

LAGGED EFFECTS OF WINTER CATCH CROPS FOLLOWED BY SWEET CORN (*ZEA MAYS* L. VAR. *SACCHARATA* KORN.) AND SUBSEQUENTLY SPRING BROCCOLI (*BRASSICA OLERACEA* L. VAR. *ITALICA* PLENCK)

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Abstract. This paper deals with lagged effects of winter catch crops on the growth, yield, and quality of spring broccoli. In the first year of the experiment (2008-2010), hairy vetch (VV), white clover (TR), winter rye (SC), and Italian ryegrass (LM) were sown as winter catch crops. In the next spring (2009-2011) they were ploughed into the soil, and sweet corn was grown on plots with incorporated catch crops. To other sweet corn plots farmyard manure was applied at a dose of 30 t·ha⁻¹. Finally, sweet corn was followed by the Loreto F₁ and Milady F₁ varieties of broccoli in 2010-2012. The effect of the catch crops was compared with the control plants (with no organic fertilizer) and that of the effect of manure. Manure application resulted in the highest broccoli yield. However, a statistically similar marketable yield of curds was also recorded on plots with the incorporated catch crops of hairy vetch, white clover, and winter rye. Grown in the second year after the incorporation of SC, VV, and manure they were richer in protein, and those grown after VV and TR contained more total sugars than the control plants. The largest concentration of P was found in broccoli grown after VV and TR as catch crops, K in plants following VV and manure, and Mg in those following VV. It was found that hairy vetch, white clover, and winter rye could be used as organic fertilizers, alternatives for manure. Their growth promoting effect extends to the second year after their incorporation.

Keywords: *FYM, green manure, nutritional value, organic fertilisation, yield*

Introduction

Broccoli (*Brassica oleracea* var. *italica*) is an important vegetable grown worldwide. The plant originates from the Mediterranean region and belongs to the *Brassicaceae* family. Considered to be a valuable source of vitamins, antioxidants, glucosinolates, and other compounds with proven anticancer activity, it is tasty and more nutritious than any other vegetable of the same kind (Parente et al., 2013). Today, the broccoli market is growing steadily all over the world since consumers find its curds an important component of a healthy diet. Over the last 35 years, the consumption of fresh broccoli has increased so much that now it is the 11th most consumed fresh vegetable.

The worldwide production of broccoli (and cauliflower) is 26.5 million tonnes. The main producer is China, with a 40% share in the volume of global production. The top 10 countries producing fresh broccoli are China, India, USA, Spain, Mexico, Italy, France, Poland, Bangladesh and Turkey (FAOSTAT, 2019). In Poland approx. 15% the total European broccoli is produced, but the largest producer in Europe is Spain, with a share of 37%. Due to the of growing demand for high-quality products and an increase in environmental awareness, agricultural producers use more environmentally friendly production methods. One of the priorities is enriching the soil with organic matter, which

restores soil fertility and increases its buffer properties. The production of fertilisers of animal origin across Europe is insufficient, and, therefore, increasing attention is paid again to green fertilisers of plant origin (Talgre et al., 2012; Fekete and Pepó, 2018; Thavarajah et al., 2019). Green manure should become a permanent element of improving soil fertility in the integrated and organic farming systems. It is a factor that alleviates the negative effect of farming intensification, excessive soil compaction, and one-sided mineral fertilization (Kristensen and Thorup-Kristensen, 2004; Rogers et al., 2004; Choi et al., 2014). Catch crops also have a many-sided effect on biological, physical and chemical soil properties. They reduce erosion, build soil organic matter, and positively influence soil organisms (Snapp et al., 2005; Reddy, 2016). Catch crops protect the forms of nutrients easily available for plants from leaching into deeper layers of the soil profile and into groundwater. During the process of catch crop mineralization, biomass N is gradually released and becomes available for the subsequent plants (Vos and van der Putten, 2001; Reddy, 2016; Iivonen et al., 2017).

Some studies have shown that the use of green fertilizers allows not only the achievement satisfactory yields of subsequent vegetable plants, but also improves their quality and nutritional value (Jabłońska-Ceglarek and Rosa, 2003; Adamczewska-Sowińska and Kołota, 2008; Zhang et al., 2010).

The purpose of this research was to determine the effect of winter catch crops on the size and quality of the broccoli yield.

