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Morphological-developmental reaction and productivity of plants and canopy of semileafless pea (*Pisum sativum* L.) after seed vaccination with *Rhizobium* and foliar micronutrient fertilization

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Summary

The determinants of semileafless peas (*Pisum sativum* L., cv. Tarchalska) crop productivity were studied during two vegetative seasons: cool 2010 and warm 2011 in south part of Poland (Modzurów 50°09'N 18°07'E; 274 m. a.s.l.. Peas was treated either with seed vaccine (Nitragina^{TM}) containing *Rhizobium* bacteria or foliar micronutrient fertilizer (Photrel^{TM}) or both of them. The range of peas response to treatments included biometrical measurements and also the measurements of vegetation indices namely, green area index (GAI), normalized difference vegetation index (NDVI) and relative chlorophyll content (SPAD), carried out in the specific stages of development, which for the compared objects were generally insignificant. In the warmer growing season, pea plants grew better, what resulted in a very high yield of seeds per plant, determined by a greater number of large seeds. It was shown that the length and weight of pea pod and the number of seeds formed in the pod depends on its position on the particular node. The longest pods, characterized by the greatest weight and number of seeds, developed on the lower nodes: 1st and 2nd one. The pea pods forming on higher nodes, from the 3rd, had reduced number of fruits and the weight of a single seed. The shortest pods were growing out of the 5th and 6th nodes, at the top of the stem. Analysis of the single pea seed mass shows a highly significant effect of its position in the fruit on pod productivity. Seeds located in the central part of the pod had the greatest mass, and this accuracy, as highly significant, was found for the pods containing from 3 to 8 seeds. The tested agrochemical treatments did not differentiate the chemical composition of seeds.

Introduction

Many legume species are believed to be invaluable to organic or sustainable farming in temperate region (Corre-Hellou and Crozat, 2005). Cousin (1997) states that because *Pisum* is of great importance as edible leguminous plants and therefore of economic importance, its planted area should expand. The intensive breeding of peas, carried out in the second part of the twentieth century, improved the genus genetically. Increased sources of variation allowed breeders to create cultivars with unique botanical and agricultural characteristics, such as shorter growing period, short stem, and semileafless (type *afila*) instead of traditional foliage. Increased breeding of field pea includes both, edible and fodder cultivars grown for seeds, which increased the attractiveness of this species for agriculture. The main purpose of such modifications was to reduce pea lodging (Stelling, 1989) and to facilitate process of combined harvesting.

Semileafless morphotypes, as compared to conventional foliage types, use expanded tendrils in reducing lodging. However, despite the enhanced morphological features of the new morphotypes, lodging was not completely eliminated in peas. Usually, lodging of semileafless pea plants and canopy occurs in the phase of maturation (the final stage of development). It is recognized, that semileafless pea cultivars are less competitive than the cereal species in a cereal-legume mixture (Semere and Froud-Williams, 2001).

Currently available non-destructive measurements allow to measure vegetation indices such as the green area index (GAI), the normalized difference vegetation index (NDVI) and the relative chlorophyll content (SPAD), in a canopy of plants linked by tendrils. Measurements of vegetation indices can give a picture of ecophysiological state of semileafless pea plants and other crops in their characteristic phases of development. Although Prusiński (2007) stated that those indices did not specify productivity of semileafless pea precisely, which is determined by the unique agrobiological properties.

It was empirically demonstrated that longer growing season and optimal weather conditions led to a higher yield of pea seeds of the semileafless cultivars that is more resistant to lodging (Boros and Sawicki, 1997; Jeuffroy and Sebillote, 1997; Dore et al., 1998). It is emphasized that water availability and nitrogen content during the growing season determined pea production (Jeuffroy and Ney, 1997). Jensen (1996) showed that peas utilize a small amount of nitrogen from the soil, for this reason placing the strains of *Rhizobium* bacteria along with the pea seeds to the soil is compulsory. Sadowsky and Graham (2001) point out that most *Rhizobium* strains, in a symbiosis relationship with the peas, require warm soil of a pH of 5.0 or higher. Soil bacteria, *Rhizobium*, *Bradyrhizobium*, *Sinorhizobium* and *Azorhizobium* provide 80% of the total nitrogen required by pulses, a group of plants that provide 25-35% of useful proteins to the world (Vance, 2001). It has been shown that vaccination of pea seeds with bacteria *Rhizobium leguminosarum* (Carranca et al., 1999; Sadowsky and Graham, 2001), including strains of *Rh. leguminosarum* bv. *viceae* R 21 (Huang and Erickson, 2007) leads to several changes in morphological features of plants and improves seed yield. Optimization of supplying essential micronutrients to pea plants, in order to stimulate growth, development and to increase yield of plants and canopy, can be obtained by foliar application to the plants in the green bud stage (Szwejkowska, 2004). Application of micronutrients in the form of foliar spray leads to a higher yield of seeds from a single shoot and plant (Palcu et al., 2008) and increases the contents of nitrate reductase and glutamine synthetase in the shoots when supplied with molybdenum (Hristozkova et al., 2006). However, the combined effect from bacterial vaccines application and the effect of leaf micronutrient fertilizer on the productivity of semileafless peas has not yet been conducted. In the previous studies, the seed yield and its components for the peas – edible or fodder cultivars, were usually analyzed with high degree of generality (Duthion and Pigeaire, 1991; Ney and Turc, 1993; Dumoulin et al., 1994; Uzun and Acikgoz, 1998; Uzun et al., 2005), regardless of differences in individual seed weight per pod.

The aim of our study was to comparatively analyse the vegetation indices, productivity, and seed yield components of a single plant and the canopy of semileafless peas, as a function of the seed vaccination with *Rhizobium* bacteria and foliar application of micronutrients. The studies included morphological features of plants and pods and the individual seed weight of peas, and their basic chemical composition. Comparisons for semileafless morphotype were made between plants and pods to estimate the correlations for the traits pairs.

