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Variability and inter-dependence of some features in the three taxa types of *Polygonum* L.

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Abstract
For over three years, research was carried out on the cultivated fields within the Wigry National Park and its surroundings, in order to determine the phenotypic variability of the three taxa of the genus Polygonum L., occurring in four agrocenoses (winter cereals, spring cereals, stubble, and potato cultivation). The analysis covered, among other things, the number of leaves, the amount of pollinator inflorescences and the quantity of seeds per one plant. An attempt was made to determine the impact of plant assimilation on their fertility.
The variance analysis carried out demonstrated that the type of crop in which they occur have a decisive influence on the traits of the analyzed taxa. Individual Polygonum L. finds better conditions for vegetative and generative development within potato cultivation, more so than in dense fields of winter and spring cereals, as proven by the significantly higher values in the traits studied.
The number of leaves in the assimilation area for every examined taxa had an influence on the number of developed inflorescences, as well as the number of seeds from one plant. The number of Polygonum lapathifolium L. subsp. pallidum (With.) Fr. inflorescences was a little smaller than for both other taxa, while an increase of Polygonum lapathifolium L. subsp. lapathifolium leaves number caused more seeds compared with other taxa.
Keywords: *variance analysis, biometric features, segetal plants, seed production, genus Polygonum L., stubble, Wigry National Park, cereal crops, potato cultivation*

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I. INTRODUCTION

Polygonum persicaria L., *Polygonum lapathifolium* L. subsp. *lapathifolium* and *Polygonum lapathifolium* L. subsp. *pallidum* (With.) Fr. are common vegetal plants that are part of the weed family, and can be found in cultivated fields. They are particularly common in root crops and cereal crops, especially spring cereals, and often constitute secondary weed infestation.

One of the most important features pertaining to the adaptation strategy of weeds is their fertility. A large number of seeds and fruits continue to flourish on crop fields, despite the ongoing efforts to remove them. This feature is of great importance, especially for species with a short-term life-span. The released amount of seeds determines their survival and spread [24, 16, 6, 7]. According to many authors [15, 16, 19, 5] weed fertility largely depends on the habitat, soil, atmospheric conditions, and above all the type of crop and its agro-mechanics. Other researchers have concluded the significant role of the genotype and physiological state of the plant [31, 6, 18]. There are several opinions that the size of the plant assimilation area is of great importance [22, 33], and that the appropriate ratio between the number and surface of leaves together with the amount of inflorescences consequently affects the number of fruit and seeds [28]. An inadequate leaf surface area can lead to a lack of nutrients which are essential for proper growth.

In the literature, there is only information on phenotypic traits and various weed species fertility, there is no data concerning the interdependencies between these traits. Such tests were carried out on commercial plants, including oats [29], buckwheat [34], ryegrass [28], wheat [22, 11] and oil plants [2, 3]. To determine the connection between the features, appropriate statistical methods were used, most of which are based on the analysis of correlation, as well as simple and multiple regression.

The aim of the work was to enhance and broaden our knowledge and understanding regarding the reproduction of common seeds of the genus *Polygonum* L. weeds, depending on the crop in which they are present, comparing the examined taxa in terms of their assimilation area and their fertility.

II. MATERIALS AND METHODS

2.1 The study area

Wigry National Park is located in north-eastern Poland and covers an area of 15 089.8 ha. The protection zone designated around the Park covers the area of 11 283.81 ha. The arable land within the Wigry National Park is predominantly private property. This occupies 1736.6 ha, or 11.5% of the Park's area. Small farms dominate the Park and its surrounding area [9]. These farms mainly cultivate cereal crops, such as rye, triticale, oats, barley, mixtures, about 80% of crops. There are also other significant areas with potato crops and industrial crops (e.g. tobacco). A large part of sowing is occupied by maize, grown for cattle feed.

The Park’s farmland is only subject to landscape protection. The use of land and agricultural production methods depend solely on the land-owners. However, difficult environmental and climatic conditions such as post-glacial ground, poor soil, harsh climate and a short vegetation period are not favourable for agricultural production [4]. Agriculture is extensive here, it is mostly manual, without mechanics or large machinery, and most of the farms have small-scale production. Mineral fertilizers are used to a small extent, but manure is normally used. Plant protection products are limited.

