roots, including: the inulin and protein content, dry matter content and biological yield of inulin per hectare. The dry matter content was determined with the use of dryer-scale method, the inulin content with the HPLC technique, and the protein content with use of Kjeldahl method.

The results were statistically processed by means of variance analysis. The difference significance was estimated using Tukey's test for significance level $\alpha = 0.05$.

RESULTS

Yield of the chicory roots. Independently of the other factors of the experiment the total yield of the chicory roots averaged out at 56.00 t ha^{-1} (tab. 1). The date of ploughing and mixing the biomass of the cover crops did not significantly affect the crop yield

Table 1. Yield of roots, mean from years 2006–2008 (t ha^{-1})

Tillage	Planting	Cover crops				Mean
		control	vetch	phacelia	oats	
Pre-winter ploughing	in ridges	52.47	59.40	62.83	59.57	58.57
	in flat soil	44.87	58.53	56.17	53.43	53.25
	mean	48.67	58.97	59.50	56.50	55.91
Spring ploughing	in ridges	50.87	60.97	61.43	56.77	57.51
	in flat soil	52.40	56.03	59.90	50.43	54.69
	mean	51.64	58.50	60.67	53.60	56.10
Mean	in ridges	51.67	60.19	62.13	58.17	58.04
	in flat soil	48.64	57.28	58.04	51.93	53.97
	mean	50.15	58.73	60.08	55.05	56.00
LSD $_{(0.05)}$ for:	tillage					n.s.*.
	planting					n.s.
	cover crops					9.90

n.s.*. – differences not significant

of chicory. The fields subjected to spring plough yielded on average of 56.10 tons of roots per hectare, while the fields subjected to pre-winter ploughing – 55.91 tons. Larger differences in root crop yields were observed between the ridged and flat growing of plants. The ridged chicory roots yielded significantly higher, with 58.04 t ha^{-1} on average, while the flat ones averaged out at just 53.7 t ha^{-1}. The plant mulches were found to have a very beneficial influence on crop yields of chicory. Compared to the chicory without cover crops, all of three examined species stimulated its crop yield. Tansy phacelia had the significantly best influence on chicory root crop yield (60.08 t ha^{-1}). In the unmulched treatments the root yield was the lower on average by 16.5%.

It was found, that the best tillage for root chicory is growing of plants in ridges, after pre-winter ploughing of tansy phacelia, used as soil-preserving plant. This combination yielded a root crop on average of 62.83 t ha^{-1}.

Inulin content of the chicory root. Independently of the other factors of the experiment the average content of inulin in fresh matter of chicory root was 17.55% (tab. 2). The date of ploughing and the type of planting did not significantly influence the content of inulin in roots. There were significant differences in inulin content depending on the biomass of the cover crops. The least amount of this compound (16.59% on average) was found in roots collected from treatments mulched with oats, with a significantly higher concentration found in roots from plots mulched with common vetch (18.39%). The inulin content in the roots of chicory cultivated without the use of plant mulch averaged out at 17.64%.

Table 2. The inulin content in roots, mean from years 2006–2008 (%)

Tillage	Planting	Cover crops				Mean
		control	vetch	phacelia	oats	
Pre-winter ploughing	in ridges	16.99	19.23	16.78	17.70	17.88
	in flat soil	17.88	17.94	18.34	15.73	17.47
	mean	17.44	18.59	17.56	16.72	17.57
Spring ploughing	in ridges	17.55	18.80	18.12	17.97	18.11
	in flat soil	17.74	17.59	17.55	14.96	16.96
	mean	17.65	18.20	17.84	16.47	17.54
Mean	in ridges	17.27	19.02	17.45	17.84	17.88
	in flat soil	17.81	17.77	17.95	15.35	17.22
	mean	17.54	18.39	17.70	16.59	17.55
$LSD_{(0.05)}$ for:	tillage					n.s.*
	planting					n.s.
	cover crops					1.56

n.s.* – differences not significant

Ridged or flat planting of chicory did not influence the content of this compound in the fresh matter of the roots. Roots collected from ridged soil contained only slightly higher amounts thereof (17.88% on average), than the roots collected from flat soil (17.22%).

Among all of the examined combinations of tillage, and taking the preservation effect of cover crops, growing chicory in ridges, after a pre-winter ploughing and mulching the soil with common vetch proved to be the most beneficial method in terms of inulin content of roots (19.23% on average).