Material, methods and research area

The research was based on the field experiment, conducted in four replicates and carried out in the experimental field of Bayer® company located in Modzurów (50°09'N 18°07'E), Silesian voivodeship. The experimental field soil was Umbrisol – slightly degraded chernozem, formed from loess, therefore the soil conditions were sufficient for the pea needs. The soil pH was neutral (pH in 1mol/dm^3 KCl - 6.28) and the richness of topsoil layer was high: 19.1 mg/100g P_2O_5 , 21.7 mg/100g K_2O, and 10.1 mg/100g Mg. A randomized block design was adopted in the conducted field experiment and it consisted of 4 replicates, and the size of each field was 8.4 m^2. The following pre-sowing doses were applied: phosphorus - 60 kg · ha^{-1}(P_2O_5) and potassium - 60 kg · ha^{-1}(K_2O). Ammonium nitrate was applied as a „starting dose" - 20 kg · ha^{-1} N. One hundred and twenty germinating seeds of 'afila' pea cv. 'Tarchalska' were sown in 1 m^2 with a span of 15 cm. The plant seeds were sown in the second week of April 2010 and in the first week of April 2011. Commercial vaccine Nitragine^{TM}, produced by the BIOFOOD company (Poland), containing *Rhizobium leguminosarum* bv. *viceae* was applied during sowing.

The foliar fertilizer Photrel was applied in the beginning of the pea budding. Photrel contains 5% B, 7% Mn, 0.4% Mo, 13.3% MgO and 36.3% SO_3. Fertilizer applied in 3 L ha^{-1} contained: 150 g B, 210 g Mn, 12 g Mo, 400 g MgO_i , and 1081 g SO_3.

At the end of the flowering stage the presence of pee weevil (*Bruchus pisorum*) and pea moth (*Laspeyresia nigricana*) was controlled Nurelle^{TM} D 550 EC (a.i. cypermethrin and chloropyrifos, producer: DowAgro Science).

The collection of plants was carried out with a plot harvester. After collection the seeds were cleaned and the moisture content was determined. The final seed yield from the plot was calculated for the water content of 14.5%. Chemical composition of seeds was determined according to AOAC (2005) methods.

Green area index (GAI) of the canopy (m^2 · m^{-2}), normalized difference vegetation index (NDVI) and relative chlorophyll content (SPAD) were determined in characteristic development phases: flower buds, beginning of flowering, flowering declining and end of flowering and development of fruits.

Before collection – during the ripening phase – 15 pea plants were sampled from the fields in order to perform the biometric analyses. Morphological and productive features of pea were determined i.e. height of 1st reproductive pod in a shoot, length of reproductive shoot, plant weight, total shoot weight, stem weight, number of seeds per pod, weight of seeds. Pod characteristics were determined i.e. length of pedicle, weight of pedicle, length of pedicle, weight of pod.

The obtained results were processed by analysis of variance (ANOVA) for a 1-factorial experiment (block design) or by linear or non-linear regression analyse, using Statistica 9.1 (StatSoft) software.

Weather course

Monthly precipitation and average temperature for 2010-2011 growing seasons in Modzurow are presented in Tab. 1. In 2010 intensive precipitation was observed in the seedling phase (May) and during the flowering phase, which contributed to the growth and development retardation of vegetative and generative stages. This reduced plant density, number of seeds and pods, consequently resulted in a low yield. In 2011 the precipitation and average temperature were optimal for the plant growth.

Results

After a warm March in the year 2010, the following months of vegetation were cooler, due to the higher cloudiness and heavy precipitations (Tab. 1). Excessive rainfalls in the early May, lasting for two weeks, resulted in the hinder germination of pea seeds, due to the excessive moisture of soil, which was also cold. Moreover, after the heavy rainfall part of the field was under the water. These stress factors resulted in lower density of semileafless pea canopy and lower values of the yield components. In 2011 the weather course, up to June, was favorable for peas. In both years the excessive rainfalls in the month of July caused a severe crop lodging (as shown in the last part of the paper), which hindered the maturation of plants, and later their combine harvesting.

Green area index (GAI) of peas canopy throughout the examined stages of development, was in the range 1.35 - 5.61 m^2 m^{-2} (Tab. 2). In the first decade of June value of this ratio was > 3, which allowed the utilization of photosynthetically active radiation at a level close to optimal. The maximum leaf surface peas developed in the flowering stage, around 15 June 2010 and 8 June 2011 r. The objects tested did not differ statistically for this trait within the terms (except July 2011). Additionally, during the phases of elongation and flowering the object where both, Nitragina$^{(TM)}$ + Photrel$^{(TM)}$ was applied, was characterized by a slightly larger GAI, in comparison with the other objects (Tab. 2).

There were no significant differences of values of vegetation index (NDVI) within the examined objects at any time of measurement (Tab. 2). The highest NDVI values were found at peas flowering stage on 15th June 2010 and 8th June 2011. NDVI values during this period ranged from 0.545 to 0.615. The largest differences between NDVI values between years were recorded in the last phases of measurement (seed maturity), when NDVI values in 2010 were more than two times lower as compared to 2011 (Tab. 2). Those differences resulted from accelerated maturation of peas in 2010, because of high temperatures in July (Tab. 1).

Leaf greenness index (SPAD), which expresses the relative content of chlorophyll and, indirectly, the degree of nitrogen nutrition of plants, ranged between 24.1 - 48.5 (Tab. 2). The highest value of SPAD was noted on 15 June 2011 (flowering stage). The lower values of SPAD in June 2010 (flowering stage), might result from the dilution of nitrogen in the higher biomass of rapidly growing pea plants because of the abundance of water, which is also indirectly indicated by the value of the GAI index in this term (Tab. 2).

Tab. 1: Weather course at Research Station at Modzurów during 2010-2011

Variable	Year	March	April	May	June	July	August
Temperature (°C)	2010	4.0	7.5	11.7	16.7	20.4	18.5
	2011	2.0	9.7	13.2	17.4	17.3	18.9
Precipitation (mm)	2010	17.0	66.5	193.2	103.5	208.5	95.1
	2011	31.1	29.2	71.5	99.5	167.5	73.2

Tab. 2: Changes in the growth indices (GAI, NDVI, SPAD) of semileafless peas canopy vaccinated with *Rhizobium* bacteria (Nitragina^{TM}) or/and leaf-fertilized (Photrel^{TM})