Material and Methods

Experimental site

A field experiment was carried out from 2008 to 2012 at the Experimental Farm of the Siedlce University of Natural Sciences and Humanities, located in central eastern Poland (52°03'N, 22°33'E) (*Figure 1*). The soil was classified as Luvisol (IUSS, 2015), with the average organic carbon content of 0.99%, the humus layer reaching a depth of 30–40 cm, and pH_{KCl} of 6.2. Total macronutrient content in air dried matter amounted to 61 mg of N (NO₃ + NH₄), 63 mg of P, 73 mg of K, 31 mg of Mg, and 255 mg of Ca per 1 dm³.

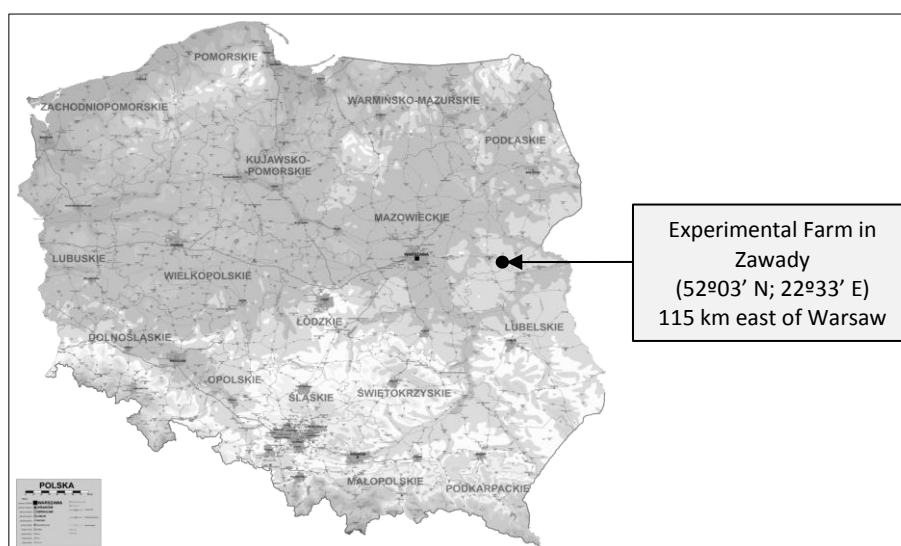


Figure 1. Location of the Experimental Farm

Experimental design

The experiment was established in a split-block design with three replicates, and it included two factors: factor I – broccoli cultivar, factor II – organic manure (*Table 1*). In the autumn each year between 2008 and 2010 catch crops were sown. They were incorporated each spring between 2009 and 2011 and followed by sweet corn. At the same time, farmyard manure at a dose of 30 t·ha⁻¹ was applied prior to planting sweet corn on other plots. Broccoli was grown between 2010 and 2012, each time in the second year after the incorporation of winter catch crops and manure. Detailed dates and succession of crops are listed in *Table 2*. The content of minerals in the catch crops and in the farmyard manure is presented in *Table 3*. The direct impact of the incorporated green fertilizers on the growth, yields and nutritional value of sweet corn has been described in previous publications (Rosa, 2014, 2015).

Table 1. Factors of the experiment

Broccoli cultivars:		
Factor I	Loreto F ₁	This cultivar is grown for summer and autumn harvests, with the first fully grown curds after 65 days. The plant is tall, strong, with leaves erected, producing large curds with a mass reaching 750 g. It is highly resistant to downy mildew and wet rot. Seminis Vegetable Seeds, Bayer Group.
	Milady F ₁	This cultivar is especially recommended for early-spring cultivation. Curds are ready for harvesting about 60 days after seedling planting. It produces curds of similar sizes, weighing more than 400 g. Plants do not form hollowed stems, and they are resistant to downy mildew and wet rot. Seminis Vegetable Seeds, Bayer Group.
Organic fertilizer:		
Factor II	Control	Without organic fertilizer.
	FYM	Farmyard manure applied at a rate of 30 t·ha ⁻¹ , incorporated in early May 2009-2011.
	VV	Hairy vetch (<i>Vicia villosa</i> Roth.) winter catch crop – seeds sown in early September at a rate of 70 kg·ha ⁻¹ , incorporated in early May 2009-2011.
	TR	White clover (<i>Trifolium repens</i> L.) winter catch crop – seeds sown in early September at a rate of 20 kg·ha ⁻¹ , incorporated in early May 2009-2011.
	SC	Winter rye (<i>Secale cereale</i> L.) winter catch crop – seeds sown in early September at a rate of 180 kg·ha ⁻¹ , incorporated in early May 2009-2011.
	LM	Italian ryegrass (<i>Lolium multiflorum</i> L.) winter catch crops – seeds sown in early September at a rate of 35 kg·ha ⁻¹ , incorporated in early May 2009-2011.