2.2 Biometric measurements

The research covered plants of three taxa of the genus *Polygonum* L.: *Polygonum persicaria* L., *Polygonum lapathifolium* L. subsp. *lapathifolium* oraz *Polygonum lapathifolium* L. subsp. *pallidum* (With.) Fr.

These are herbaceous plants, with a short (annual) lifespan. They have straight, elongated, lanceolate leaves with extremely pronounced mid-nerves and lateral nerves. On the stem, the leaves are arranged in a twisted fashion, on short petioles. These taxa contain bi-sexual flowers, they are collected in cylindrical, chamomile inflorescences, composed of few-flower twists, and they bloom from June to October. They are able to self-pollinate, but can also be cross-pollinated by the wind or insects. Their fruit is a small, oval, smooth, shiny black or brown nut. A bovine sperm containing a lot of starch completely fills the fruit chamber, and the embryo is placed along the rounded edge. These plants only reproduce with seeds. One plant cans give anywhere from 200 to 800 seeds, with certain specimens producing up to several thousand seeds [20, 30, 21, 26, 35, 23, 27].

Specimens of studied taxa were collected in 2009-2011 from the winter and spring cereal crops, as well as the potato plantations from within the Wigry National Park and its surrounding agricultural area. The amount of leaves, inflorescences and seeds from one plant were established for each of the collected plants. The number of seeds from one plant was obtained by adding seeds from all inflorescences on the plant. Each of these characteristics for each taxon was measured in 120 repetitions in every tested year. 360 measurements were made per year and 1080 **-** in three years.

2.3 Statistical analysis

Linear models of variance analyses require the assumption of distribution normality for the studied traits. The measured phenotypic traits had sporadically occurring high values, suggesting a positive skew, i.e. incompatibility with the normal distribution. Therefore, the procedure of transforming features with the logarithmic function was carried out beforehand, and this transformation reduced the skewness. The transforming function gave a skewness close to zero for each of the factors combination (tax × type of use × year) present in the experiment.

The analysis of variance according to a mixed linear model was used for statistical analysis. The taxa and the type of use were fixed factors, whereas the year was a random factor within in a combination of constant factors.

Taxa and the interactions with taxa demonstrating the effect of the taxon on the examined trait were aggregated into homogeneous groups, based on the Tukey test, at the significance level of $\alpha = 0.05$. In case of significant interaction, the response of the species on particular type of use was portrayed.

The relationships between the selected features were verified using the linear regression function and its confidence interval. Functions of the phenotypic phenomena reactions on the generated number of leaves on the plant were calculated; a feature which was found to be crucial for the vital functions of the plant. Confidence intervals for the regression function allowed for the conclusions on the homogeneity of the studied taxa.

Statistical software was used for the statistical calculations [25]. The skewness was calculated with the skewness function from the moments package [12]; the variance analysis with the lme4 package lmer function [1]; homogeneous group divisions with the Tukey test by the lsmeans function from the lsmeans package [17]; and linear regression and its confidence interval with the lm and predict functions of the stats package [25].

III. RESULTS

Tables 1-3 represent the mean values and the range of variability of the phenotypic traits considered: the amount of leaves, inflorescences and seeds from one plant, achieved by plants *Polygonum persicaria* L., *Polygonum lapathifolium* L. subsp. *lapathifolium* and *Polygonum lapathifolium* L. subsp. *pallidum* (With.) Fr. in the analyzed agrocenoses for each year of research.

Table 1: The mean values and the range of variability of the phenotypic traits achieved by plants *Polygonum persicaria* L. in the analyzed agrocenoses between 2009 and 2011.

