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The effect of meteorological factors on the productivity of catch crops in sustainable and organic farming systems

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Abstract

Field experiments were carried out for three years under the conditions of sustainable agriculture at the Lithuanian University of Agriculture's Experimental Station and under the conditions of organic agriculture in Kazli kiai organic farm. The study was aimed to evaluate the effects of climate factors on the productivity of different catch crop species (*Trifolium pratense* L., *Lolium multiflorum* Lam., *Sinapis alba* L., *Brassica napus* L.) under sustainable and organic farming systems.

In both farming systems, climate factors had no effect on the productivity of undersown catch crops (red clover and Italian ryegrass). In the organic farming system, winter rape productivity was influenced by the duration of vegetation period (r = 0.89, P < 0.01), that of white mustard by the amount of precipitation (r = 0.81, P < 0.01) and hydrothermal coefficient (HTC) (r = 0.79, P < 0.05). In the sustainable farming system, climate factors had no effect on the productivity of post-harvest catch crops (white mustard and winter rape). The productivity of red clover, Italian ryegrass and winter rape was determined by crop density (strong and very strong correlations were established) in both farming systems. In the sustainable farming system, the productivity of the post-harvest catch crop species was more stable than that of the undersown catch crop species as the latter were suppressed by main crop (winter wheat) fertilized with mineral fertilizers and sprayed with pesticides. In the sustainable farming system, the highest dry mass yield obtained in autumn was that of white mustard (0.92 Mg ha^{-1}), while the yield of red clover, Italian ryegrass and winter rape was lower – 29.3%, 59.8% and 37.0%, respectively. The yield of the aboveground dry mass in spring of red clover and winter rape was similar – 0.37 and 0.30 Mg ha^{-1} respectively. In organic farming the highest yield in autumn was that of red clover – 2.38 Mg ha^{-1}. The yield of Italian ryegrass, white mustard and winter rape was by 4.1, 2.0, 2.4 times in autumn and winter rape was by 1.8 times in spring lower than that of red clover.

Key words: catch crops, productivity, climate factors, sustainable agriculture, organic agriculture.

Introduction

Catch crop is a crop that grows quickly and can be planted between two regular crops grown in successive seasons or between two rows of crops in the same season. Catch crops perform optimal uptake of the nutrients, existing in the soil, solar energy and precipitation, while the incorporated aboveground and underground mass of these plants enrich the soil with organic matter (Hampl, 1996; Целовальников, 2007; Bodner et al., 2010). Planting of catch crops and reducing tillage intensity may also be viable alternatives to reduce the amount of soil loss resulting from global climate change (Williams et al., 1999).

The productivity of catch crops depends on the sowing time, sowing methods, growing season and summer – autumn meteorological conditions (Heißenhuber, Schmidtlein, 1987; Lehmann et al., 1991; Renius, Lütke Entrup, 1992; Sorensen, 1992; Hampl, 1996; Monstvilaitė, 1996; Stancevičius et al., 1997; Brant et al., 2011). According to Lehmann et al. (1991) the biggest aboveground mass yield of white mustard and oil-radish was obtained, when the plants had been sown at the beginning of August and the duration of vegetation period was not less than 80 days. Delay of sowing reduced the productivity of white mustard and oil-radish. Sorensen (1992) found, that the productivity of catch crops was influenced not only by the duration of vegetation period, but, very likely, also by the day length and average daily temperature. Therefore it is recommended to choose the plant species that have a short growing season (Diercks, Heitefuss, 1990; Kerschberger, 1995).

The aim of the study was to evaluate the effects of climate factors on the productivity of different catch crop species (red clover, Italian ryegrass, white mustard and winter rape) under sustainable and organic farming systems.