Table 2. Chronology of field operations

Winter catch crops (2008-2011)	Catch crops sowing	8 September 2008, 10 September 2009, 9 September 2010
↓	Catch crops incorporated (Farmyard manure incorporated)	7 May 2009, 11 May 2010, 5 May 2011
Sweet corn (2009-2011)	Sweet corn sowing	14 May 2009, 24 May 2010, 11 May 2011
↓	Sweet corn harvest	8 September 2009, 23 August 2010, 3 September 2011
Broccoli (2010-2012)	Broccoli sowing	15 March 2010, 17 March 2011, 14 March 2012
	Broccoli planting	19 April 2010, 15 April 2011, 20 April 2012
	Broccoli harvest	14 June 2010, 16 June 2011, 11 June 2012

Table 3. The quantity of fresh and dry matter and the amount of macronutrients incorporated with farmyard manure and catch crops

Kind of organic manure / catch crops	Year of incorporation	Fresh matter (t·ha ⁻¹)	Dry matter (t·ha ⁻¹)	N	P	K	Ca	Mg
				Accumulation (kg·ha ⁻¹)				
Farmyard manure (FYM)	2009	30.0 ^a	7.1 ^a	90.8 ^a	46.3 ^a	126.4 ^a	58.1 ^a	32.8 ^a
	2010	30.0 ^a	7.6 ^a	106.4 ^a	49.7 ^a	140.0 ^a	70.1 ^a	39.1 ^a
	2011	30.0 ^a	8.1 ^a	120.7 ^a	53.1 ^a	133.2 ^a	64.1 ^a	45.4 ^a
	Mean	30.0 ^{CD}	7.6 ^B	106.0 ^B	49.7 ^B	133.2 ^B	64.1 ^B	39.1 ^C
Hairy vetch (VV)	2009	18.5 ^a	2.9 ^a	105.4 ^a	11.4 ^a	38.7 ^a	26.4 ^a	5.6 ^a
	2010	15.7 ^a	2.6 ^a	92.9 ^a	8.9 ^a	36.7 ^a	23.8 ^a	6.1 ^a
	2011	20.0 ^a	3.4 ^a	127.7 ^a	14.3 ^a	46.0 ^a	29.0 ^a	6.8 ^a
	Mean	18.1 ^B	3.0 ^A	108.7 ^B	11.5 ^A	40.5 ^A	26.4 ^A	6.2 ^A
White clover (TR)	2009	11.8 ^a	2.1 ^a	56.0 ^a	9.9 ^a	52.7 ^a	22.0 ^a	6.0 ^a
	2010	12.4 ^a	2.4 ^a	84.8 ^a	10.4 ^a	62.7 ^a	25.1 ^a	7.4 ^a
	2011	10.6 ^a	1.9 ^a	52.1 ^a	8.6 ^a	47.2 ^a	20.0 ^a	5.3 ^a
	Mean	11.6 ^A	2.1 ^A	64.3 ^A	9.6 ^A	54.2 ^A	22.4 ^A	6.2 ^A
Winter rye (SC)	2009	36.0 ^a	8.7 ^a	167.5 ^b	60.5 ^a	182.6 ^a	61.3 ^a	30.6 ^a
	2010	35.1 ^a	6.9 ^a	120.7 ^{ab}	54.4 ^a	150.7 ^a	55.2 ^a	25.2 ^a
	2011	35.3 ^a	6.4 ^a	115.9 ^a	50.1 ^a	128.7 ^a	49.9 ^a	23.7 ^a
	Mean	35.5 ^D	7.3 ^B	134.7 ^C	55.0 ^B	154.0 ^B	55.5 ^B	26.5 ^B
Italian ryegrass (LM)	2009	17.8 ^a	4.2 ^b	72.5 ^a	20.5 ^a	165.5 ^b	24.1 ^a	13.3 ^a
	2010	9.5 ^a	1.9 ^a	31.2 ^a	10.9 ^a	99.4 ^a	11.7 ^a	7.2 ^a
	2011	12.4 ^a	2.5 ^{ab}	43.8 ^a	13.5 ^a	128.7 ^{ab}	18.4 ^a	7.9 ^a
	Mean	13.2 ^{AB}	2.9 ^A	49.2 ^A	15.0 ^A	131.2 ^B	18.1 ^A	9.5 ^A

Means followed by different lowercase and uppercase letters in columns differ significantly at $p \leq 0.05$

Seedling preparation

Broccoli seedlings were grown in a non-heated greenhouse. Seeds were sown in the successive growing seasons on 15, 17 and 14 March to multi-trays with a size of 400 × 600 mm and 54 cells with a diameter of 54 mm. The Aura substrate produced by Hollas - Greenyard Horticulture Poland Ltd. was used for the production of seedlings. It was made of de-acidified ‘highmoor’ peat with 5.5-6.5 pH and salinity not greater than 2 g of NaCl per litre. The substrate was enriched with mineral fertilisers (NPK: 14-16-18%) and Mg (5%). On average nutrient content in the substrate was as follows (mg·dm⁻³): 238 NO₃-N, 18 NH₄-N, 70 P, 207 K, 1016 Ca, and 158 Mg.

