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THE EFFECT OF PLANT MULCHES ON SOIL MOISTURE IN VEGETABLE CULTIVATION

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ABSTRACT

Catch crop cultivation and soil mulching offer many benefits pertaining to environment protection, and match well the rules of organic and sustainable agriculture. Soil mulching is also one of the methods which positively influence physical soil properties as well as moisture. A field experiment was conducted over the years 2002–2006. The objective of this work was to evaluate the effect of plant mulches (phacelia, spring vetch, serradella, oat) incorporated and retained as mulch on the soil surface on soil moisture changes (0–20 cm and 20–40 cm) in red cabbage and onion cultivation. The effect of mulching was compared to an unmulched control. Soil samples were taken after planting of cabbage seedlings, in the period of cabbage head formation and before cabbage harvest, and after sowing onion seeds, in the period of onion formation and before onion harvest. Higher moisture contents of both the upper and lower soil layers at all the dates of sampling in cabbage cultivation were found in the plots where plant mulches had been ploughed down in the autumn or left on the surface until the end of cabbage growing season, in comparison with the spring-ploughed plots. Phacelia and oat produced more organic matter and, when used as a mulch, they more beneficially influenced soil moisture content compared with serradella and spring vetch. The influence of the above catch crops lasted for the whole growing season of cabbage whereas the effect of oat was noticed even in the following year, after onion planting. Legumes undergo decomposition more rapidly and their mulching effect is much shorter than plants representing other botanical families.

Keywords: catch crops, mulching, soil water content, red cabbage, onion

INTRODUCTION

Soils in Poland are characterised by relatively low available water reserves [30]. The management of such resources in crop production, particularly in the field cultivation of vegetables, is becoming more and more of a problem. Rainfall is the main source which replenishes water reserves. However, over the recent years precipitation is highly variable. The greatest shortages of rainfall occur in May and August as well as April and July. Water losses due to evaporation are the primary problem in summer months [22].

Retention of organic matter as mulch on the soil surface is one of the ways of limiting the water loss. Application of mulches beneficially influences soil structure, reduces negative effects of wind and water erosion, and decreases soil warming in summer months [3, 8, 9, 12, 20, 23, 24, 25, 27, 34].

So far there have been no studies which would explicitly answer the question of the influence of mulching on soil moisture. Increased soil water retention after direct drilling into mulch compared with conventional plough-based cultivation was reported by Ferrares et al. [5], Wolkowski [33], Włodek et al. [31], Kuc and Zimny [16] and Pabin et al. [18]. By contrast, Schjönning and Rasmussen [26] reported decreased soil moisture associated with direct sowing into mulch compared with plough-based cultivation. Pabin et al. [19], Włodek et al. [32] and De Azevedo et al. [1] found no effect of mulch on the ability of soil to accumulate water.

According to Kostuch [15], legumes have got a particularly beneficial effect on soil water properties whereas Franczuk [6] has emphasized a favourable effect of not only legumous catch crops (winter vetch) but also rye and phacelia. Such an effect has also been reported by Franczuk et al. [7] whereas Konopiński et al. [14] and Konopiński [13] obtained similar results for oat.

Many studies have demonstrated a varied effect of mulch on soil moisture depending on soil layers which were sampled [12, 17, 27].

Cabbage and onion, which were main crops in the study, are characterized by substantial water demand. While the above-ground mass of cabbage is great, onion has got a shallow and poorly developed root system. According to Kaniszewski [11], the water demand of red cabbage and onion in the growing season is, respectively, 400–600 and 350–500 mm.

The objective of this work was to evaluate the effect of plant mulches on soil moisture changes over the growing season of red cabbage and onion. Typical catch crop (phacelia, spring vetch, serradella, oat) mulches cultivated in Poland were used.

MATERIALS AND METHODS

A field experiment was conducted over the years 2002–2006 at the Experimental Farm in Zawady. It is located in the central-eastern Poland (52^{o}03'N, 22^{o}33'E), 115 km east of Warsaw. The trial was set up as a split-block design in three replications. The experimental site had a history of winter triticale cultivation. The soil type was a Luvisol; the soil organic matter (SOM) content averaged 1.5% and the soil humus horizon reached the depth of 30–40 cm. Before the experiment set-up, soil pH determined in H_2O was 5.73. The total phosphorus content in the soil was 67 mg·kg^{-1} a.d.m. (air dry matter), potassium 108 mg·kg^{-1} a.d.m., magnesium 39 mg·kg^{-1} a.d.m., N-NO_3 10 mg·kg^{-1} a.d.m., N-NH_4 6 mg·kg^{-1} a.d.m., calcium 380 mg·kg^{-1} a.d.m. Moisture of the upper soil layer prior to the experiment set-up was 6.61% whereas for the lower layer it was slightly higher and equalled 7.02%.