Materials and methods

The investigations were carried out under the conditions of sustainable agriculture (trial I) in the Experimental Station and under the conditions of organic agriculture (trial II) in Kazliškiai organic farm of the Lithuanian University of Agriculture (54º53′ N, 23º50″ E). In trial I, the soil was *Calc(ar)i-Endohypogleyic Luvisol* (*LVg-n-w-cc*) with a texture of medium loam on light sandy loam. In trial II, the soil was *Endohypogleyic-Eutric Planosol* (*PLe-gln-w*) with a texture of medium loam on light sandy loam.

Different catch crops for green manure were sown into winter wheat (*Triticum aestivum* L.) or after its harvesting. Red clover *Trifolium pratense* L. 'Liepsna' (8 kg ha^{-1}) and Italian ryegrass *Lolium multiflorum* Lam. 'Rapid' (14 kg ha^{-1}) were undersown into wheat in early spring. White mustard *Sinapis alba* L. 'Karla' (35 kg ha^{-1}) and winter rape *Brassica napus* L. (in the first year of the experiment – 'Apex', in the second year of the experiment – 'Accord', in the third year of the experiment – 'Valesca' 20 kg ha^{-1}) after wheat harvesting were direct drilled into the stubble. After wheat harvesting, in the plots without catch crop the stubble was no-tilled until the primary soil tillage.

Catch crops for green manure were incorporated into the soil in autumn or in spring. In one part, catch crops for green manure were deeply ploughed (at the depth of 23–25 cm) in late autumn. In the other part, they were left not incorporated during winter until the following spring. In the first year of the experiment, the plots of this treatment were shallowly rotovated with a rotary cultivator before barley sowing. In the spring of the next two years, in organic agriculture catch crops for green manure were shallowly ploughed at the depth of 10–12 cm. In sustainable agriculture, the no-tilled soil with catch crops and plant residue was sprayed with glyphosate in spring (4.0 l ha^{-1}).

The yield of the aboveground dry mass of catch crop species (red clover, Italian ryegrass and winter rape) was determined before deep incorporation in autumn and before shallow incorporation in spring at randomly selected 4 registration sites of 0.25 m^2 of each plot. The yield of the aboveground dry mass of white mustard was taken in autumn at the flowering stage. Plants were weighed and dried for 24 h in a thermostat at 105ºC. The yield of dry biomass was expressed in Mg ha^{-1}.

Experiments in sustainable and organic farming systems were carried out in three replicates. Analyses of variance ($P < 0.05$) were performed using the *SAS GLM* procedure (SAS Users Guide, 1999). The *Fisher LSD* test was used to determine significant treatment effects.

Meteorological conditions were assessed based on the data obtained from Kaunas Meteorological Station.

HTC (hydrothermal coefficient) was calculated using the formula of Selianinov (Хомяков, 1989):

HTC = $\Sigma p \times (0.1 \times \Sigma t)^{-1}$, where Σp – total rainfall mm during the catch crops' vegetation period, Σt – sum of air temperatures ≥ 10ºC during the same period.

Results and discussion

Meteorological conditions. In the first year of the experiment, April was cold and dry. As a result, red clover and Italian ryegrass were undersown into winter wheat only at the end of April. Clover and ryegrass germinated slowly (Tables 1 and 2). According to Stenberg (1998), soil moisture highly affects growth of undersovn catch crop. The average daily temperature of May and June was 1.1 and 1.3ºC higher than the long-term mean. The hydrothermal coefficients were 1.02 and 1.20, respectively (optimal irrigation). July was cold and dry, which inhibited winter wheat harvesting and sowing of white mustard and winter rape. In August, the hydrothermal coefficient was 1.83 (excess irrigation), in September 0.65 (medium drought). The weather conditions were optimal, which resulted in intensive development of catch crops. During the post-harvest period of catch crops, the sum of active temperatures varied from 464.7 to 842.5, hydrothermal coefficients ranged from 1.33 to 1.81, respectively (Tables 1 and 2). The overwintering conditions for winter catch crops were favourable.