Field work

The crop preceding broccoli was sweet corn (*Zea mays* L. var. *Saccharata*), to which organic treatment was applied (organic fertilisers in the form of winter crops and farm manure according to the doses in *Table 1*) with mineral fertilisers (pre-sowing treatment: 60 kg N, 50 kg P₂O₅, 180 kg K₂O per 1 ha + top dressing of 60 kg N·ha⁻¹). After harvesting the cobs, sweet corn plants were cut down and removed from the field. In the autumn the field was ploughed, and in the spring, two weeks before planting seedlings, disc harrowing was used. After that, mineral fertilizers were applied up to the optimal level for broccoli: 205 kg N, 145 kg P₂O₅, 275 kg K₂O per ha. Plants were planted in the successive study years on the 19, 15 and 20 of April, at a spacing of 50 × 50 cm. The area of a plot (unit) was 8 m² (2 m × 4 m), with 32 plants in each. The area of the whole field together with paths between experimental combinations and replicates was 750 m². After broccoli were planting, they were covered with the polypropylene fibre Pegas Agro 17UV (Rybnik, Poland). The cover was removed after three weeks. Then 50 kg of N per hectare was applied (top dressing).

Sample collection and laboratory analysis

Broccoli was harvested by hand on 14 June in 2010, 16 June in 2011, and 11 June in 2012. The area of each plot to be harvested was 6 m² (12 plants). The marketable yield, weight of the marketable curd, length of the curd arc, and the stalk diameter were determined after the harvest. From each plot a curd sample was collected (four randomly selected curds) for chemical analysis to determine: dry matter content by drying to the constant weight at 105°C (Polish Standard PN-EN 12145, 2001); protein content with the Kjeldahl method, using the 6.25 factor (AOAC, 1984); L-ascorbic acid content with the Tillmans method (PN-A-04019, 1998); total sugars content with the Luff-Schoorl method (EU, 2009). In 2011 and 2012, the content of macronutrients (P, K, Ca and Mg) in broccoli was also determined. P content was measured by colorimetry with the SPEKOL 221 spectrophotometer (Carl Zeiss AG, Germany). The content of K and Ca was determined with the FLAPHO 41 flame photometer (Carl Zeiss AG, Germany). The content of Mg was determined with the SOLAR 929 absorption spectrophotometer (ATI Unicam Ltd., UK). In 2009-2011, the quantity of fresh and dry matter of catch crops and the content of accumulated macronutrients were determined.

Statistical analysis

The results were statistically processed with ANOVA for the split-block design. The significance of differences was determined with Tukey's test at the significance level of $P \leq 0.05$. All the calculations were performed with the Statistica software (version 10, Statsoft, USA).

Weather conditions

The basic weather conditions of the experimental area in individual growing seasons are presented in *Table 4*. Years 2010 and 2012 were characterized by similar average temperatures during the growing period and favourable precipitation distribution for the growth and development of broccoli. The least favourable conditions were in 2011, with higher mean air temperatures than in the other growing seasons, but with insufficient quantity of precipitation.

Table 4. Weather condition in the experiment area, 2010–2012 (Zawady Meteorological Station, Poland)

Month	2010		2011		2012	
	T (°C)	P (mm)	T (°C)	P (mm)	T (°C)	P (mm)
April	8.9	10.7	10.1	31.0	8.9	29.9
May	14.0	93.2	13.4	36.1	14.6	53.4
June	17.4	62.6	18.1	39.1	16.3	76.2
Mean	13.4	-	13.9	-	13.3	-
Total	-	166.5	-	106.2	-	159.5

T – average temperature, P – sum of precipitation

Results and Discussion

The quantity of incorporated fresh and dry matter and macronutrient content in catch crops varied across the years of research (*Table 3*). On average, between 2009 and 2011, the highest yields of fresh matter were recorded for winter rye (35.5 t·ha⁻¹), and the lowest

for white clover and Italian ryegrass. The amount of dry matter (DM) in incorporated winter rye ($7.3 \text{ t}\cdot\text{ha}^{-1}$) was similar to the amount of DM in the incorporated farmyard manure (FYM) with an average of $7.6 \text{ t}\cdot\text{ha}^{-1}$ DM. The least DM was produced by white clover (TR). O'Reilly et al. (2011) and Dolijanovic et al. (2012) report that the biomass produced by the catch crops of rye and hairy vetch can correspond even to $30 \text{ t}\cdot\text{ha}^{-1}$ FYM.