In the years 2002, 2003 and 2004, seeds of plants cultivated for mulch purposes were sown in early August. In 2003, 2004 and 2005 in the same plots red cabbage cv 'Koda' was cultivated and in 2004, 2005 and 2006 onion cv 'Kristine' was grown. The whole experimental area was 2275 m^2, one plot was 25 m^2. The number of plots amounted to 45. The area of one plot and harvested plot was 25 and 16 m^2, respectively.

Effects of the following factors were investigated in the experiment:

- A – the date of mulch incorporation (ploughing down): A1 – in the autumn in late October; A2 – in the spring of the following year in mid-May before planting cabbage seedlings; A3 – left without ploughing down till the end of cabbage growing season.
- B – kind of mulch: B1 – unmulched control; B2 – phacelia (seeding rate 15 kg·ha^{-1}); B3 – spring vetch (seeding rate 140 kg·ha^{-1}); B4 – serradella (seeding rate 60 kg·ha^{-1}); B5 – oat (seeding rate 240 kg·ha^{-1}).

In the treatments, where mulch was left unincorporated until the end of cabbage growing season (A3) disc harrowing was applied before planting of seedlings to cut mulch and loosen the upper soil layer and prepare it for planting. The harrowing did not turn over the topsoil and made it possible to retain the mulch on the soil surface.

Soil samples were taken from the central part of the 0–20 cm layer (at the depth of about 10 cm) and from the central part of the 20–40 cm layer (at the depth of about 30 cm) at the following dates: after planting of cabbage seedlings, in the period of cabbage head formation and before cabbage harvest, and after sowing onion seeds, in the period of onion formation and before onion harvest. The samples were taken randomly from four different places in each plot and placed in 100 cm^3 Kopecky cylinders.

Metal cylinders, 50 mm in diameter and 51 mm high, were tightly closed with a gum lid to limiting soil evaporation until the time of weighing. Soil moisture was determined by the oven-drying gravimetric methods. The samples were weighed using a MEDICAT LTD 160 M electronic scale company to an accuracy of 0.01 g. Samples were taken from all the experimental plots at two depths. Soil moisture was calculated following the formula:

$$S_m = \frac{Kmw - Kmd}{Kmd - Km} \times 100 \quad (\%)$$

where:

Sm – soil moisture (%)

Kmw – weight of cylinder with moist soil (g)

Km – weight of cylinder (g)

Kmd – weight of cylinder with soil after drying (g)

Following cabbage and onion harvests, deep ploughing of both the experimental sites was performed.

The results were statistically analysed by means of the analysis of variance according to the mathematical model for the split-block design. Comparison of mean values by Tukey test was used at the significance level of p = 0.05. Calculations were performed by the authors' program based on the textbook "Methodology of agricultural experiments" [28].

Rainfall in the study period had a significant influence on the soil moisture in the growing season of mulching plants, cabbage and onion (Figure 1).