Vegetation indices	Years	Growth stages*	Treatment				LSD	Significance level	CV %
			Control	Nitragina^{TM}	Photrel^{TM}	Nitragina^{TM} + Photrel^{TM}			
GAI** (m^2 m^{-2})	2010	1	-	-	-	-	-	-	-
		2	3.41	3.61	3.33	3.64	NS	0.857	23.5
		3	4.98	5.48	5.00	5.61	NS	0.564	20.7
		4	-	-	-	-	-	-	-
	2011	1	1.54	1.35	1.40	1.68	NS	0.254	16.6
		2	3.89	3.95	3.83	4.14	NS	0.689	9.2
		3	3.63	3.58	3.66	4.04	NS	0.238	9.4
		4	3.09	2.72	2.93	2.98	0.241	0.036	6.7
NDVI	2010	1	-	-	-	-	-	-	-
		2	0.611	0.612	0.606	0.591	NS	0.562	3.77
		3	0.589	0.615	0.602	0.610	NS	0.127	2.77
		4	0.184	0.153	0.180	0.193	NS	0.583	22.68
	2011	1	0.351	0.346	0.352	0.346	NS	0.993	9.07
		2	0.554	0.545	0.558	0.557	NS	0.098	1.50
		3	0.577	0.569	0.583	0.586	NS	0.060	1.79
		4	0.418	0.407	0.424	0.437	NS	0.701	8.06
SPAD	2010	1	-	-	-	-	-	-	-
		2	37.8	36.5	36.1	36.7	NS	0.337	3.7
		3	44.7	42.7	44.5	43.9	NS	0.456	4.1
		4	-	-	-	-	-	-	-
	2011	1	35.4	37.4	39.0	38.1	NS	0.299	14.1
		2	43.5	44.2	46.0	45.0	NS	0.773	12.2
		3	48.1	48.2	47.2	48.5	NS	0.989	17.9
		4	22.6	28.2	25.2	24.1	NS	0.527	35.8

* Growth stages of pea: 1 – Flower buds phase (BBCH 51-57), 2 – Beginning of flowering phase (BBCH 62-64), 3 – Flowering declining and end of flowering phases (BBCH 67-69), 4 – Development of fruits (BBCH 77-79) – (Meier 2001)
GAI - Green Area Index [m^2 m^{-2}]; NDVI - Normalized Difference Vegetation Index; SPAD - Relative Chlorophyll Content.

In both years, growth of semileafless pea cv. ‚Tarchalska', vaccinated with *Rhizobium* resulted in a reduced height of deposition of the pods on the first reproductive node of the plants (Tab. 3). The opposite trend was showed after foliar fertilizer application, which has increased the elongational growth of stems, increasing the height of pea plants and also the height of pods deposition, which was especially evident in 2011. At the same time the application of trace elements in a form of Photrel^{TM} fertilizer, in the stage of buds formation, did not cause a significant increase in production potential and yield. Higher plants of pea undoubtedly increase the tendency for lodging during adolescence. Foliar applied fertilizer did not change significantly the generative growth. At the same time, the length of pea shoots treated both, with seed vaccine Nitragina^{TM} and foliar fertilizer Photrel^{TM} has increased, but differences were not significant.

Pea seeds vaccination in combination with foliar application of fertilizer also increased the number of nodes with pods, which was particularly evident in 2010 year, which was climatically less favorable for growth of plants. The same combination of seed vaccine and foliar fertilizer applied in 2010 increased the total mass of pea shoots, assessed at the end of the growing season. As a result, the highest seed yield per single plant of peas was obtained from this combination as well. Pre-vaccination of pea with Nitragina^{TM} resulted also in the increase of the whole plant and the stem biomass. This was particularly pronounced in 2010 year, climatically unfavorable for peas, as a result of excessive rainfall during the growing season, which washed out mineral nitrogen compounds. from the humus layer of soil. more efficient *Rhizobium*, delivered to pea plants as a commercial product Nitragina^{TM}, provided nitrogen, which promoted the acceleration of plant growth to some extent, and increase in biomass as a result. Harvest index of pea plants varied between the growing seasons. Higher values of this index were reported in the year 2011, comparing to the year 2010 (Tab. 3).

Density of pea plants before harvest was significantly differentiated between the objects studied, as a cause of the lower plant density in objects of pea vaccinated with *Rhizobium* bacteria and also with both, *Rhizobium* and micronutriend fertilizer (Tab. 3). However, the small values of coefficients of variation (CV%) for the pea crop productivity, are evidence of the similar plant density, which can be considered as a stability of field replications per each object. The seed yield of pea varied between the growing seasons 2010 and 2011 by about 33%, due to agroclimatic conditions, which shows the sensitivity of semileafless morphotype of pea to the set of conditions that determine its growth and development, and as a consequence shape the crop productivity.

Fig. 1 shows the relations that occur between seed yield (y) from a single shoot, and the four independent variables. The dependent variable was poorly determined by the length of the fruiting part

Tab. 3: Comparison of morphologic and productive traits of semileafless pea, vaccinated with *Rhizobium* bacteria (Nitragina™) or/and leaf-fertilized (Photrel™)

Traits	Unit	Year	Treatment				LSD	Significance level	CV %
			Control	Nitragina™	Photrel™	Nitragina™ + Photrel™			
Plant height	(cm)	2010	80.7	75.0	85.5	87.5	9.36	0.045	16.3
		2011	78.5	74.7	81.5	79.1	NS	0.075	9.2
Height to 1st pod	(cm)	2010	61.1	54.3	61.1	60.5	NS	0.110	15.3
		2011	58.8	57.5	64.2	57.9	4.77	0.024	11.6
Length of fruiting stem	(cm)	2010	19.7	20.7	24.4	27.0	NS	0.099	39.8
		2011	19.7	17.2	17.3	21.1	NS	0.091	27.2
Reproductive node per stem	(pcs)	2010	3.3	3.8	3.3	4.3	0.81	0.049	31.2
		2011	3.7	3.5	3.4	4.0	NS	0.301	24.6
Pods per stem	(pcs)	2010	5.7	6.3	5.1	7.4	1.61	0.036	37.7
		2011	6.7	6.7	6.3	7.2	NS	0.451	23.4
Seeds per plant	(pcs)	2010	19.9	23.4	19.0	27.6	NS	0.087	45.7
		2011	30.7	30.2	27.7	30.1	NS	0.685	25.0
Seed mass	(g)	2010	4.94	6.43	4.93	7.13	NS	0.054	46.2
		2011	9.17	8.17	7.71	8.42	NS	0.251	24.0
Stem mass	(g)	2010	3.60	3.87	3.73	4.36	NS	0.545	38.9
		2011	4.51	4.42	4.15	4.09	NS	0.689	25.9
Plant mass	(g)	2010	8.53	12.59	8.66	11.49	NS	0.111	39.9
		2011	13.68	10.30	11.86	12.51	NS	0.385	22.6
Harvest index	(g g^{-1})	2010	0.564	0.624	0.532	0.620	0.075	0.045	18.5
		2011	0.670	0.650	0.647	0.673	NS	0.360	7.5
Plant density	(pcs. m^{-2})	2010	69.5	56.9	72.7	52.6	6.67	0.000	16.2
		2011	62.8	67.3	70.1	67.0	NS	0.189	11.9
Lodging at harvest	Scale* (1-9)	2010	3.2	3.4	2.9	3.1	NS	0.076	8.3
		2011	2.5	2.6	2.5	2.6	NS	0.092	6.8
Seed yield	t ha^{-1}	2010	3.59	3.63	3.55	3.71	NS	0.833	6.7
		2011	5.32	5.45	5.35	5.58	NS	0.919	9.8