Protein content of the chicory root. The protein content of the chicory root, independently of the other factors of the experiments, averaged out at 1.68% (tab. 3). The date of mixing the biomass of cover crops with the soil, the method of chicory planting, and the species of cover crop did not influence the synthesis of protein in roots significantly.

Table 3. Content of protein in roots, mean from years 2006–2008 (%)

Tillage	Planting	Cover crops				Mean
		control	vetch	phacelia	oats	
Pre-winter ploughing	in ridges	1.74	1.82	1.56	1.68	1.70
	in flat soil	1.73	1.65	1.59	1.57	1.64
	mean	1.74	1.74	1.58	1.63	1.67
Spring ploughing	in ridges	1.56	1.75	1.67	1.69	1.67
	in flat soil	1.68	1.83	1.73	1.56	1.70
	mean	1.62	1.79	1.70	1.63	1.68
Mean	in ridges	1.65	1.79	1.62	1.69	1.68
	in flat soil	1.71	1.74	1.66	1.57	1.67
	mean	1.68	1.76	1.64	1.63	1.68
LSD $_{(0.05)}$ for:	tillage					n.s.*
	planting					n.s.
	cover crops					n.s.

n.s.* – differences not significant

The only, slight, differences of the protein content in roots, under the influence of varying cover crops was noticed for common vetch. The least protein was found in roots originating from treatments mulched with oats biomass (1.63%), while the highest concentration was found in those coming from plots mulched with common vetch (1.76%).

The most beneficial tillage combinations, when it comes to the protein content of the chicory root, were its growing in ridges after pre-winter ploughing (1.82%) and in flat planting after spring ploughing (1.83%), in both cases mulching the soil with common vetch.

Dry matter content of the root. The factors of the experiment did not significantly influence the dry matter content of the chicory roots. Independently of the examined factors of experiment the dry matter content of the chicory root averaged out at 25.92% (tab. 4). The roots collected from the plots ploughed in spring contained, on average, 26.03% of dry matter, while the ones collected from the treatments with pre-winter plough 25.80%. The only slight differentiation of the dry matter content under the influence of different methods of tillage was observed. The roots of chicory collected from ridged treatments were characterised by a slightly higher content of dry matter (26.05% on average), than the ones collected from flat method of planting (25.79%).

The species of cover crops did not significantly affect the content of dry matter in roots. Its highest concentration was found from plots mulched with common vetch (26.40% on average), the lowest one in the roots from plots mulched with oats (25.59%).

Table 4. Content of dry matter in roots, mean from years 2006–2008 (%)

Tillage	Planting	Cover crops				Mean
		control	vetch	phacelia	oats	
Pre-winter ploughin	in ridges	25.53	26.90	24.40	26.35	25.80
	in flat soil	25.28	26.34	26.81	24.77	25.80
	mean	25.41	26.62	25.61	25.56	25.80
Spring ploughing	in ridges	25.65	26.27	26.85	26.41	26.30
	in flat soil	26.51	26.07	25.69	24.82	25.77
	mean	26.08	26.17	26.27	25.62	26.03
Mean	in ridges	25.59	26.59	25.63	26.38	26.05
	in flat soil	25.90	26.21	26.25	24.80	25.79
	mean	25.74	26.40	25.94	25.59	25.92
LSD $_{(0.05)}$ for:	tillage					n.s.*.
	planting					n.s.
	cover crops					n.s.

n.s.* – differences not significant

Table 5. Biological yield of inulin, from years 2006–2008 (t ha^{-1})

Tillage	Planting	Cover crops				Mean
		control	vetch	phacelia	oats	
Pre-winter ploughing	in ridges	8.91	11.42	10.54	10.54	10.35
	in flat soil	8.02	10.50	10.30	8.40	9.31
	mean	8.47	10.96	10.42	9.47	9.83
Spring ploughing	in ridges	8.93	11.46	11.13	10.20	10.43
	in flat soil	9.29	9.85	10.51	7.54	9.30
	mean	9.11	10.66	10.82	8.87	9.86
Mean	in ridges	8.92	11.44	10.84	10.37	10.39
	in flat soil	8.66	10.18	10.41	7.97	9.30
	mean	8.79	10.81	10.62	9.17	9.85
LSD $_{(0.05)}$ for:	tillage					n.s.*
	planting					0.71
	cover crops					1.53

n.s.* – differences not significant

As far as dry matter content in the roots of chicory is considered, the most beneficial tillage combination proved to be a ridged planting, with pre-winter ploughing and soil mulched with common vetch (26.90%).