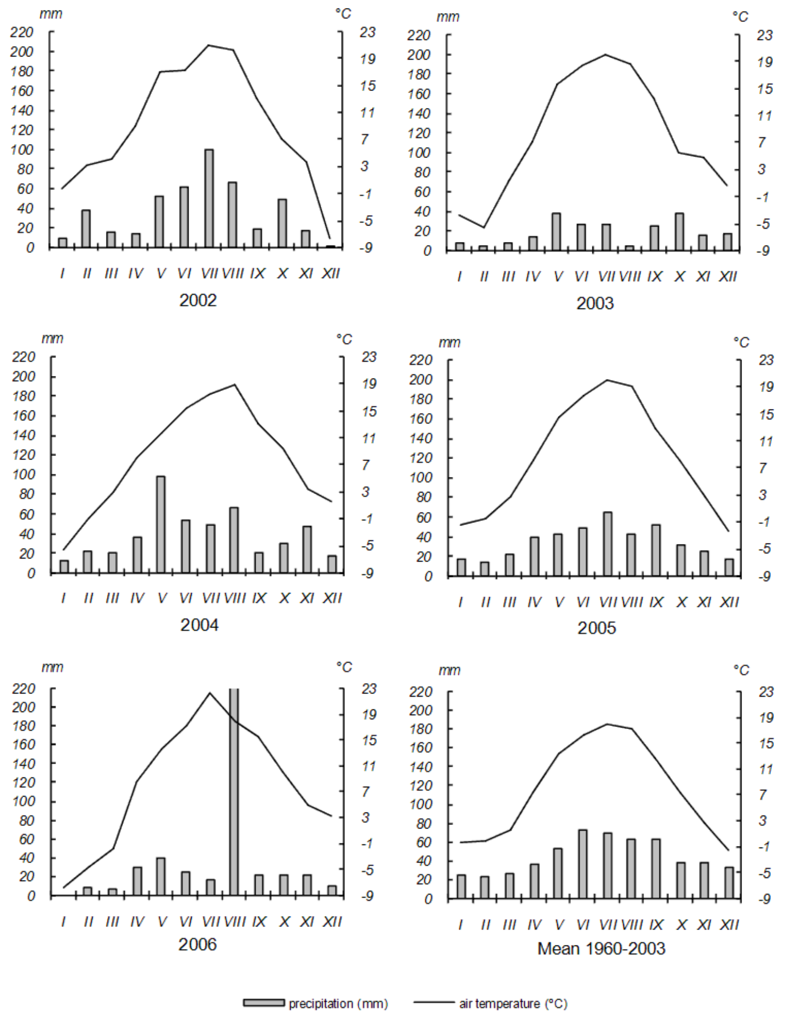


Figure 1. Weather conditions in the study years

The moisture conditions of the year 2002 were the most favourable for plants used for mulching purposes. Heavy rainfall in July stimulated seed emergence, and in August and October contributed to increased yields of plant matter. 2003 was least favourable for the plans as the sum of rainfall over the growing season amounted to 93.1 mm and was by 138.7 mm lower than the long-term mean.

In the all the study years of growing cabbage there were observed rainfall shortages. The years 2004 and 2005 were more favourable for cabbage growth (more rainfall and better distribution) compared with 2003. Moisture conditions in 2006 were not good for onion cultivation. Low rainfall in May, June and July, much below the long-term mean, hampered onion growth. Heavy rainfall in August stimulated plant growth, which resulted in cracking scales of onions. In the years 2004 and 2005 there were much better conditions for onion growth because of a more favourable rainfall distribution over the growing season.

Table 1. Sielianinow coefficients in vegetation period

Years	Mont							Growth period		
	IV	V	VI	VII	VIII	IX	X	mulching plants VII–X	cabbage VI–X	onion IV–IX
2002	0.48	1.01	1.19	1.58	1.10	0.48	2.35	1.38	-	-
2003	0.64	0.79	0.48	0.43	0.08	0.60	2.32	0.86	0.78	-
2004	1.50	2.77	1.14	0.93	1.18	0.50	1.04	0.91	0.96	1.34
2005	0.47	1.66	0.92	1.43	0.86	0.35	1.20	-	0.95	0.95
2006	1.18	0.97	0.47	0.24	4.21	0.45	0.74	-	-	1.25

< 0.5 – drought period; 0.51–1.0 – semi-drought period; 1.01–2.0 – relativery moist period; > 2.01 – high-moist period

In order to more thoroughly characterise the moisture conditions in the years of soil moisture determination Hydrothermal Sielianinov's coefficient values (HTC) were calculated according to the formula (Table 1):

$$HTC = \frac{P}{0.1 \times \sum t}$$

where:

P – monthly sum of rainfall mm,

Σ*t* – monthly sum of air temperature >0°C [21].

Hydrothermal coefficient (HTC) values indicated that the best moisture conditions were in the growing seasons 2002 and 2004. The worst was the growing season of 2003 which, except for October, was dry. Droughts were also recorded in the second half of 2005 and in the first half of 2006.

RESULTS

Phacelia and oat produced similar biomass yields which did not differ significantly (Table 2). The fresh matter yields of phacelia and oat were over 2.5 times higher than the yield produced by vetch and serradella. The dry matter yield of vetch was significantly higher than the yield of serradella dry matter.