The highest amount of N was in incorporated winter rye (SC). Its amounts accumulated by hairy vetch (VV) catch crops were similar, whereas in TR and LM the content of this macronutrient was significantly lower than in FYM. The quantity of P in SC was similar to that of FYM. Non-leguminous catch crops and FYM contained significantly more K than leguminous catch crops. SC accumulated significantly more Ca and Mg than VV, TR, and LM. Incorporated FYM introduced the most Ca and Mg into the soil. The total amount of macronutrients accumulated by the catch crops constituted 40-122% of the quantity introduced with $30 \text{ t}\cdot\text{ha}^{-1}$ FYM. Thorup-Kristensen (2001) and Kramberger et al. (2009) reported that rye was one of the most effective catch crop plants recovering nutrients from deeper soil strata. The quantity of macronutrients in catch crops depends on a number of factors, including plant species, soil type, climatic conditions, and timing of cultivation. N is the element which exerts the greatest effect on the yield. The amounts of N in hairy vetch may range from 52 to $227 \text{ kg}\cdot\text{ha}^{-1}$ (Caporali et al., 2004; Franczuk, 2006; Salmerón et al., 2011). White clover leave soil in good condition, fixing from 100 to $240 \text{ N}\cdot\text{ha}^{-1}$ (Kärner and Kärner, 1996; Kramberger et al., 2014). In turn, rye may enrich the soil with $40\text{-}143 \text{ kg}\cdot\text{ha}^{-1}$ (Thorup-Kristensen, 2001; Franczuk, 2006).

Weather conditions in the successive growing seasons had a significant influence on the marketable yield of broccoli curds, mass of the marketable curd, and biological parameters (Tables 5–6). The highest marketable yield ($26.3 \text{ t}\cdot\text{ha}^{-1}$) and the highest weight of the curd (696.3 g) was in 2010, the most favourable for broccoli growth (Table 5). Both broccoli cultivars tested in the experiment produced similar yields, but the Loreto F₁ cultivar developed slightly bigger curds than Milady F₁. Statistical analysis of the results showed a significant effect of the types of organic fertilizer on broccoli yields. On average, across the growing seasons the largest marketable yield of curds ($27.9 \text{ t}\cdot\text{ha}^{-1}$) was on plots where in the previous year manure (FYM) was applied to sweet corn. A similar yield of curds was recorded in plants grown after incorporated hairy vetch (VV), white clover (TR), and winter rye (SC). Compared with control plants the commercial yield of broccoli from the FYM and VV plots was greater by 64% and 42%, respectively, with these differences being statistically significant. An increase in the yield of broccoli grown after the other catch crops was 8-34% greater than in the control plot, but the results were not statistically significant.

The largest broccoli curds (725.9 g) were harvested on plots where manure was applied to sweet corn (Table 5) in the previous year. A weight similar to the above, with a borderline statistical significant difference, was recorded for broccoli plants grown after VV, TR, and SC incorporation. In addition, broccoli preceded by FYM, VV, TR, and SC in crop rotation developed curds of a substantially greater weight than the control plants. de Freitas et al. (2011), using green manure (GM) of legume plants at doses of 5.0 and $2.5 \text{ t}\cdot\text{ha}^{-1}$ DM before planting broccoli, obtained curds with a mass greater by 180 and 120% than those in the control plot (without fertilization). However, production effects of green manure were worse than those obtained on plots with intensive mineral fertilizer treatment. An increase in the production of broccoli after GM was also recorded by Diniz et al. (2015), who observed that the yield of curds increased with an increase in a dose of GM biomass. Peralta-Antonio et al. (2019) suggest that on soils with average fertility,

GM used on its own is insufficient to significantly affect the growth and yield of broccoli. Combined use of mineral fertilizer and GM is necessary, which is a viable option to reduce the amounts of the former. Production results of such combined application are similar to those obtained with high doses of mineral fertilizers.