Type of use / Feature	winter cereals	spring cereals	stubble	potato cultivation
	mean value (range of variability)	mean value (range of variability)	mean value (range of variability)	mean value (range of variability)
2009				
number of leaves	**17,50** (5,00-65,00)	**16,63** (6,00-83,00)	**17,73** (6,00-48,00)	**51,83** (10,00-121,00)
number of inflorescences	**7,13** (1,00-39,00)	**7,63** (1,00-48,00)	**17,53** (4,00-51,00)	**75,63** (7,00-217,00)
number of seeds	**84,90** (1,00-603,00)	**126,87** (3,00-974,00)	**195,97** (33,00-724,00)	**2294,87** (63,00-8957,00)
2010				
number of leaves	**8,13** (3,00-28,00)	**10,63** (3,00-28,00)	**25,73** (5,00-64,00)	**73,67** (16,00-213,00)
number of inflorescences	**3,10** (1,00-8,00)	**4,97** (1,00-16,00)	**24,70** (3,00-113,00)	**95,13** (11,00-405,00)
number of seeds	**46,47** (13,00-147,00)	**100,30** (16,00-314,00)	**165,10** (25,00-1107,00)	**3015,80** (114,00-12530,00)
2011				
number of leaves	**13,07** (2,00-57,00)	**11,53** (4,00-38,00)	**17,77** (5,00-47,00)	**49,47** (21,00-120,00)
number of inflorescences	**4,53** (1,00-16,00)	**4,17** (1,00-12,00)	**17,17** (2,00-58,00)	**64,37** (15,00-138,00)
number of seeds	**21,67** (8,00-50,00)	**22,07** (6,00-48,00)	**48,30** (10,00-105,00)	**1262,53** (118,00-3250,00)

Table 2: The mean values and the range of variability of the phenotypic traits achieved by plants *Polygonum lapathifolium* L. subsp. *lapathifolium* in the analyzed agrocenoses between 2009 and 2011.

Type of use / Feature	winter cereals	spring cereals	stubble	potato cultivation
	mean value (range of variability)	mean value (range of variability)	mean value (range of variability)	mean value (range of variability)
2009				
number of leaves	-	**14,37** (5,00-46,00)	**16,63** (4,00-39,00)	**58,43** (13,00-138,00)
number of inflorescences	-	**8,17** (2,00-31,00)	**25,53** (4,00-69,00)	**73,03** (10,00-283,00)
number of seeds	-	**152,50** (8,00-937,00)	**298,13** (36,00-673,00)	**4507,50** (67,00-10904,00)
2010				
number of leaves	**8,50** (5,00-21,00)	**11,27** (5,00-27,00)	**22,67** (8,00-65,00)	**66,00** (23,00-198,00)
number of inflorescences	**3,27** (1,00-11,00)	**5,80** (1,00-18,00)	**18,97** (1,00-55,00)	**79,00** (11,00-320,00)
number of seeds	**38,10** (11,00-191,00)	72,47 (10,00-506,00)	57,27 (13,00-135,00)	**3021,50** (20,00-15120,00)
2011				
number of leaves	**13,37** (5,00-40,00)	**14,53** (6,00-38,00)	**16,50** (4,00-39,00)	**60,30** (12,00-321,00)
number of inflorescences	**6,43** (1,00-20,00)	7,30 (2,00-18,00)	**21,77** (4,00-69,00)	**68,80** (16,00-337,00)
number of seeds	**40,90** (10,00-180,00)	37,23 (10,00-85,00)	**219,60** (12,00-473,00)	**1895,93** (150,00-10753,00)

Table 3: The mean values and the range of variability of the phenotypic traits achieved by plants *Polygonum lapathifolium* L. subsp. *pallidum* (With.) Fr. in the analyzed agrocenoses between 2009 and 2011.

Type of use / Feature	winter cereals	spring cereals	stubble	potato cultivation
	mean value (range of variability)	mean value (range of variability)	mean value (range of variability)	mean value (range of variability)
2009				
number of leaves	**12,67** (7,00-43,00)	**16,10** (4,00-50,00)	**16,03** (7,00-40,00)	**46,00** (11,00-114,00)
number of inflorescences	**5,97** (1,00-43,00)	**8,97** (1,00-38,00)	**11,20** (1,00-38,00)	**47,17** (8,00-137,00)
number of seeds	**114,40** (9,00-1203,00)	**155,83** (10,00-869,00)	**65,07** (10,00-284,00)	**700,60** (35,00-3620,00)
2010				
number of leaves	**8,00** (3,00-20,00)	**11,83** (5,00-22,00)	**17,93** (5,00-52,00)	**61,13** (14,00-175,00)

number of inflorescences	**2,93** (1,00-7,00)	**6,30** (1,00-20,00)	**13,93** (2,00-60,00)	**72,23** (13,00-273,00)
number of seeds	**32,13** (6,00-91,00)	**110,70** (10,00-723,00)	**41,43** (10,00-85,00)	**2359,50** (138,00-11320,00)
2011				
number of leaves	**17,50** (5,00-52,00)	**12,97** (4,00-40,00)	**11,10** (4,00-30,00)	**49,27** (27,00-121,00)
number of inflorescences	**6,90** (1,00-26,00)	**4,27** (1,00-13,00)	**8,80** (1,00-21,00)	**51,10** (13,00-145,00)
number of seeds	**41,67** (15,00-200,00)	**23,03** (12,00-43,00)	**41,47** (10,00-97,00)	**1439,87** (250,00-4177,00)