Table 2. Yield of fresh and dry mass of mulching plants ($t \cdot ha^{-1}$) (mean for years 2003–2005)

Mulching plants	Fresh mass ($t \cdot ha^{-1}$)				Dry mass ($t \cdot ha^{-1}$)			
	2002	2003	2004	Mean	2002	2003	2004	Mean
Phacelia	38.6 d*	19.6 c	21.6 b	26.6 b	6.9 d	4.1 b	4.3 b	5.1 c
Spring vetch	14.3 b	8.5 b	10.2 a	11.0 a	2.8 b	2.2 a	2.5 a	2.5 b
Serradella	10.6 a	7.9 a	12.8 a	10.4 a	1.5 a	1.4 a	2.2 a	1.7 a
Oat	25.6 c	23.2 d	25.7 c	24.8 b	4.7 c	4.9 b	5.1 c	4.9 c

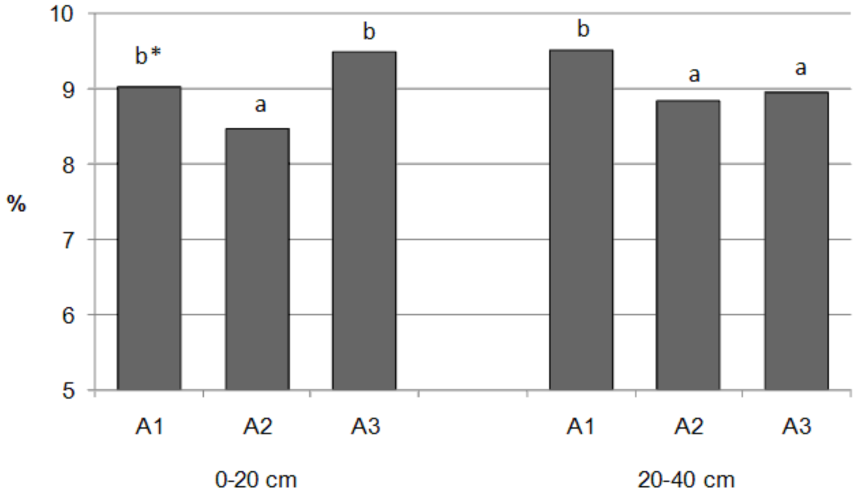
* Means within rows followed by different letters are significantly at $P = 0.05$

In cabbage cultivation in both the soil layers 0–20 and 20–40 cm the highest mean moisture was determined in 2004 when rainfall was high (Table 3). In 2003 the highest soil moisture at both depths was found directly before cabbage harvest and in the years 2004 and 2005 after planting of seedling and over the period of cabbage head formation. Moisture in the consecutive years and at dates of sampling depended on rainfall level and distribution.

Table 3. Soil moisture (%) in the subsequence study years in the cabbage cultivation

Soil layer	Years	Date of samples taken			Mean
		after seedlings planting	in the period of head formation	before harvest	
0–20 cm	2003	6.84	4.22	10.45	7.17
	2004	10.52	10.13	6.18	8.94
	2005	9.62	9.52	3.40	7.51
20–40 cm	2003	7.65	4.81	9.74	7.40
	2004	10.46	11.55	6.12	9.38
	2005	9.22	10.46	4.09	7.92

The date of mulch incorporation had a significant influence on soil moisture (Figure 2). Spring incorporation of mulch contributed to decreased soil moisture in the 0–20 cm soil layer compared to autumn-incorporated and unincorporated mulch. In turn, in the 20–40 cm soil layer significantly the highest soil moisture was found following autumn incorporation of the mulch. Soil cultivation in the autumn contributed to better water accumulation in the lower soil layer. Loosening of the upper soil layer by autumn tillage resulted in better permeation of water to deeper layers.



A1 - ploughing down in the autumn, A2 - ploughing down in the spring, A3 - left without ploughing down

* Means within rows followed by different letters are significantly at $P = 0.05$

Figure 2. Soil moisture (%) at the depth of 0–20 and 20–40 cm
after planting cabbage seedlings depending on the date of plant mulches incorporation

In the 0–20 cm soil layer which was loosened by autumn or spring ploughing down or disking the differences in moisture did not occur. Significant differences between the treatments examined were found in the 20–40 cm soil layer where there was observed a significant interaction of the date of mulch incorporation and kind of mulch (Figure 3). When incorporated in the autumn (A1), phacelia and oats significantly reduced the moisture content of the lower soil layer compared with the control. Phacelia and oat produced high biomass yield (Table 2), which, when introduced to the soil in the autumn, limited water permeation down the soil profile during winter and spring. When left until spring without incorporation, the phacelia mulch reduced water evaporation from the soil surface, which resulted in lower moisture losses during the winter and spring. Substantial amounts of spring-incorporated organic mass of phacelia blocked water permeation from deeper layers of soil profile to the topsoil and decreased moisture losses from the 20–40 cm layer.