Table 5. Effect of winter catch crop on the yield of broccoli and the weight of curds

Organic manure	Year			Broccoli cultivar		Mean
	2010	2011	2012	Loreto F ₁	Milady F ₁	
Marketable yield (t·ha ⁻¹)						
Control	17.5	18.4	15.0	16.5	17.5	17.0 ^a
FYM	31.4	25.8	26.5	27.2	28.7	27.9 ^c
VV	30.1	19.2	23.1	26.8	21.5	24.1 ^{bc}
TR	30.9	16.9	20.7	22.6	23.1	22.8 ^{abc}
SC	26.9	20.0	19.0	22.9	20.9	21.9 ^{abc}
LM	21.0	18.0	16.1	18.8	17.9	18.4 ^{ab}
Mean	26.3 ^B	19.7 ^A	20.1 ^A	22.4	21.6	22.0
<i>HSD</i> _{0.05} : year = 3.8, broccoli cultivar = NS, organic manuring = 6.8, interactions = NS						
Weight of marketable curd (g)						
Control	481.1	512.0	470.3	464.0 ^a	511.5 ^a	487.8 ^a
FYM	795.3	678.6	703.8	694.6 ^{cd}	757.3 ^b	725.9 ^c
VV	796.3	550.9	639.2	742.7 ^d	581.6 ^a	662.2 ^{bc}
TR	813.8	523.1	564.9	638.7 ^{bcd}	629.2 ^a	633.9 ^{bc}
SC	698.2	622.3	503.9	626.0 ^{bc}	590.2 ^a	608.1 ^{abc}
LM	592.9	543.6	470.7	551.8 ^{ab}	519.6 ^a	535.7 ^{ab}
Mean	696.3 ^B	571.7 ^A	558.8 ^A	619.6	598.2	608.9
<i>HSD</i> _{0.05} : year = 69.8, broccoli cultivar = NS, organic manuring = 136.4, broccoli cultivar × organic manuring = 17.7, other interactions = NS						

Means followed by different lowercase letters in columns and different uppercase letters in rows differ significantly at $p \leq 0.05$; FYM – farmyard manure, VV – hairy vetch, TR – white clover, SC – winter rye, LM – Italian ryegrass; NS – not significant

In the present experiment significant interaction of broccoli cultivars with organic fertilisers was recorded. The Loreto F₁ cultivar grown after VV (742.7 g) produced the biggest curds, with similar results recorded when it followed incorporated FYM or when it followed TR and SC. However, when it was grown after FYM incorporation, the Milady F₁ cultivar produced significantly the largest curds (757.3 g).

Hairy vetch, white clover and winter rye cultivated as winter catch crops may successfully replace farmyard manure. Many researchers point to their short-term and long-term effects on the yields of subsequent crops (Salmerón et al., 2011; Choi et al., 2014; Zandvakili et al., 2017; Makarewicz et al., 2018; Thavarajah et al., 2019). However, the yield is not the only reason why catch crops should be included into crop rotation. They should be planted due to ecological reasons, such as reduction of weed infestation and herbicide use, limitation of soil erosion, recovery of nutrients from deeper soil strata and protection against them being leached out into groundwater, an increase in the amount of organic matter, as well as a positive reaction of micro and mesofauna in the soil (Hartwig and Ammon, 2002; Snapp et al., 2005; Reddy, 2016).

In 2010 broccoli plants had stems with a larger diameter than those grown in 2012. Plants grown in 2010 and 2012 had a longer curd arc than in 2011 (Table 6). Organic

fertilisers also differentiated the biometric parameters of broccoli curds. Across the growing seasons, the largest stem diameter and the longest curd arc were recorded in broccoli grown on plots with manure applied to sweet corn the previous year (4.02 cm and 33.7 cm, respectively). Similar values were also found in plants grown after VV. As an average for all treatments the Loreto F₁ cultivar developed longer curd arcs than the Milady F₁ cultivar.

Table 6. Effect of winter catch crop on broccoli curd biological parameters

Organic manure	Year			Broccoli cultivar		Mean
	2010	2011	2012	Loreto F ₁	Milady F ₁	
Stalk diameter (cm)						
Control	3.68 ^{ab}	3.85 ^{bc}	3.19	3.49 ^a	3.65 ^c	3.57 ^a
FYM	4.14 ^b	4.31 ^c	3.60	3.98 ^c	4.06 ^d	4.02 ^b
VV	3.86 ^{ab}	3.68 ^{abc}	3.56	3.88 ^{bc}	3.52 ^{abc}	3.70 ^{ab}
TR	3.43 ^a	3.09 ^a	3.45	3.45 ^a	3.19 ^a	3.32 ^a
SC	3.44 ^a	3.18 ^a	3.44	3.43 ^a	3.28 ^{ab}	3.35 ^a
LM	3.61 ^{ab}	3.57 ^{ab}	3.57	3.56 ^{ab}	3.61 ^{bc}	3.58 ^a
Mean	3.69 ^B	3.61 ^{AB}	3.47 ^A	3.63	3.55	3.59
<i>HSD</i> _{0.05} : year = 0.17, broccoli cultivar = NS, organic manuring = 0.39, year × organic manuring = 0.66, broccoli cultivar × organic manuring = 0.35, other interactions = NS						
Curd circumference length (cm)						
Control	34.05	24.77	31.07	31.01	28.91	29.96 ^a
FYM	38.15	28.88	34.03	35.69	31.69	33.69 ^b
VV	37.32	25.95	36.78	36.06	30.63	33.34 ^b
TR	32.40	22.68	33.13	30.98	27.83	29.40 ^a
SC	31.95	21.05	32.22	29.63	27.18	28.41 ^a
LM	32.17	22.18	32.25	29.29	28.44	28.87 ^a
Mean	34.34 ^B	24.25 ^A	33.25 ^B	32.11 ^B	29.11 ^A	30.61
<i>HSD</i> _{0.05} : year = 1.20, broccoli cultivar = 0.78, organic manuring = 2.77, interactions = NS						