* Lodged scale – 1: total lodging; 9: vertical plants

of stem (1a), as for this pair of features the correlation coefficient $R^2 = 0.181$. Another independent variables (1b, 1c) improved the prediction of seed yield per peas plant. Moderate correlation was obtained for the number of nodes per shoot ($R^2 = 0.472$) and for the number of pods per shoot ($R^2 = 0.621$). A highly significant linear relationship occurred between yield of pea seeds and the number of seeds per shoot (1d), as for this pair $R^2 = 0.9396$.

A further analysis of a yield of semileafless pea plant, including relations between reproductive nodes and pod characteristics, allowed the accurate estimation of their contribution to the creation of individual plant productivity (Fig. 2). Fig. 2a shows the changes in the number of pods per subsequent nodes of pea stem. It has been proven that the nodes of peas formed a similar number of pods, and their number was decreasing with increasing reproductive node layer. The number of seeds was highest at the first node, and then visibly decreased at subsequent nodes (Fig. 2b). The weight of a single pea seed was similar, if the seeds developed on the nodes labeled from 1 to 4 (Fig. 2c). The seed weight of two top nodes, the 5th and 6th, was lower, but the differences between the objects significantly increased. The seed yield per plant of pea (Fig. 2d), was arranged in a similar way as the number of pods and seeds, but differences between the objects were not significant.

The relative contribution of seeds sub-yield per each reproductive node in a total yield of seeds per plant, did not differ significantly between the objects (Fig. 3a). As expected, the share of additional nodes in seed yield per plant decreased steadily. Predictors of this trend were previously discussed, using data presented in Fig. 2a-d. The input of reproductive nodes in the total number of seeds per pea plant was arranged similarly (Fig. 3b). The individual contribution of each node, including the different pea treatments, in a total seed yield per plant was highly significant (Fig. 3c). Supremacy of the 1st reproductive node is visible, as the contribution of the 2nd node is smaller, although the statistical difference between both nodes is negligible. The contribution of the other nodes in the pea seed yield per plant, was significantly smaller. It should be emphasized that the overall contribution of reproductive nodes 1 to 4, in the overall yield per plant, was ca 97%. The other two upper nodes, the 5th and 6th had a little or no contribution to the total plant seed yield. These regularities, in a general way, have already been revealed, as Fig. 1 shows the poor correlation coefficient between seed yield of pea

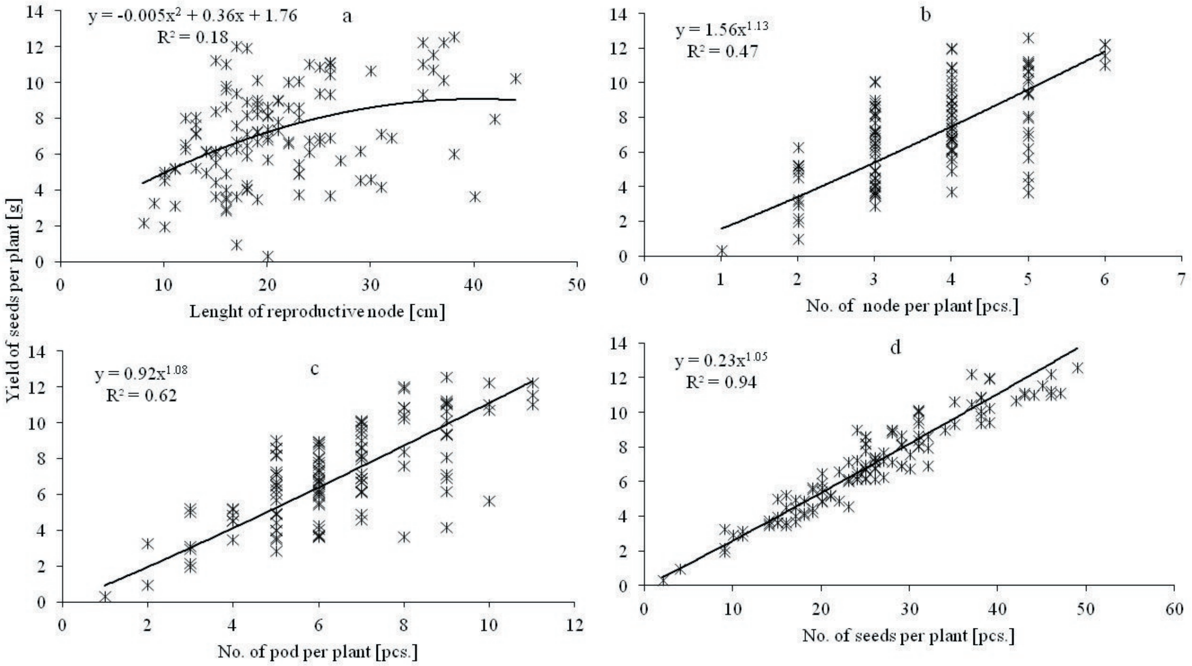

Fig. 1: Correlation indices for peas seed yield and length of fruiting part of stem (a); number of reproductive nodes (b); number of pods per stem (c) and number of seeds per stem (d) (n=120)