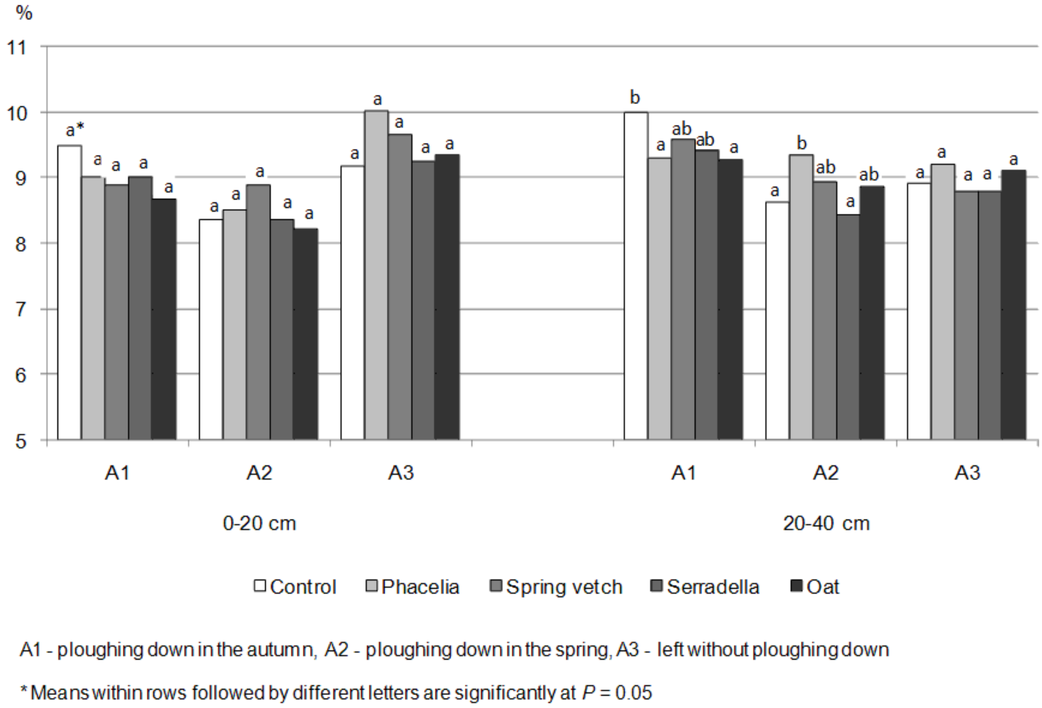


Figure 3. Soil moisture (%) at the depth of 0–20 and 20–40 cm
after planting cabbage seedlings depending on investigated factors (mean for years 2003–2005)

An interaction of the date of mulch incorporation and the kind of mulch significantly influenced the moisture content in both the upper and lower soil layers over the period of cabbage head formation (Figure 4).