Means followed by different lowercase letters in columns and different uppercase letters in rows differ significantly at $p \leq 0.05$; FYM – farmyard manure, VV – hairy vetch, TR – white clover, SC – winter rye, LM – Italian ryegrass; NS – not significant

The average content of dry matter in broccoli curds was 8.51%, with protein constituting 4.17% FM (fresh matter), ascorbic acid 71.76 mg·100g⁻¹ FM, and total sugars 2.78 g·100g⁻¹ FM (Table 7). Chemical composition of vegetables is genetically determined, but it is modified by factors affecting the plant during its growth (Lee and Kadar, 2000). In the present studies, the effects of weather conditions and organic fertilizers on the content of minerals and nutrients in broccoli were significant. The plants produced the driest matter and total sugars in 2012, protein in 2011, and ascorbic acid in 2011 and 2012. The smallest amounts of dry matter and ascorbic acid were in broccoli grown in 2010, protein in 2012, and total sugars in 2011.

Broccoli plants grown after sweet corn treated with incorporated SC, VV, and manure were significantly richer in protein than those grown in control. The difference was 0.24-0.32%. Broccoli grown after SC contained more protein than after TR and LM. The highest amounts of total N (Table 3) were recorded in plants grown after manure (FYM), winter rye (SC), and hairy vetch (VV). After the mineralization of organic matter, taking place in the first and second years after catch crop incorporation, N became available to

broccoli. Plants used it for tissue building and protein synthesis. In addition, broccoli plants grown on plots with incorporated TR and VV contained significantly more total sugars than those grown in control, respectively, by 0.21 and 0.19 g·100g⁻¹ FM. According to Worthington (2001) and Talgre et al. (2012), an increase in available N content stimulates protein production, which may explain increased protein content in plants following legume catch crops, those additional sources of available N living in symbiosis with N-fixing bacteria. Increased content of protein and vitamin C was earlier recorded by Jabłońska-Ceglarek and Rosa (2003), who used spring-incorporated green manures.

Table 7. The content of selected components of nutritive value of broccoli

Treatment	Dry matter (%)	Protein (% FM)	Ascorbic acid (mg·100g ⁻¹ FM)	Total sugars (g·100g ⁻¹ FM)
Years				
2010	7.58 ^a	4.15 ^a	69.81 ^a	2.81 ^b
2011	8.56 ^b	4.30 ^b	72.40 ^b	2.62 ^a
2012	9.39 ^c	4.05 ^a	73.08 ^b	2.92 ^c
Broccoli cultivar				
Loreto F ₁	8.45	4.13 ^a	72.44 ^b	2.84 ^b
Milady F ₁	8.57	4.21 ^b	71.08 ^a	2.72 ^a
Organic manure				
Control	8.28	4.00 ^a	71.79	2.66 ^a
FYM	8.64	4.24 ^{bc}	73.02	2.80 ^{ab}
VV	8.58	4.24 ^{bc}	73.19	2.85 ^b
TR	8.53	4.10 ^{ab}	70.22	2.87 ^b
SC	8.69	4.32 ^c	70.68	2.79 ^{ab}
LM	8.32	4.10 ^{ab}	71.66	2.73 ^{ab}
Mean	8.51	4.17	71.76	2.78

*HSD*_{0.05} for dry matter: years = 0.79, broccoli cultivar = NS, organic manure = NS;

*HSD*_{0.05} for protein: years = 0.11, broccoli cultivar = 0.07, organic manure = 0.16;

*HSD*_{0.05} for ascorbic acid: years = 2.02, broccoli cultivar = 1.32, organic manure = NS;

*HSD*_{0.05} for total sugars: years = 0.10, broccoli cultivar = 0.07, organic manure = 0.17.