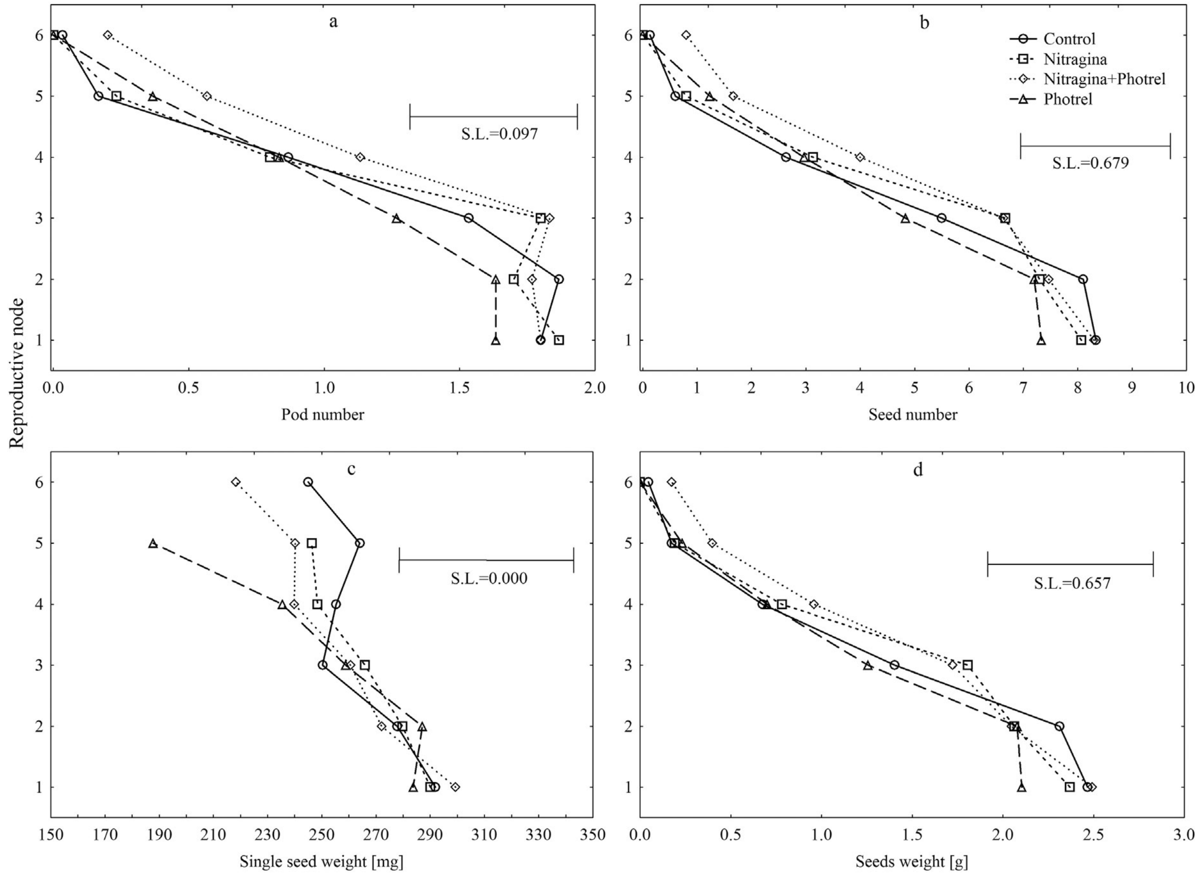

Fig. 2: Relation of pod number of compared treatments (a); seed number (b); single seed weight (c); total seeds weight (d) per each of semileafless peas nodes (average from vegetative seasons); S.L. - Significance level

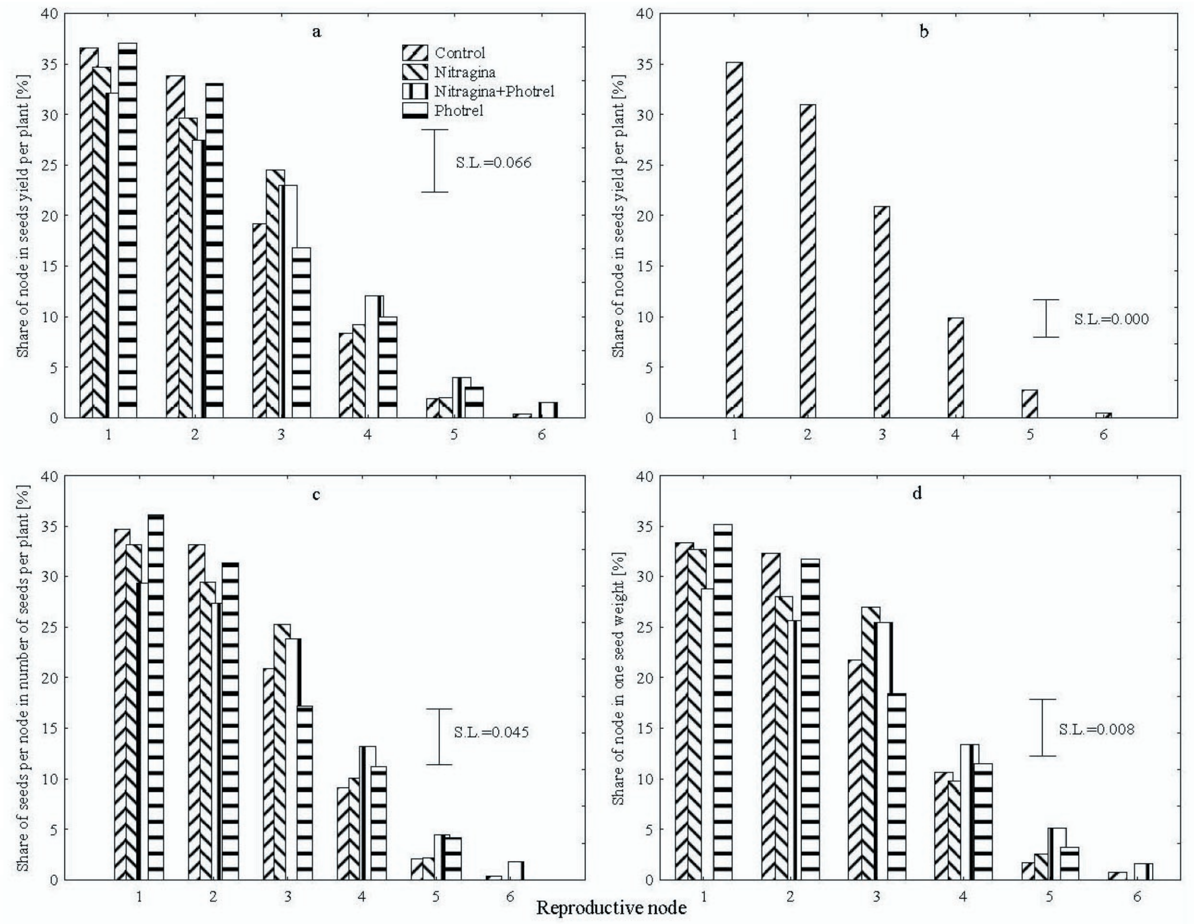

Fig. 3: Evaluation of contribution of peas seeds sub-yields per each reproductiye node into total plant yield (a); individual contribution of reproductive nodes in total plant yield (means from all objects and two vegetative seasons) (b); contribution of number of seeds per each node into a total number of seeds per plant (c); Comparison of relative mass of single seed per each node (d); S.L. - Significance level

plants, and the number of reproductive nodes on the stem.