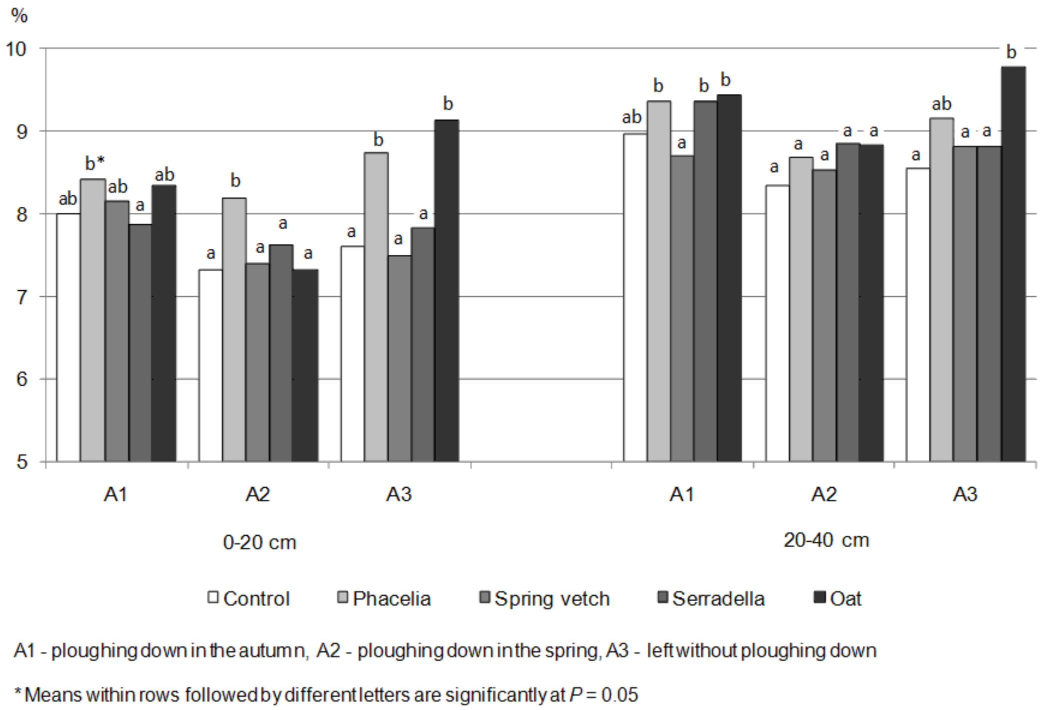


Figure 4. Soil moisture (%) at the depth of 0–20 and 20–40 cm
in the period of cabbage head formation depending on investigated factors (mean for years 2003–2005)

In the 0–20 cm layer after autumn incorporation (A1) of all the catch crops, soil moisture was similar to the control. Only in the treatment with autumn-incorporated phacelia significantly higher soil moisture content was recorded compared with the treatment with autumn-incorporated serradella. When ploughing was performed in the spring (A2), significantly the highest moisture content was associated with phacelia, whose high yield of organic mass (Table 2) introduced to the soil influenced beneficially water properties. However, in the treatment where plants had been left on the soil surface as a mulch, a significantly higher moisture content was found after oat and phacelia rather than vetch, serradella and the unmulched control. Great biomass of oat and phacelia better protected the soil against water evaporation than the considerably lower organic mass of vetch and serradella which was decomposing much faster.

In the 20–40 cm soil layer significantly higher soil moisture was determined after autumn-incorporated (A1) oats, phacelia and serradella compared with spring vetch incorporated at the same date. After the spring incorporation of the mulches (A2), no significant differences were found in moisture content between the plant mulches investigated. Of the plants left as a mulch (A3) over the period of cabbage head formation, the most beneficial was the impact of oat on soil moisture. A similar influence was found for phacelia. A significantly lower moisture content in the 20–40 cm soil layer was found under mulches with serradella and vetch as well as in the unmulched control.

The date of mulch incorporation significantly affected the moisture content of the soil upper layer (Figure 5). Significantly higher soil moisture was determined in the plots where catch crops were left as a mulch until the end of cabbage growing season (A3) compared with spring-incorporated plots before planting of seedlings (A2). In the 20–40 cm soil layer the date of mulch incorporation did not have a significant influence on the soil moisture. There were found no statistically significant changes in soil moisture as a result of an application of different mulches.

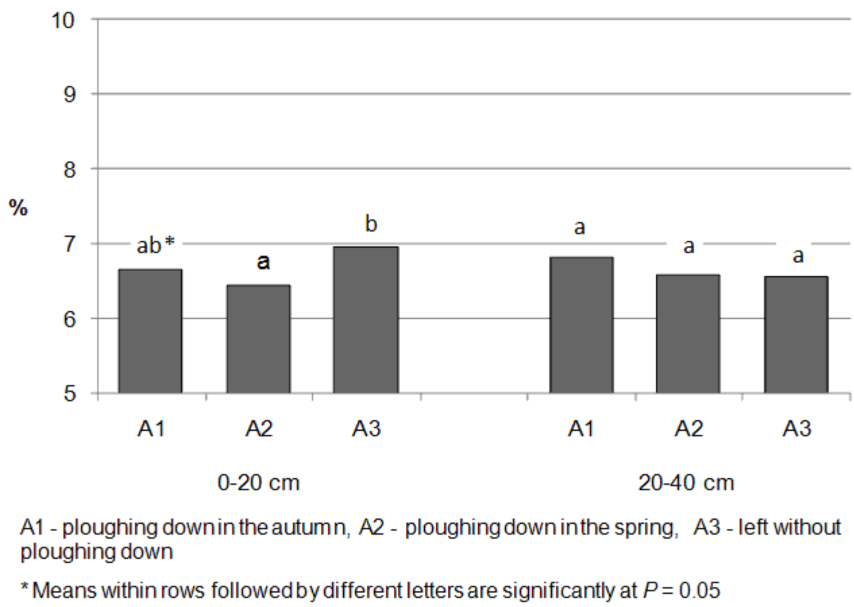


Figure 5. Soil moisture (%) at the depth of 0–20 and 20–40 cm directly before cabbage harvest depending on the date of plant mulches incorporation (mean for years 2003–2005)