In the second year of the experiment, the spring was early. May was cold and dry with a rainfall 21.7 mm lower than the long-term mean, therefore red clover and Italian ryegrass developed slowly. The average daily temperature of June and July was 3.6 and 2.5ºC higher than the long-term average. The hydrothermal coefficients were 0.94 (optimal irrigation) and 0.49 (strong drought), respectively. In August, the hydrothermal coefficient was 1.63 (excess irrigation), in September 0.71 (medium drought), which slowed catch crops' development. The winter was mild.

In the third year of the experiment, April was warm and very dry (the hydrothermal coefficient – 0.15), as a result, red clover and Italian ryegrass developed slowly. Drought continued until the end of May. In June, the hydrothermal coefficient was 1.44 (optimal irrigation), in July 2.25 (excess irrigation), which inhibited winter wheat harvesting and sowing of post-harvest catch crops. In August, the hydrothermal coefficient was 1.07 (optimal irrigation). September was very dry with 28.2% less rainfall, and the average daily temperature of the month 1.6ºC lower, compared with the long-term mean, which slowed catch crops' development. During the post-harvest period of catch crops, hydrothermal coefficients were from 0.84 to 1.10, respectively (Tables 1 and 2). The overwintering conditions were favourable.

Catch crop productivity in sustainable farming system. It has been established that the productivity of post-harvest catch crop species was more stable than that of undersown catch crop species as the latter were suppressed by the main crop (winter wheat) fertilized with mineral fertilizers and sprayed with pesticides.

Table 1. The meteorological conditions during the vegetation period of catch crops in the sustainable farming system

Catch crop	Year of the experiment	Vegetation period (day, month)	Average daily temperature ºC	Sum of the active temperatures ºC	Amount of precipitation mm	Hydrothermal coefficient (HTC)
1. Red clover	I	13 05–05 08*	15.8	1281.8	192.2	1.50
		05 08–15 10*	11.8	730.0	121.8	1.67
	II	11 05–27 07*	17.6	1325.9	93.7	0.71
		27 07–12 10**	15.2	1089.1	168.1	1.54
	III	01 05–02 08*	14.8	1356.9	219.1	1.61
		02 08–10 10**	13.3	807.1	68.7	0.85
2. Italian ryegrass	I	13 05–05 08*	15.8	1281.8	192.2	1.50
		05 08–15 10**	11.8	730.0	121.8	1.67
	II	11 05–27 07*	17.6	1325.9	93.7	0.71
		27 07–12 10**	15.2	1089.1	168.1	1.54
	III	01 05–02 08*	14.8	1356.9	219.1	1.61
		02 08–10 10**	13.3	807.1	68.7	0.85
3. White mustard	I	13 08–23 09	13.3	526.1	70.1	1.33
	II	13 08–13 09	15.5	481.3	22.1	0.46
	III	16 08–25 09	12.9	441.3	48.6	1.10
4. Winter rape	I	13 08–15 10	11.4	610.0	102.1	1.67
	II	16 08–12 10	13.9	712.5	95.7	1.34
	III	16 08–10 10	12.5	579.2	48.6	0.84

Note. * – the vegetation period of red clover and Italian ryegrass from germination till wheat harvesting, ** – the vegetation period of red clover and Italian ryegrass from wheat harvesting till catch crop incorporation.

Table 2. The meteorological conditions during the vegetation period of catch crops in the organic farming system