Tab. 4 presents the data related to different morphological features of pods, which may contribute to of their individual productivity. As a consequence of the increase of reproductive nodes number per stem an increase in the number of pods was noted, which was recorded in 2010 for an object with a combined use of see vaccination (Nitragina^{TM}) and foliar fertilizer application (Photrel^{TM}). This pattern of results largely determined the number of pods per shoot of peas. The objects were not significantly differentiated in terms of number of seeds per pod. The different conditions during both vegetative seasons influenced the number of seeds per pod, which was visible especially in the year 2011, when a higher air temperature in the growing season occurred, and the fruits of pea contained more seeds as compared to the previous year. The features of pods as well as seed yield were characterized by a great diversity, which was discussed previously, and as evidenced by high variation coefficients. Comparisons relating to pods were extended with information relating to the length and weight of pedicel. In 2011, peas' pedicels were significantly longer, but their weight was only slightly higher. The pod length was similar in the both years of study, and demonstrated significant differences between objects for vegetative seasons were characterized by alternating arrangement. A higher proportion of seeds per pod was noted for the vegetative season 2011, seeds also had a higher weight. The share of seeds in the pod of semileafless peas was high and fluctuated in a range between 81-86%. Pod weight was higher in 2011, as a consequence of the presence of higher number of mature seeds.

There was a moderate and positive correlation between the weight of seeds from a single pod of semileafless peas and the length of the fruit in both vegetative seasons (Fig. 4a). For this pair of traits correlation coefficient value oscillated around $R^2 = 0.6$, which demonstrates that the prediction of the productivity of pea fruit based on this trait is not very precise due to the varying number of seeds per pod, ranging from 1 to 8 pieces. The stronger correlation was observed for the mass of seeds per pod and the number of seeds per pod (Fig. 4b). During the both vegetation periods, so climatically different, the correlation characteristics for this pair of traits was relatively constant and of linear relationship, as evidenced by the high value of the correlation coefficient R^2. The number of pea seeds, developing in the pod or on the shoot, is strongly determined by seeds mass, and both these features are easy to determine. The other correlations, shown in Fig. 4c and 4d were poor. Correlation between the mass of seeds and their share in the pod weight, turned out to be poor, although the empirically stated share of seeds in the pod weight was high, in the range of 75-90% and 80-91%, for vegetative seasons 2010 and 2011, respectively.

A comparison of the mass of a single pea seed, depending on their number and their individual position in the pod is presented in Tab. 5; this summary has an acognitive context for semileafless pea morphotype, represented by cv. 'Tarchalska', providing seeds for edible purpose. Eight categories of pods, because of the number of educated seeds, were distinguished. A tendency to increase the weight of a single pea seed within a pod, with the increase of seeds number per pod was clearly indicated. This arrangement of

Tab. 4: Traits and productivity of pods of semileafless peas in each vegetative season depending on seed vaccination with *Rhizobium* bacteria (Nitragina^{TM}) or/and leaf-fertilization (Photrel^{TM})

Traits	Unit	Year	Treatment				LSD	Significance level	CV %
			Control	Nitragina^{TM}	Photrel^{TM}	Nitragina^{TM} $^{+}$ Photrel^{TM}			
Pedicel length	(cm)	2010	3.42	3.23	2.98	3.14	NS	0.296	49.3
		2011	5.03	4.92	5.79	6.19	0.886	0.012	44.2
Pedicel mass	(g)	2010	0.085	0.089	0.084	0.120	0.027	0.028	40.8
		2011	0.103	0.093	0.095	0.108	NS	0.471	29.3
Pod length	(cm)	2010	5.64	6.08	5.58	5.68	0.295	0.003	17.9
		2011	5.88	5.30	5.29	5.30	0.296	<0.001	20.1
Pod dry matter	(g)	2010	1.045	1.231	1.163	1.166	NS	0.086	43.0
		2011	1.587	1.438	1.442	1.363	0.1381	0.013	34.5
Mass of seeds per pod	(g)	2010	0.861	1.016	0.975	0.981	NS	0.076	43.5
		2011	1.344	1.236	1.235	1.175	NS	0.050	35.7
Stripped pods mass	(g)	2010	0.183	0.215	0.200	0.202	NS	0.098	42.7
		2011	0.243	0.204	0.207	0.189	0.025	<0.001	43.4
Share of seeds per pod mass	(%)	2010	81.8	82.3	81.1	81.2	NS	0.676	9.2
		2011	83.8	85.6	85.5	86.0	1.33	0.005	5.7
Number of seeds per pod	(pieces)	2010	3.45	3.69	3.78	3.73	NS	0.356	35.2
		2011	4.54	4.41	4.41	4.18	NS	0.231	29.7
Single seed weight	(mg)	2010	245	278	260	259	NS	0.057	13.0
		2011	298	275	278	284	NS	0.194	11.2

data refers directly to the location of the pod on the stem of peas. Pods developing at the lowest nodes contained the highest number of seeds, which is showed in the Fig. 2a and 2b. The second observed relation is that seeds located in the pod on the first and the last position was characterized by a lower biomass. Seeds located in the central part of the pod had the highest biomass, and the highly significant tendency was found for the pods containing from 3 to 8 seeds.

The compared pea objects did not differ significantly in terms of chemical composition (Tab. 6). Total protein content in pea seeds was higher in 2010, as compared to 2011. The lower protein content in semileafless pea in 2011 was probably due to the higher weight of a single seed. However, in the both vegetative seasons slightly higher protein and fat content was noted for seeds of peas treated both, with Nitragina^{TM} vaccine and foliar fertilizer Photrel^{TM}. Fiber content in pea seeds was slightly higher in 2010, due to their smaller biomass, because larger seeds, collected in the following year were characterized by a lower content of this component. Similar relations were noted for the fat and ash content, which proves that climatic conditions in a subsequent vegetation seasons change the content of the most important elements of the peas seeds to a small extent.