The results of the calculated skew of the considered phenotypic features for each combination of the studied factors (tax × type of use × year) are shown in the box plot graphs (Figure 1). The logarithmic transformation was used to eliminate the skew of the studied features. Before the transformation, the skewness of features for the combination of studied factors was positive (left plots), whereas after the transformation, the average was very close to zero and were symmetrically scattered on the graph (right plots). This data could then be analyzed using parametric methods [13].

The variance analysis with the mixed model (Table 4) illustrated that in terms of the number of leaves, the main effects of the type of use were significant. In potato crops, studied taxa specimens developed the largest number of leaves (Table 5). In addition, the values of this feature in specimens on shoots were significantly higher than in crop plants, both spring and winter.

However, the variance analysis for the number of inflorescences illustrated the significance of the interaction of the 2nd order (taxon × type of use) and the decisive influence of the type of use (Table 4). *Polygonum persicaria* L. and *Polygonum lapathifolium* L. subsp. *lapathifolium* contained more inflorescences than *Polygonum lapathifolium* L. subsp. *pallidum* (With.) Fr. when grown on the stubble (Table 6). For all three taxa, potato cultivation produced the largest number of inflorescences, a smaller number was observed on shoots and the lowest in spring and winter cereal crops ex aequo.

In terms the number of seeds, this showed the significance of the main effects of the type of use. In potato crops, the studied taxa specimens developed the largest number of seeds (Table 7). Moreover, the values of this feature in specimens present on shoots were significantly higher than in plants from winter cereal crops.

The dependence of the number of seeds and the number of inflorescences on the number of leaves is shown in the graphs of the linear regression function and its confidence interval (Figure 2-3). Small differences between the taxa were observed.

Taxanes *Polygonum lapathifolium* L. subsp. *lapathifolium* and *Polygonum persicaria* L. have a similar inflorescences reaction on the plant to the number of leaves obtained, whereas *Polygonum lapathifolium* L. subsp. *pallidum* (With.) Fr., in comparison, has a smaller number of inflorescences. For the difference between the number of seeds per plant and the obtained number of leaves *Polygonum lapathifolium* subsp. *pallidum* (With.) Fr. and *Polygonum persicaria* L. we can see a similar function, while *Polygonum lapathifolium* L. subsp. *lapathifolium* has a larger number of seeds when the number of leaves is greater. The calculated reaction functions according to linear regression estimators are presented in Table 8.

The research results confirmed the significance of the assimilation surface area of the tested taxa plants for their fertility. They indicated that the number of leaves affects the number of inflorescences and the number of seeds obtained from one plant. In all three taxa with fewer leaves, the number of seeds is comparable.