Catch crop	Year of the experiment	Vegetation period (day, month)	Average daily temperature ºC	Sum of the active temperatures ºC	Amount of precipitation mm	Hydrothermal coefficient (HTC)
1. Red clover	I	13 05–30 07*	15.6	1169.3	181.7	1.55
		30 07–13 10**	12.5	842.5	123.9	1.47
	II	11 05–27 07*	17.6	1325.9	93.7	0.71
		27 07–12 10**	15.2	1089.1	168.1	1.54
	III	01 05–02 08*	14.8	1356.9	219.1	1.61
		02 08–10 10**	13.4	756.6	68.7	0.91
2. Italian ryegrass	I	13 05–30 07*	15.6	1169.3	181.7	1.55
		30 07–13 10**	12.5	842.5	123.9	1.47
	II	11 05–27 07*	17.6	1325.9	93.7	0.71
		27 07–12 10**	15.2	1089.1	168.7	1.54
	III	01 05–02 08*	14.8	1356.9	219.1	1.61
		02 08–10 10**	13.4	756.6	68.7	0.91
3. White mustard	I	06 08–10 09	13.5	464.7	84.1	1.81
	II	13 08–13 09	15.5	481.3	22.1	0.46
	III	16 08–25 09	12.9	441.3	48.6	1.10
4. Winter rape	I	06 08–13 10	11.8	713.6	110.9	1.55
	II	16 08–12 10	13.9	712.5	95.7	1.34
	III	16 08–10 10	12.5	579.2	48.6	0.84

Note. * – the vegetation period of red clover and Italian ryegrass from germination till wheat harvesting, ** – the vegetation period of red clover and Italian ryegrass from wheat harvesting till catch crop incorporation.

In the first year of the experiment, the highest dry mass (DM) yield obtained in autumn was that of red clover (1.58 Mg ha^{-1} DM); while the yield of Italian ryegrass, white mustard and winter rape was significantly lower (from 41.8% to 67.1%) (Fig. 1). According to Askegaard and Eriksen (2007), the legume catch crops had a significantly larger aboveground dry mass production in the autumn than the non-legumes. In the second year of the experiment, there was a shortage of moisture during the vegetation period when the amount of rainfall was 93.7 mm, hydrothermal coefficient was 0.71 (Table 1), as a result the growth of red clover and Italian ryegrass was suppressed. The dry mass yield of white mustard and winter rape in autumn was 0.85 and 0.58 Mg ha^{-1}, respectively. In the third year of the experiment, the biggest dry mass yield obtained in autumn was that of white mustard (0.99 Mg ha^{-1}); while the yield of red clover, Italian ryegrass and winter rape was significantly lower (from 35.4% to 68.7%). During the post-harvest period, the meteorological conditions had no significant effect on the productivity of different catch crop species. The productivity of red clover and Italian ryegrass was determined by crop density. The results of the correlation and regression analyses show significant positive dependency of clover and ryegrass dry mass yield on crop density (accordingly $r = 0.86$, $y = -0.06 + 0.002x$, $P < 0.05$ and $r = 097$, $y = -0.30 + 0.01x$, $P < 0.01$).

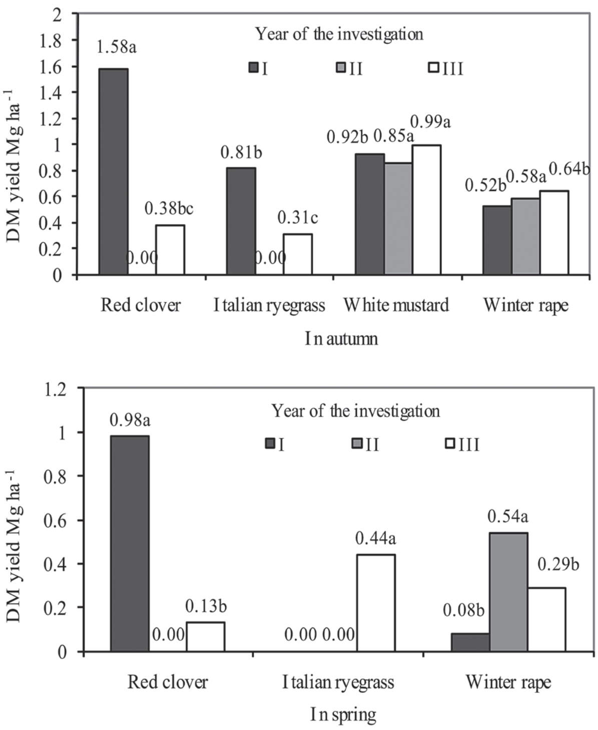
In spring, in the first year of the experiment under the stress of physiological drought rape crop was thin (Fig. 1). Therefore the dry mass yield of winter rape was very low (0.08 Mg ha^{-1} DM). The dry mass yield of red clover was by 12.3 times bigger than that of winter rape. In spring, in the second year of the experiment the dry mass yield of winter rape was 0.54 Mg ha^{-1}. In the third year of the experiment, even Italian ryegrass, as an exception in Lithuanian conditions, overwintered successfully. Therefore the dry mass yield of ryegrass was 0.44 Mg ha^{-1}. The yield of red clover and winter rape was by 70.4 and 34.1% lower than that of Italian ryegrass. The productivity of red clover and winter rape depended on crop density. Significant positive correlations were identified between dry mass yield of red clover and crop density ($r = 0.96$, $y = -0.02 + 0.002x$, $P < 0.01$) and between dry mass yield of winter rape and crop density ($r = 0.73$, $y = -0.07 + 0.004x$, $P < 0.05$).