Discussion

It was found that the seed yield and aboveground biomass of edible and fodder peas cultivars, are characterized by high variability, caused by habitat conditions and the weather course during the growth (Jeuffroy and Sebillote, 1997; Baigorri et al., 1999; Carranca et al., 1999; Poggio et al., 2005; Annicchiarico and Iannucci, 2008). According to Olszewski (2004) peas variable yielding, in a climatically diverse vegetative seasons is the result of interaction of different kind of stress factors that may cause the reversible changes in the plants resulting in the slowed down growth, but can also induce irreversible changes resulting in death of plants, which in consequence leads to a decrease in the canopy production potential. This phenomenon became apparent in our studies in the growing season 2010, when unfavorable agroclimatic conditions for peas, led to a decrease in plant and canopy yield.

Our study has shown that the productive potential of edible pea cv. 'Tarchalska', representing semileafless morphotype, was differentiated stronger by climate variables during vegetative seasons, as compared to treatments applied. Most of the analyzed morphological differences, as a quantitative picture of peas productivity in the full maturity stage, were generally insignificant. This pattern of results indicates the high stability of species traits on the one hand, on the other the effects of commercial preparations Photrel^{TM} and Nitragina^{TM}, turned out to be weaker, as the creators of plant growth and development and, consequently, a crop yield. The main reason to apply foliar fertilizer to the peas was an expectation for a seed yield increase. Czyż (1993) emphasizes that foliar application of three micronutrients solution (B+ Mn + Mo) increased the peas seed yield and protein content. Szwejkowska (2004) found that an increase in the outlay for the cultivation of peas significantly affect peas seed yield and partially compensate for the adverse weather conditions for this species during the growing season. In our studies semileafles pea plants were developing in the contrasting weather conditions during two growing seasons. A variable course of precipitation and average air temperature during plant growth and development, lead to different quantitative and qualitative characteristics of individual plants and canopy. In the colder and more humid season 2010, semileafless pea canopy has developed greater assimilation area (GAI) than during the next, drier season 2011. Abundance of water boosted the development of plants, GAI in the phase of full flowering was of 5.48 m^2 m^{-2}, but this did not translate into a positive effect on seed yield from a single shoot, or canopy. Obtained by Prusiński (2007) GAI of pea cultivars in the

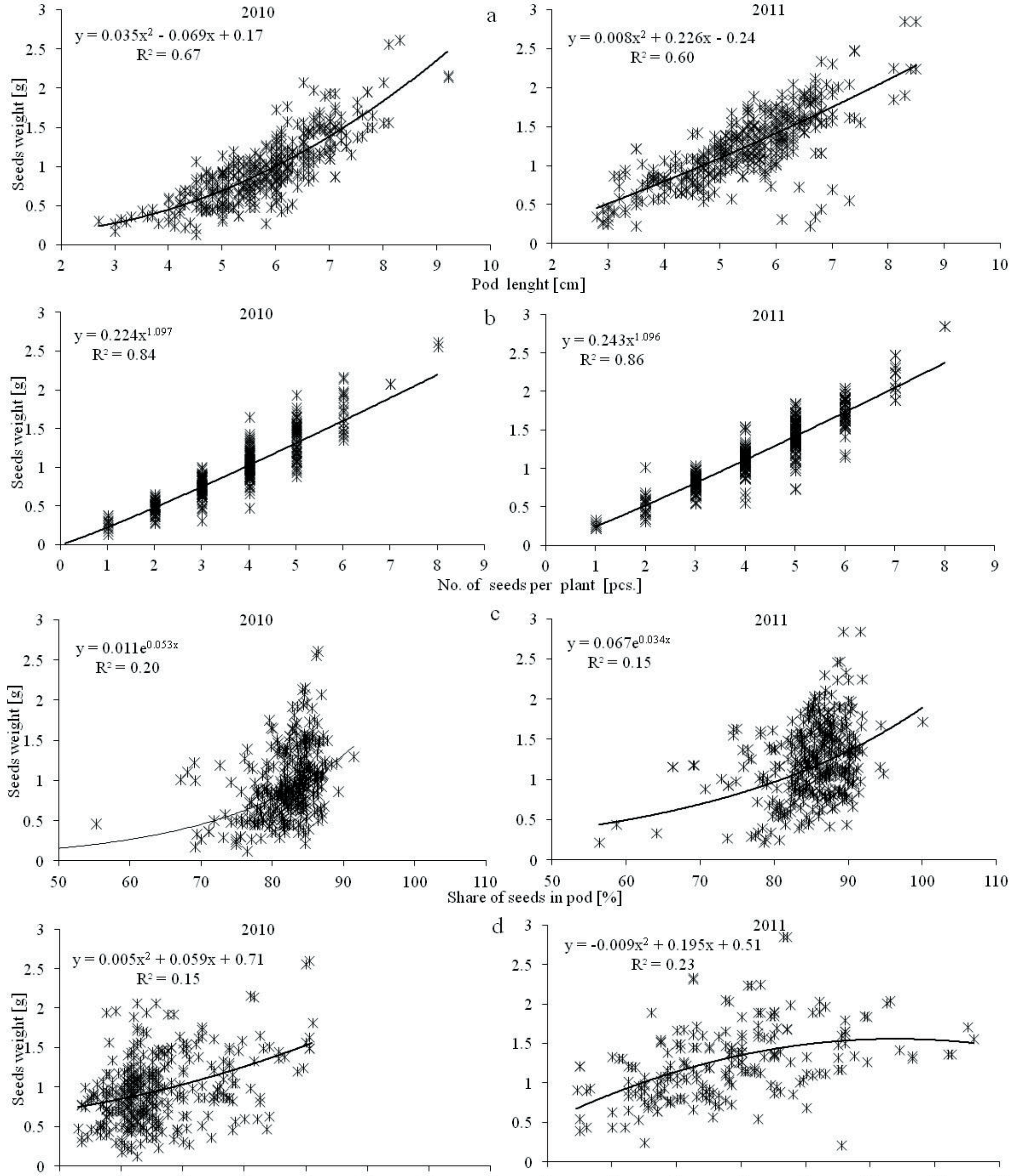

Fig. 4: Correlation coefficients for mass of peas seeds per pod and: pod length (a); seeds number (b); share of seeds in the pod mass (c); length of pedicels (d)