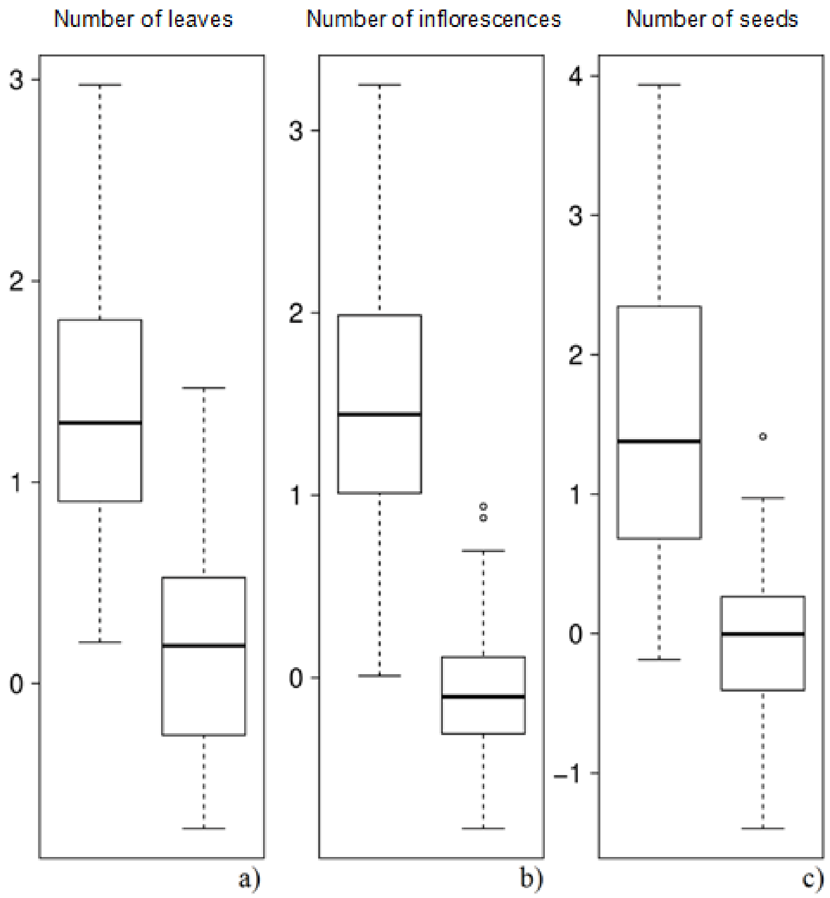

Figure 1: Box plot graphs showing oblique characteristics: a) number of leaves, b) number of inflorescences, c) number of seeds for measured values (graph on the left), and after transformation (graph on the right).

Table 4: The variance analyzes for the examined traits depending on the taxon and type of use with the year as random factor.

Source and trait	Sum of squares	Degree of freedom	F	P
number of leaves				
taxon	0.21	2	0.35	0.709
type of use	138.95	3	149.17	<0.001
tax x type of use	2.04	6	1.10	0.383
number of inflorescences				
taxon	5.61	2	4.89	0.013
type of use	572.37	3	332.42	<0.001
tax x type of use	9.41	6	2.73	0.028
number of seeds				
taxon	6.42	2	3.18	0.055
type of use	420.40	3	138.70	<0.001
tax x type of use	11.76	6	1.94	0.104

Table 5: The average number of developed leaves and the impact of habitat conditions on the number of leaves.

Environmental conditions (management)	mean	group†
winter cereals	2.30	A
spring cereals	2.43	A
stubble	2.72	B
potato cultivation	3.87	C

† Homogeneous groups of conditions formed according to the Tukey test.

Table 6: The average numbers of inflorescences developed on plants, similarity of the impact of various habitat conditions on each of the considered taxa and similarity of taxa depending on habitat conditions.

Environmental conditions	*P. persicaria* L.		*P. l.* L. subsp. *lapathifolium*		*P. l.* L. subsp. *pallidum* (With.) Fr.	
(management)	mean	group†	mean	group†	mean	group†
winter cereals	1.28	$_a$ ^{A}	1.26	$_a$ ^{A}	1.29	$_a$ ^{A}
spring cereals	1.39	$_a$ ^{A}	1.70	$_a$ ^{A}	1.54	$_a$ ^{A}
stubble	2.69	$_b$ ^{B}	2.81	$_b$ ^{B}	2.14	$_a$ ^{B}
potato cultivation	4.11	$_a$ ^{C}	4.01	$_a$ ^{C}	3.81	$_a$ ^{C}

† Homogeneous groups of taxa created according to the Tukey test for each type of environmental condition separately are marked by lower-case letters ($_a$, $_b$); homogeneous groups for the impact of environmental conditions on each taxon are marked in capital letters in the upper index (^{A}, ^{B}, ^{C}).

Table 7: The average number of seeds developed on plants and similarity of the impact of habitat conditions on the number of leaves.

Environmental conditions (management)	mean	group†
winter cereals	3.50	A
spring cereals	3.85	AB
stubble	4.27	B
potato cultivation	6.90	C

† Homogeneous groups of environmental conditions created according to the Tukey test.