Tripolskaya and Romanovskaya (2006) determined that in Lithuanian conditions, on sandy loam *Luvisol* after barley harvesting the undersown red clover is capable of generating a large (2.78 Mg ha^{-1} DM) biomass (aboveground parts and roots), on average twice as high as oil-radish (1.33 Mg ha^{-1} DM), within a short period (mid-August – late October). According to Arlauskienė and Maikštėnienė (2008), the largest amount of aboveground mass 2.55 Mg ha^{-1} of dry matter was produced by undersown red clover with a longer growing season. The largest aboveground mass of the post-sown-crop white mustard was formed in the plots of the treatments in which the seed was direct drilled into stubble-broken soil or into the stubble (2.43 and 2.53 Mg ha^{-1} DM respectively). Masilionytė and Maikštėnienė (2010) found that in the catch crop the highest dry matter mass and the amount of nutrients were accumulated in the white mustard grown with buckwheat or white mustard grown as a monocrop.

Catch crop productivity in the organic farming system. It was established that the dry mass yield of undersown (red clover and Italian ryegrass) and post-harvest (white mustard and winter rape) catch crop species greatly fluctuated.

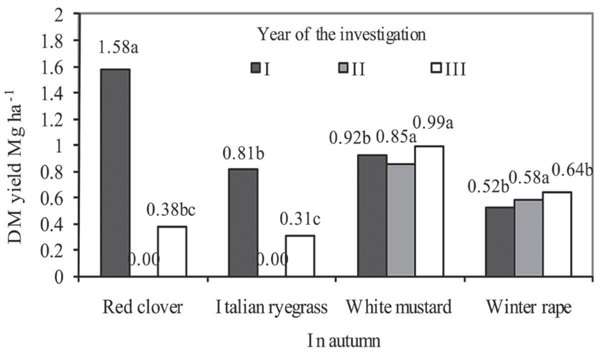
In the first year of the experiment, the biggest dry mass yield obtained in autumn was that of red clover (3.04 Mg ha^{-1}); while the yield of Italian ryegrass, white mustard and winter rape was significantly lower (from 40.8% to 57.6%) (Fig. 2). Over the next two years, under the unfavourable meteorological conditions resulting from moisture shortage in spring and summer (Table 2) the average dry mass yield of catch crops was by 47.0–86.8% and 18.1–78.3% lower, than that in the first year. Rinnofner et al. (2008) determined that catch crop biomass was about 4 times higher under moderately dry conditions than under drought conditions in summer and autumn. Under favourable meteorological conditions, catch crops can accumulate from 3.34 to 5.78 Mg ha^{-1}, under less favourable 1.25–3.75 Mg ha^{-1} DM. According to Arlauskienė and Maikštėnienė (2010), undersown catch crop – red clover produced the highest biomass during all study years. In the second and third year of the experiment, the biggest dry mass yield obtained in autumn was that of red clover (1.60 and 2.49 Mg ha^{-1} DM), while the yield of Italian ryegrass, white mustard and winter rape was significantly lower (from 44.4% to 89.4% and from 61.8% to 88.8%, respectively). Our research findings show that dry mass yield of red clover and Italian ryegrass was in close relationship with the crop density (accordingly $r = 0.91$, $y = -0.74 + 0.01x$, $P < 0.01$ and $r = 0.88$, $y = -0.17 + 0.01x$, $P < 0.01$). The productivity of white mustard depended on the amount of precipitation and hydrothermal coefficient. Significant positive correlations were identified between dry mass yield of mustard and amount of precipitation ($r = 0.81$, $y = 0.48 + 0.01x$, $P < 0.01$) and between dry mass yield of mustard and hydrothermal coefficient ($r = 0.79$, $y = 0.50 + 0.61x$, $P < 0.05$). The productivity of winter rape was influenced by the duration of vegetation period ($r = 0.89$, $y = -4.93 + 0.10x$, $P < 0.01$).