full flowering phase was in a range of 4.23-5.28 m^2 m^{-2}, and even though the semileafless peas cv. 'Venus' was characterized by a significantly lower GAI rate as compared to cultivars of normal foliage, still it was characterized by the highest biomass yield and, consequently, the highest seed yield. In the semileafless type of peas cultivars a significant role in photosynthesis play bracts and tendrils, and later also the green pods (KOF et al., 2004). In our studies value of relative chlorophyll content (SPAD) was not differentiated by any treatment. The value of SPAD ratio depends on the color of leaves, which informs not only of the nutritional status, but also is an inherited trait, as reported by AMBROSE (2010). According to this Author, genotypes of pea with dark-green bracts are characterized by higher SPAD values, > 60, and those of the bright green bracts have SPAD values < 30. In the present study we used the same genotype, so in both vegetative seasons the differences were only due to the habitat conditions and objects tested. RIDAO et al. (1996) under conditions of unlimited water availability(irrigation) obtained GAI, of semileafless pea cultivars in the phase of the foliage development, ranging from 4 to 5 m^2 m^{-2} depending on the growing season, with much smaller values for the non-irrigated sites. In this regard, the use of PAR GAI (RPI = APAR / PAR) was greater than 0.8.

This study provides an objectively shown diversification of

Tab. 5: Comparison of mass (mg) of single seed of peas (n= 3109) in relation to the number of seeds per pod, including the position of seed in the pod

Number of seeds per pod	Position of seed in pod								LSD	Significance level
	1st n=769	2nd n=749	3rd n=670	4th n= 507	5th n=292	6th n= 99	7th n= 19	8th n= 4		
1	259.5±72.7								-	-
2	243.3±52.5	243.2±46.9							NS	0.987
3	253.5±46.1	267.0±44.4	255.6±47.6						9.70	0.009
4	258.2±46.6	278.4±46.1	275.8±47.6	259.0±47.4					8.87	<0.001
5	271.9±44.7	289.6±45.4	290.4±47.1	289.5±43.7	266.1±48.9				9.18	<0.001
6	270.9±40.7	296.9±37.3	300.0±35.3	297.3±35.4	292.6±32.5	263.0±41.1			11.50	<0.001
7	278.0±43.3	311.3±30.0	324.0±29.7	326.7±27.4	324.7±28.3	308.7±33.4	290.7±32.6		23.53	< 0.001
8	292.5±20.6	355.0±23.8	367.5±20.6	352.5±26.3	355.0±28.9	350.0±23.1	327.5±37.7	317.5±9.6	36.36	0.005
LSD	29.29	27.86	30.41	31.57	35.23	36.83	NS	-		
Significance level	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.067			

Mean ± standard. deviation

Tab. 6: The chemical composition of peas seeds (g kg^{-1}) and protein and starch yield (kg ha^{-1}) in different vegetation seasons for plants vaccinated with *Rhizobium* bacteria (Nitragina™) or/and leaf-fertilized (Photrel™)

Item	Years	Treatment				LSD	Significance level	CV %
		Control	Nitragina™	Photrel™	Nitragina™ + Photrel™			
Protein	2010	236.9	238.4	242.4	242.9	NS	0.509	2.68
	2011	206.6	206.1	206.8	209.4	NS	0.892	2.88
Starch	2010	396.7	400.6	394.8	400.8	NS	0.843	2.63
	2011	396.5	405.8	396.4	404.8	NS	0.160	1.96
Fibre	2010	57.3	54.8	56.4	60.2	NS	0.765	12.03
	2011	49.5	48.5	50.7	47.3	NS	0.205	4.73
Fat	2010	16.5	18.9	19.3	21.2	NS	0.706	28.08
	2011	13.1	15.8	12.3	14.1	NS	0.479	22.81
Ash	2010	28.3	30.0	29.5	29.6	NS	0.363	4.65
	2011	23.3	22.9	24.1	23.6	NS	0.561	4.96
Protein yield	2010	999.9	1016.8	1014.4	1062.0	NS	0.764	7.91
	2011	1294.0	1322.1	1300.3	1376.8	NS	0.863	10.57
Starch yield	2010	1675.2	1711.9	1647.0	1752.7	NS	0.735	7.76
	2011	2483.2	2601.2	2493.7	2658.9	NS	0.762	9.99

productive potential of each of reproductive nodes of peas and it enabled to show the accurate range of components influencing the structure of seed yield at the level of a single plant. The presented data fill the gap relating to studies on productivity of semileafless pea plant that dominates these days in cultivation, as productively efficient and characterized by high seeds yield. Cv. 'Tarchalska' is a high-yielding cultivar in the conditions of southern Poland (Silesia province), because its seed yield (t ha^{-1}) in the years 2008, 2009 and 2010 was 7.01, 5.02 and 6.10, respectively, exceeding the yielding of the other 11 cultivars (Ryszka 2011). In the previous work Zając et al. (2006) showed that the position of seed in a faba bean pod determines its individual weight: seeds located in the middle part of the pod reached the greatest mass, while the smallest seeds were formed in pods located in the upper part of the shoot. Similar trend was also observed in our study, for a semileafless edible peas cv. 'Tarchalska'. We have found that the length and weight of pea pod and the number of seeds formed in the pod depends on its location on the frutinig part of a stem. The longest pods with the highest weight and the number of seeds have been found in the lowest nodes – from the 1st to the 2nd. Slightly shorter pods were found in the 3rd and 4th nodes, located in the middle part of the stem. The shortest pods were found in the 5th and the 6th nodes, on top of the stem.

Conclusions

1. Agroclimate conditions highly differentiated growth of plants and canopy of semileafless pea in the south-western region of Poland (Modzurów). In the warmer growing season 2011, generative growth of plants was better, resulting in very high yield of seeds per plant, determined by higher number of large seeds. Also the seed yield of peas from a unit area in that season was high.
2. Length, weight and number of pod of pea depends on the pod location along the fruiting part of stem. The longest pods with the highest weight and the number of seeds develop in the lowest nodes – from the 1st to the 2nd. Shorter pods grow on the 3rd and 4th nodes located in the middle part of stem. The shortest pods are obtained from the 5th and 6th nodes, on top of the stem.
3. Seeds located in the central part of the peas' pod have the greatest mass, as found with highly significant correlation for the pods, containing from 3 to 8 seeds. The analysis of a single seed, demonstrates position as a major determinant of seed mass.

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