Biological yield of inulin. The inlulin crop, after recalculation to hectare of root chicory plantation, averaged out at 9.85 t ha^{-1} (tab. 5). Date of ploughing, inserting the biomass of cover crops into the soil, did not significantly influence the yield of inulin. But the different planting methods of chicory proved to have a significant effect on inulin yield. Independently of the date the biomass was ploughed, and the species of cover crop, a significantly higher inulin yield was obtained from ridged chicory plants (10.39 t ha^{-1} on average), than from flat one (9.30 t ha^{-1}).

The use of cover crops for preservation of soil also influenced the inulin yield per unit of area in a beneficial way. Independently of the date of ploughing and the method of chicory planting the highest inulin yield (10.81 t ha^{-1} on average) was obtained from plots mulched with common vetch. The lowest inulin yield (on average by 18.7%) was found in roots from unmulched plots.

Taking the interdependencies of the examined factors of the experiment into account, the best tillage combinations for high yield of inulin per unit of area, were the ridged planting of chicory, after pre-winter ploughing (11.42 t ha^{-1} on average) and spring ploughing (11.46 t ha^{-1} on average) – in both cases in plots mulched with common vetch.

DISCUSSION

Three years experiment on the influence of different pre-sowing tillage, pre-winter or spring ploughing, cover crops: common vetch, tansy phacelia and oats, as well as ridged and flat planting has proven that the different factors of the experiment influenced the yield of the root chicory and its nutritional value to a different degree. It was found out, that the date of ploughing had no significant effect on the examined features, as opposed to results of the experiments with different root plants, that is salsify [Konopiński 2009] and scorzonera [Konopiński 2011]. In case of these two plants the spring ploughing and mixing the soil with plant mulch significantly influenced the total root crop and the inulin productivity from unit area. From the two types of planting subjected to the experiment, growing of chicory in ridges proved to be more beneficial than flat one. The total root yield from ridged chicory was, on average, 4.07 t ha^{-1} higher than the yield from flat method. Similar results were noticed during experiments with salsify [Konopiński 2009] and scorzonera [Konopiński 2011]. The planting of root chicory in ridges had a significant positive influence on the biological inulin yield. The beneficial effect of ridged method of planting of root plants on its yield was also confirmed by other authors [Saiful-Islam et al. 1998; Sady and Cebulak 2000; Michalik 2003; Wierzbicka et al. 2004]. The ridges provide the plants with good conditions for growth and root development through lower densification of the soil and its higher porosity. They also have an important meaning in protecting the soil against erosive phenomena, which are often intensified through numerous agricultural practices and chemicalization of the crops.

In trying to keep high soil fertility the agricultural technology of vegetable plants includes the preserving method, with the use of cover crops for soil mulching. Plant mulches protect the soil from the influence of adverse external factors, as well as from loss of humidity [Nyakatawa et al. 2001; Resende et al. 2005; Kęsik et al. 2006]. The cover crops had very positive meaning in the cultivation of root chicory. The biomass mixed with the soil had a significantly positive influence on the total chicory root yield (in the case of tansy phacelia), the content of inulin in the roots (in the case of common vetch) and the inulin yield per unit of area (in the case of common vetch and tansy phacelia). All of the cover crops used in the experiment beneficially affected the yield of chicory. A significantly positive effect of common vetch mulch was observed in the case of total root yield of salsify and its inulin productivity, as well as the effects of tansy phacelia mulch on the inulin content of the root, its yield per unit of area, and dry matter [Konopiński 2009]. In experiments with scorzonera Konopiński [2011] proved the significantly beneficial effect of mulching the soil with oats on the total root yield of scorzonera as well as the productivity of inulin per unit of area.