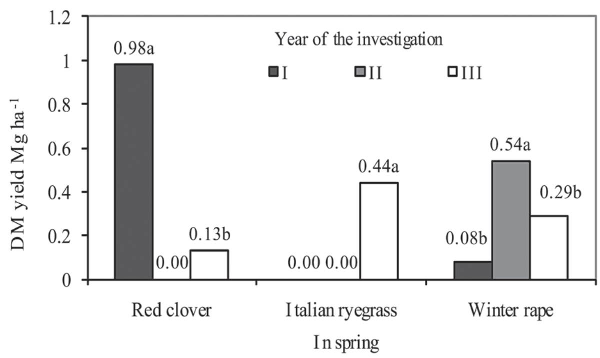
In the first year of experiment, only 19.8% of winter rape overwintered. Therefore in spring the dry mass yield of winter rape was very low (0.07 Mg ha^{-1}) (Fig. 2). In the second and third year of the experiment, the average dry mass yield of winter rape was by 7.0 and 4.6 times lower, than that at the beginning of



Note. Means not sharing a common letter (a, b, c) are significantly different ($P < 0.05$).

Figure 1. The yield of aboveground dry mass of catch crop species in the sustainable farming system





Note. Means not sharing a common letter (a, b, c) are significantly different ($P < 0.05$).

Figure 2. The yield of aboveground dry mass of catch crop species in the organic farming system

the experiment. In the first and third year, the dry mass yield of red clover was by 7.7 and 2.1 times higher, in the second year of the experiment – by 1.5 times lower than that of winter rape. In the third year of the experiment, Italian ryegrass overwintered successfully and till incorporation formed 0.45 Mg ha^{-1} dry mass yield. The productivity of red clover and winter rape was influenced by crop density. Significant positive correlations were identified between dry mass yield of red clover and crop density ($r = 0.89$, $y=0.19 + 0.001x$, $P<0.01$) and between dry mass yield of winter rape and crop density ($r = 0.77$, $y = -0.02 + 0.003x$, $P<0.05$).

Conclusions

1. Climate factors had no effect on the productivity of undersown catch crops (red clover and Italian ryegrass) in both farming systems. In the organic farming system, winter rape productivity was influenced by the duration of vegetation period ($r = 0.89$, $P < 0.01$), that of white mustard by the amount of precipitation ($r = 0.81$, $P < 0.01$) and HTC ($r = 0.79$, $P < 0.05$). In the sustainable farming system, climate factors had no effect on the productivity of post-harvest catch crops (white mustard and winter rape)

2. The productivity of red clover, Italian ryegrass and winter rape was determined by crop density (strong and very strong correlation was established) in both farming systems. In the sustainable farming system, the productivity of the post-harvest catch crop species was more stable than that of undersown catch crop species, since the latter were suppressed by the main crop (winter wheat) fertilized with mineral fertilizers and sprayed with pesticides.