In the years 2004 and 2006 there was observed a higher mean moisture of the soil under onion compared to 2005 (Table 4). In the years 2004 and 2005 there was determined a higher moisture of soil after seed sowing and over the period of onion formation than before harvest. In turn, in 2006 higher moisture was recorded in the period after seed sowing and before harvest compared with the period of onion formation.

Table 4. Soil moisture (%) in the subsequence study years in the onion cultivation

Soil layer	Years	Date of samples taken			Mean
		after sowing onion seeds	in the period of onion formation	before harvest	
0–20 cm	2004	10.69	10.56	3.82	8.36
	2005	6.86	6.66	3.59	5.70
	2006	8.06	6.13	9.93	8.04
20–40 cm	2004	11.06	12.13	4.63	9.27
	2005	6.46	5.93	4.76	5.72
	2006	8.50	5.25	10.53	8.09

An average soil moisture content after onion seed sowing ranged from 8.54% for the 0–20 cm layer to 8.67% for the 20–40 cm layer. Significant was only the effect the kind of mulch on the moisture content of the upper soil layer (0–20 cm). Moisture content of the soil, where oat mulch had been applied, was significantly higher compared with the remaining combinations (Figure 6).

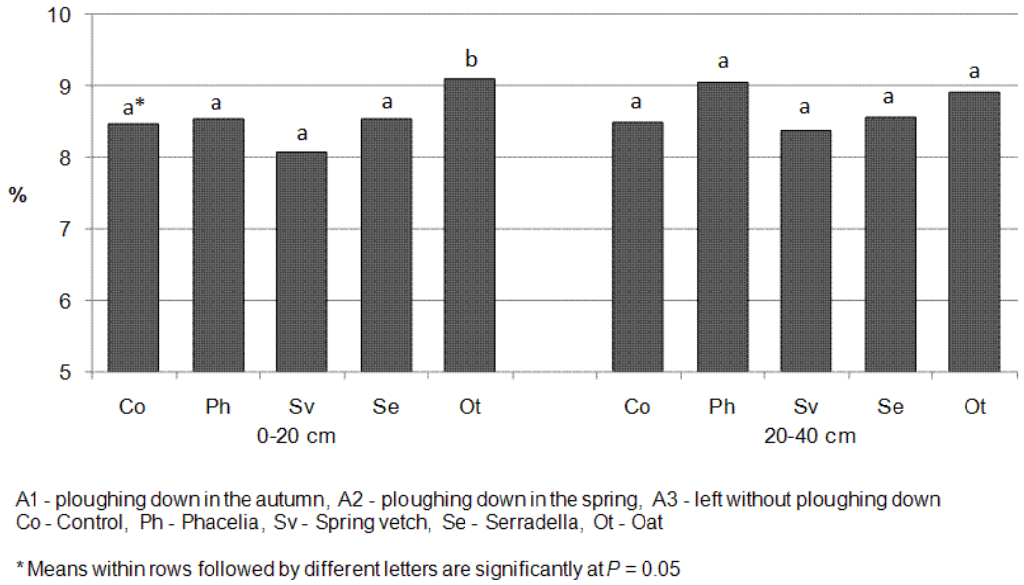


Figure 6. Soil moisture (%) at the depth of 0–20 and 20–40 cm
after onion seeds sowing depending on the species of mulching plants (mean for years 2004–2006)

An average soil moisture over the period of onion formation in both the soil layers was similar and amounted to 7.77% and before harvest it amounted to 5.78% and 6.64% in the 0–20 cm and 20–40 cm layer, respectively. The date of incorporation and species of plant mulches used in cabbage cultivation had no significant secondary effect on moisture changes in both the upper and lower soil layers during onion formation and before onion harvest.