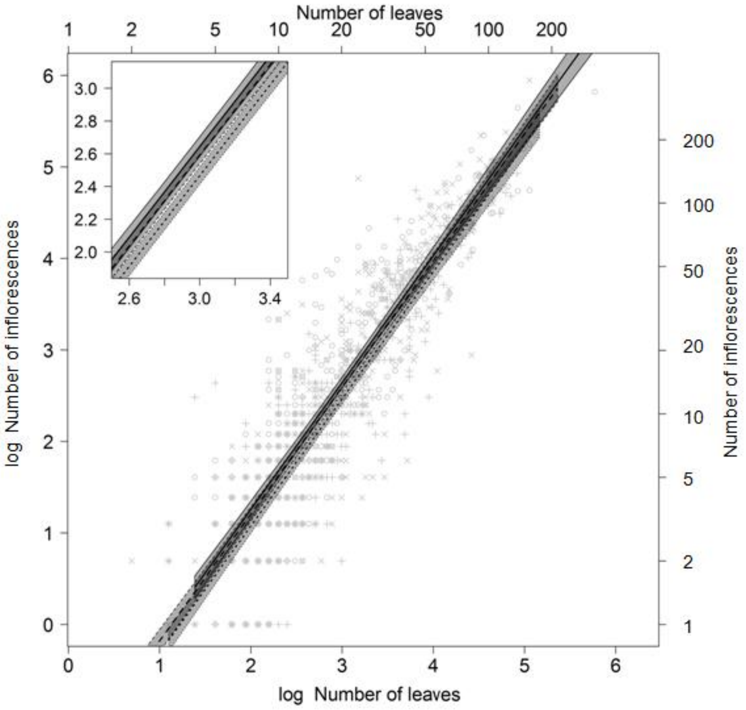

Figure 2: The linear regression function for taxa *Polygonum persicaria* L. (dashed line) *Polygonum lapathifolium* L. subsp. *lapathifolium* (solid line) *Polygonum lapathifolium* L. subsp. *pallidum* (With.) Fr. (dotted line) and their confidence intervals (gray area) showing the dependence of the number of inflorescences on the number of leaves.

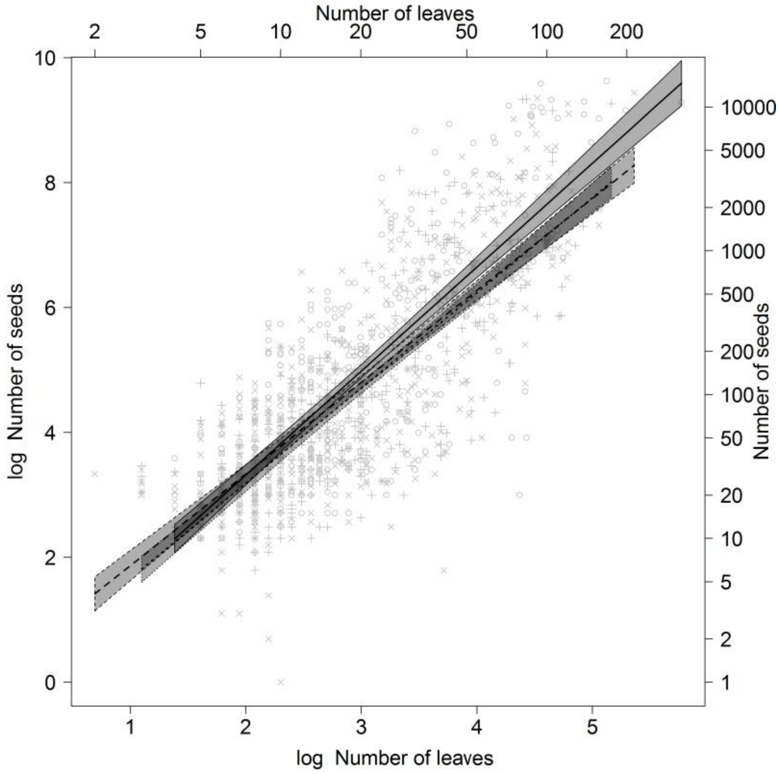

Figure 3: The linear regression function for taxa *Polygonum persicaria* L. (dashed line) *Polygonum lapathifolium* L. subsp. *lapathifolium* (solid line) *Polygonum lapathifolium* L. subsp. *pallidum* (With.) Fr. (dotted line) and their confidence intervals, showing the dependence of the number of seeds on the number of leaves.