Means followed by different letters in columns differ significantly at $p \leq 0.05$; FYM – farmyard manure, VV – hairy vetch, TR – white clover, SC – winter rye, LM – Italian ryegrass; FM – fresh matter; NS – not significant

The content of the nutrients was also dependent on the broccoli cultivar. The Loreto F₁ cultivar contained more ascorbic acid and total sugars, but less protein than Milady F₁.

Between 2011 and 2012 concentrations of P, K, Ca, and Mg were determined in broccoli curds. In 2011 plants contained significantly less P and Ca, but significantly more Mg than in 2012 (Table 8). Both varieties contained similar amounts of P, K, and Ca, while the Loreto F₁ cultivar contained significantly more Mg. The catch crops and manure, both incorporated before sweet corn, had a significant impact on the concentrations of P, K and Mg in broccoli. The most P was recorded in broccoli grown after VV and TR as winter catch crops, significantly more than in control plants and more than plants on plots preceded by FYM and LM. Significantly the most K was recorded in broccoli grown after FYM and VV. Broccoli plants grown after VV were also the richest in Mg. The approximate amount of this element was recorded in broccoli grown after incorporated manure and TR.

Table 8. Concentrations of macronutrients in broccoli

Treatment	P	K	Ca	Mg
	(g·kg ⁻¹ DM)			
Years				
2011	4.53 ^a	23.0	3.33 ^a	2.16 ^b
2012	5.23 ^b	22.8	3.37 ^b	2.01 ^a
Broccoli cultivar				
Loreto F ₁	4.89	22.9	3.34	2.11 ^b
Milady F ₁	4.87	22.8	3.36	2.06 ^a
Organic manure				
Control	4.36 ^a	22.4 ^a	3.29	1.99 ^a
FYM	4.62 ^{ab}	23.5 ^b	3.38	2.15 ^{bc}
VV	5.39 ^c	23.4 ^b	3.37	2.20 ^c
TR	5.25 ^c	22.8 ^a	3.36	2.13 ^{bc}
SC	4.91 ^{bc}	22.5 ^a	3.32	2.06 ^{ab}
LM	4.76 ^{ab}	22.6 ^a	3.38	1.99 ^a
Mean	4.88	22.9	3.35	2.09

*HSD*_{0.05} for P: years = 0.08, broccoli cultivar = NS, organic manure = 0.49;

*HSD*_{0.05} for K: years = NS, broccoli cultivar = NS, organic manure = 0.5;

*HSD*_{0.05} for Ca: years = 0.02, broccoli cultivar = NS, organic manure = NS;

*HSD*_{0.05} for Mg: years = 0.04, broccoli cultivar = 0.04, organic manure = 0.09.

Means followed by different letters in columns differ significantly at $p \leq 0.05$; FYM – farmyard manure, VV – hairy vetch, TR – white clover, SC – winter rye, LM – Italian ryegrass; DM – dry matter; NS – not significant

Conclusions

1. The effect of winter catch crops ploughed into the soil, like *Vicia villosa* Roth., *Trifolium repens* L. and *Secale cereale* L. on the broccoli yield was statistically similar to that of manure applied at a dose of 30 t·ha⁻¹. Among the above catch crops, hairy vetch affected the yield of subsequent crops the most.
2. Organic fertilisers applied to the crops preceding broccoli affected its content of protein and sugars. A significant increase in protein content in relation to control was observed in broccoli plants grown after farmyard manure and incorporated hairy vetch and winter rye treatments, and in total sugars after hairy vetch and white clover.
3. The largest P concentration was in broccoli grown after hairy vetch and white clover, while the largest amounts of K was after farmyard manure application and after hairy vetch incorporation, and Mg when broccoli was grown after hairy vetch.
4. Broccoli varieties produced similar yields. The Loreto F₁ cultivar contained more ascorbic acid, total sugars and Mg, but less protein than the Milady F₁ cv.
5. It was found that in horticulture, winter catch crops like hairy vetch, white clover and winter rye can be an alternative for manure, an organic fertiliser increasingly more difficult to obtain. The beneficial effect of those crops, similar to the effect of manure, on the yield of following crops was also evident in the second year. They can be successfully used in the following sequence: winter catch crops – sweet corn – broccoli.
6. The results of the research allowed to issue practical recommendations to farmers on the use of these catch crops in the cultivation of sweet corn and broccoli.
7. Research on other plants and their mixtures is still necessary to replace FYM and to reduce mineral fertilisation in vegetable cultivation.

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