DISCUSSION

The results obtained in this work were associated with a statistically significant influence of the date of incorporation and species of plant mulches on soil moisture. Retention of plants as a mulch until the end of cabbage growing season and autumn incorporation of catch crops in the year preceding cabbage cultivation had the most beneficial effect on soil water retention in the 0–20 cm layer. Spring incorporation of catch crops made the upper soil layer too dry. In the 20–40 cm soil layer a higher moisture content was recorded only at the beginning of cabbage growing season following autumn-incorporation of catch crops. As the growing season advanced, the moisture of lower soil layer was similar irrespective of the date of mulch incorporation. Results of different studies have indicated that incorporation of biomass increases autumn and spring water accumulation which creates optimal moisture conditions for the following plant at the beginning of its growing season. However these dependences do not refer to the whole growing season in the following year [2, 7, 29]. Pabin et al. [18] found that catch crops left on the soil surface as a mulch more beneficially influenced the soil moisture than incorporation. Ferrares et al. [5], Wolkowski [33], Kuc and Zimny [16] as well as Kęsik et al. [12] observed increased soil moisture under plant mulches compared to non-covered soil. Iles and Dosmann [10] reporated a higher soil moisture after different organic mulches (pine bark, pine wooden chips, hardwood, mostly oak, bark) compared with the unmulched control. According to the authors, mulch provided a kind of cover protecting against evaporation. Nevertheless, not all studies have demonstrated a favourable influence of mulching on water accumulation in the soil. Schjönning and Rasmussen [26] and Włodek et al. [32] showed a lower moisture of mulched soil compared to the conventional soil cultivation (plough-based cultivation). The authors have claimed that the higher density of soil after direct sowing hampered water permeation and increased water evaporation in the upper soil layer. The mulching effect could be dominated by this phenomenon as it limits evaporation from the soil surface. In the studies by De Azevedo et al. [1] an application of catch crops had no significant effect on soil moisture in the whole soil profile and, as a result, on the process of water accumulation over the whole growing season. Also Odhiambo and Bomke [17] have shown that an application of catch crops had no influence on soil water content at the depth of 20–40 or 40–60 cm.

The present studies demonstrated a significant influence of mulch species on soil moisture in the spring in the lower soil layer (20–40 cm). When incorporated in the autumn, phacelia and oat reduced the moisture content compared with the control. However, leaving phacelia as a mulch over winter and incorporation in the spring contributed to significant increase in soil moisture compared with the control. Also Duer [4] has shown that soil mulching with winter-kill plants left on the surface increased water content in the spring. A favourable influence of phacelia, oat and spring vetch on soil water management directly in the post-winter period was also found by Konopiński et al. 14]. Over the period of cabbage head formation in the treatments with autumn-incorporated catch crops, the highest moisture content in the 0–20 cm layer was found after phacelia and oat, and in the 20–40 cm layer after phacelia, serradella and oat. Phacelia and oat left as a mulch until the end of cabbage growth most beneficially influenced soil moisture in the whole soil profile. At the depth of 0–20 cm a significantly higher soil moisture than in the control was recorded after phacelia and oat and at the depth of 20–40 cm after oat. Tomar et al. [27] demonstrated higher soil moisture at the depth of 0–30 cm in mulched plots compared with the control. According to the authors, the effect of mulching was less pronounced at the 30–90 cm depth but mulches retained relatively more moisture than the control. In the present study there was found no significant influence of catch crops incorporated at different dates and left as a mulch on the soil moisture during cabbage harvest. However, Konopiński et al. [14] found a tendency towards increased soil moisture under white mustard, phacelia, vetch and oat as well as spring vetch and rye in onion cultivation [12].

Our results demonstrated that oat applied as a mulch (irrespective of the date of ploughing down) beneficially influenced the moisture content in the upper soil layer in the spring of the following year. It was particularly important because onion seed were sown at this date. As the onion growing season advanced, differences in soil moisture after consecutive mulches were smaller and smaller. A beneficial secondary effect of oat and vetch applied as a mulch on the soil moisture was also reported by Konopiński et al. [14] and Konopiński [13].

CONCLUSIONS

1. Catch crops incorporated in the autumn and left as a mulch on the soil surface until the end of growing season of the following plant more beneficially influence soil moisture than spring-incorporated mulches.
2. Plants which produce more biomass are better mulches. Of the plants used in the experiment – phacelia and oat were such plants. Their influence lasted till the end of cabbage growing season, the effect of oat observed even in the following year, after onion seed sowing.
3. Legumes, because of a higher nitrogen content in the tissue, decompose more rapidly and their mulching effect is much shorter compared with plants representing other botanical families.

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