Table 8: The regression functions for the number of inflorescences and the number of seeds is dependent on the number of leaves per plant.

taxon	the dependency formula	group
the number of inflorescences depends on the number of leaves		
Polygonum persicaria L.	$Y = 0.21 * X^{1.384}$	a
Polygonum lapathifolium L. subsp. *lapathifolium*	$Y = 0.22 * X^{1.386}$	a
Polygonum lapathifolium L. subsp. *pallidum* (With.) Fr.	$Y = 0.18 * X^{1.387}$	b
the number of seeds depends on the number of leaves		
Polygonum persicaria L.	$Y = 1.48 * X^{1.704}$	b
Polygonum lapathifolium L. subsp. *lapathifolium*	$Y = 0.99 * X^{1.663}$	a
Polygonum lapathifolium L. subsp. *pallidum* (With.) Fr.	$Y = 1.14 * X^{1.525}$	b

IV. DISCUSSION

The large number of seeds is one of the elements of a plant's adaptation to varying conditions, which allows the spread of species. A condition for high yield is often a high intra-species variation [6, 34].

Many authors [15, 16] indicate that the crop field is closely affected by the development of weeds. The given results indicate that the species of crop, in which the examined taxons developed, were influential on the values of the traits examined. The most favourable conditions for seed reproduction for the majority of the weeds, including *Polygonum* L. taxa, which is confirmed by this study, are found in root crops. In conditions of wide row spacing, good light access, manure fertilization, long growing season and less competition, they are able to produce a larger amount of seeds.

In compact fields, for example cereals, there is more competition from the crop and weeds have less possibility to create generative shoots, and thus produce fruits and seeds. A significant increase in the accumulation of biomass from weeds occurs only in the initial phase of grain growth. Later, due to the growing canopy, some of the weeds are 'drowned out' by the crop. Under the influence of increased sowing density, a significant reduction in weed biomass and limiting their productivity was found [10, 5]. In addition, data from the literature [16] indicates that weed fertility in the winter is much higher than in spring plants, as competition with spring crops is more limited by their rapid germination, growth and shadowing. This is not confirmed in these works. Observed values of traits in *Polygonum* L. taxa in winter and spring crops are insignificantly different, what is more, for all 3 taxa in winter the values are smaller and not bigger, which suggests a reverse dependence than described in the cited work. Differences in yield in winter and spring cereal crops are also conditioned geno-typically and depend on the weed species. Some of them are characterized by higher fertility in winter, others **-** in spring crops.

Studied *Polygonum* L. taxa displayed significantly higher values of the studied features on shoots than in cereal crops, especially winter crops. After the harvest of cereal plants, the shoots often remain very much uncultivated until late autumn [8]. The favourable thermal, light and moisture conditions that prevail in the after-harvest period on stubble fields enable further development of the weeds. During this time, some of them cut during harvesting grow back on the side branches generative organs, other undamaged at the time of harvesting grain can spend the seeds.

Research on correlations between important phenotypic traits and fertility has been conducted so far only for arable crops, among others rye, oats, rape or wheat. In plant breeding, it is desirable to learn the variability and interdependence of the basic morphological and utilitarian characteristics of the plant to determine the criteria for selection of genotypes with high potential fertility, resulting inter alia from the appropriate relationship of these traits. The purpose of this research was primarily to obtain plants with high productivity. Understanding the range of the variation of traits within the genus may contribute to the breeding of new, more resistant and more fertile varieties [29, 2, 14, 11, 32]. In terms of vegetal plants, knowledge on this subject could be useful in research for limiting the development of weeds in crops, especially their extensive seed production, feeding the seed bank in soil. An important issue is to understand the relationship between morphological features of plants and determine which ones determine high fertility.

V. CONCLUSION

1. The reaction of the number of leaves, the number of inflorescences and the number of seeds of three examined taxa of the genus *Polygonum* L. on environmental conditions was alike but not identical.
2. The species of crop, in which the examined taxons developed, were influential in terms of the values of the examined traits.
3. Individuals of the studied *Polygonum* L. taxa find better conditions for vegetative and generative development in potato cultivation than in compact fields of winter and spring cereals.

4. The relationship between the number of leaves and the number of developed inflorescences and seeds on one plant was established. There were slight differences in these relationships between taxa.

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