3. In the sustainable farming system, the highest dry mass yield obtained in autumn was that of white mustard (0.92 Mg ha^{-1}), while the yield of red clover, Italian ryegrass and winter rape was lower 29.3%, 59.8% and 37.0%, respectively. The yield of aboveground dry mass in spring of red clover and winter rape was similar 0.37 and 0.30 Mg ha^{-1}, respectively. In the organic farming system, the highest yield in autumn was that of red clover – 2.38 Mg ha^{-1}. The yield of Italian ryegrass, white mustard and winter rape was by 4.1, 2.0, 2.4 times in autumn and winter rape by 1.8 times in spring lower than that of red clover.

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Meteorologinių veiksnių įtaka tarpinių pasėlių produktyvumui, taikant tausojamąją ir ekologinę žemdirbystę

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Santrauka

Tyrimai vykdyti trejus metus tausojamosios žemdirbystės sąlygomis Lietuvos žemės ūkio universiteto Bandymų stotyje ir ekologinės žemdirbystės sąlygomis Kazliškių ekologiniame ūkyje. Tyrimų tikslas – nustatyti klimato veiksnių įtaką tarpinių pasėlių skirtingų rūšių (*Trifolium pratense* L., *Lolium multiflorum* Lam., *Sinapis alba* L., *Brassica napus* L.) produktyvumui taikant tausojamąją ir ekologinę žemdirbystę. Nustatyta, kad klimato veiksniai neturėjo įtakos įsėlinių tarpinių pasėlių (raudonųjų dobilų ir gausiažiedžių svidrių) produktyvumui taikant abi žemdirbystės sistemas. Ekologinės žemdirbystės sąlygomis žieminių rapsų derlingumas priklausė nuo vegetacijos trukmės (r = 0,89, P < 0.01), o baltųjų garstyčių – nuo kritulių kiekio (r = 0,81, P < 0,01) ir hidroterminio koeficiento (r = 0,79, P < 0,05). Tausojamosios žemdirbystės sąlygomis klimato veiksniai neturėjo įtakos posėlinių tarpinių pasėlių (baltųjų garstyčių ir žieminių rapsų) derlingumui. Raudonųjų dobilų, gausiažiedžių svidrių ir žieminių rapsų derlingumą lėmė pasėlio tankumas (nustatyti stiprūs ir labai stiprūs koreliaciniai ryšiai). Tausojamosios žemdirbystės sąlygomis posėlinio tarpinio pasėlio augalų rūšių derlingumas buvo stabilesnis nei įsėlinio, nes įsėliniai augalai buvo nustelbti mineralinėmis trąšomis tręšto ir pesticidais purkšto antsėlio (kviečių). Taikant šį žemės dirbimą rudenį gautas didžiausias baltųjų garstyčių antžeminės masės derlius (0,92 Mg ha^{-1} absoliučiai sausų medžiagų), o raudonųjų dobilų, gausiažiedžių svidrių, žieminių rapsų – mažesnis, atitinkamai 29,3, 59,8 ir 37,0 %. Pavasarį atžėlusių raudonųjų dobilų ir žieminių rapsų antžeminės masės derlius buvo panašus – atitinkamai 0,37 ir 0,30 Mg ha^{-1} absoliučiai sausų medžiagų. Taikant ekologinę žemdirbystę, rudenį gautas didžiausias raudonųjų dobilų antžeminės masės derlius (2,38 Mg ha^{-1} absoliučiai sausų medžiagų). Gausiažiedžių svidrių, baltųjų garstyčių ir žieminių rapsų derlius rudenį buvo atitinkamai 4,1, 2,0 ir 2,4 karto, o žieminių rapsų pavasarį – 1,8 karto mažesnis nei raudonųjų dobilų.

Reikšminiai žodžiai: tarpiniai pasėliai, produktyvumas, klimato veiksniai, tausojamoji žemdirbystė, ekologinė žemdirbystė.