The positive influence of mulching the soil on the yield of the plants is also confirmed by results of experiments of numerous authors. Mulching of the soil produced the increase of yield of beans [Skarphol et al. 1987], tomatoes [Masiunas et al. 1995], peas [Knott 1996], onions [Kęsik et al. 2000] and carrots [Khatun and Farooque 2005]. The effects of plant mulches are long lasting, similar to those of use of manure [Jabłońska-Ceglarek and Zaniewicz 1994]. Many authors [Błażewicz-Woźniak et al. 2001; Epperlein and Martinez-Vilela 2001; Konopiński et al. 2001; Pięta and Kęsik 2007] claim that the cover crop biomass ploughed into the soil improves its water-air proportions and beneficially influences the aggregate state and structure of the soil as well as its biological activity.

The conducted experiment has proven, that the factors of the experiment did not influence the protein and dry mass content of the chicory roots in a significant way, as it was noticed in experiments with scorzonera [Konopiński 2011].

CONCLUSIONS

1. The date of ploughing had no significant influence on the chicory root yield and the qualitative features such as: the content of inulin, protein and dry matter, as well as inulin productivity per unit of area.

2. Ridged planting of chicory stimulated the yield of the plants and significantly influenced the increase of inulin yield per unit of area, when compared with flat growing of this plant.

3. Common vetch, tansy phacelia and oats had a positive effect on the yield of root chicory, when compared to plots without mulching. A significant increase in root yield was found in the case of mulching the soil with tansy phacelia. Among the plant mulches the weakest effects were observed for oats mulch.

4. The use of common vetch mulch allowed for a significant increase of inulin content of chicory roots, and the largest inulin yield per unit of area, when compared to mulching the soil with oats biomass.

5. The factors of experiment had no significant effect on the content of protein and dry matter in the roots of chicory.

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WPŁYW ROŚLIN MIĘDZYPLONOWYCH I ZRÓŻNICOWANEJ UPRAWY ROLI NA PLON I WARTOŚĆ ODŻYWCZĄ CYKORII KORZENIOWEJ (*Cichorium intybus* var. *sativum* Bisch.)

Streszczenie. W uprawie roślin korzeniowych jednym z głównych czynników decydujących o ich plonowaniu jest uprawa roli. Na znacznych obszarach współczesnych upraw coraz częściej obserwuje się zjawiska degradacji gleby. Są one wynikiem m.in. wzrostu częstotliwości zabiegów uprawowych i zaniechania uprawy międzyplonów na przyoranie. W wyniku niszczenia struktury agregatowej gleby i spadku zawartości w niej substancji organicznej pogorszeniu ulegają warunki wzrostu i plonowania roślin uprawnych. Doświadczenia polowe przeprowadzono w latach 2006–2008, na glebie płowej o nietrwałej strukturze. Rośliną doświadczalną była cykoria korzeniowa (*Cichorium intybus* var. *sativum* Bisch.) odmiany 'Polanowicka', gatunek ważny gospodarczo, dostarczający cennego surowca do produkcji inuliny. W badaniach uwzględniono dwa sposoby przedsiewnej uprawy roli i zagospodarowania międzyplonów: a) zespół uprawek przedsiewnych, siew roślin międzyplonowych (II dekada sierpnia) i przyoranie międzyplonów orką przedzimową, b) zespół uprawek przedsiewnych, siew roślin międzyplonowych (II dekada sierpnia), pozostawienie międzyplonów do wiosny i przyoranie orką wiosenną, dwie metody uprawy roślin: na redlinach i na płask oraz trzy rośliny międzyplonowe (międzyplony letnie): wykę siewną, facelię błękitną i owies. Wykazano istotnie korzystny wpływ mulczowania gleby facelią błękitną na plon korzeni ogółem cykorii w porównaniu z uprawą bez mulczu. Najwyższą zawartość inuliny stwierdzono w korzeniach cykorii zebranych z obiektów mulczowanych wyką siewną. Była ona istotnie większa od stwierdzonej w korzeniach pochodzących z obiektów mulczowanych owsem. Pod względem plonowania i produktywności inuliny z jednostki powierzchni, najkorzystniejszą kombinacją uprawową była uprawa cykorii na redlinach po wiosennym wymieszaniu z glebą mulczu z wyki siewnej. Badane czynniki doświadczenia nie miały istotnego wpływu na zawartość suchej masy i białka w korzeniu cykorii.

Słowa kluczowe: uprawa roli, redliny, cykoria korzeniowa, inulina, białko

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