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Analysis of *Setaria glauca* (L.) P. Beauv. Population's Vital Parameters in Grain Agrophytocenoses

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The paper presents the results of research on key vital parameters of a one-year late spring segetal species *Setaria glauca* (L.) P. Beauv. in crops of grain and legumes in the conditions of the north-rast forest-steppe Ukraine. It has been observed that in *S. glauca* there is a statistically significant change in the complex population characteristics, in particular, indicators of development of the vegetative sphere and reproductive organs against the background of changes in the field conditions. It turns out that the values of the main morphometric parameters and their dynamics in weed plants statistically significantly change by gradient of different crops, which are dominant agrocenoses and significantly affect the development of segetal wild species. It is proved that each cultivated plant is an edificator of agrocenosis and has a significant phytocoenotic effect on the state of *S. glauca* populations. The study found that favorable conditions for the development of weed emerged in fields of peas and winter wheat, while the crops of winter rye and buckwheat significantly inhibited the development of *S. glauca* populations. Knowledge of the dynamics of vital parameters of *S. glauca* populations under various field conditions allows the effective application of the system of anti-weed crop rotation, which allows controlling the clogging of fields using environmentally safe methods without application of herbicides.

Keywords: population, vitality, production process, absolute growth rate, reproductive effort, index of renewal, index of generative.

Introduction

The problem of regulating weed abundance in areas planted with cultivated plants is complex and ambiguous. Intensive methods of controlling unwanted agrocenosis plants by chemical methods have led to negative side effects in the agrosphere and the biosphere, which means that herbicide leftovers constantly enter the soils, and do not fully decompose but accumulate in excessive quantities (Ligostaeva, 2005; Ajayanet al., 2011; Muzik, 1970). The vegetative plant population research in agrophytocenoses of cultivated plants aiming at their growth features and development study lasts more than one year and remains relevant because modern agribusiness built on the uncontrolled application of pesticides in recent decades has led to such negative phenomena as the decrease in resistance to modern storm varieties of cultivated plants, emergence of varieties of weeds resistant to chemical influence, soil and groundwater contamination by pesticides, accumulation of residual amounts in product crop production, and decline in overall biodiversity in the agrosphere. All these processes negatively affect human health (Urazaev, 1981). According to some researchers' opinions, intensive land-use practices will lead to the loss of natural soil fertility in a few decades (Da Costa & Duta, 2001). The problem of biodiversity conservation in agro-ecosystems is urgent because the sustainability of any ecological system is closely linked to the diversity of species of plants, animals, and micro-organisms that inhabit it. Considerable literature is devoted to addressing this global problem (Didukh, 2018; Rahman, 2018; Galperina & Soprunova, 2018; Wilsey, 2018). Recent studies have made it possible to reconsider general provisions on the status of segetal plant species. Modern agro-ecology changes the concept of total weed destruction to the progressive idea of regulating their number to an economically safe level (Zlobin et al., 2013). Instead of a virtually impossible procedure to destroy weeds, it is more economically appropriate not to allow them to grow massively. Besides, the rejection of aggressive chemical methods of segetal vegetation control can solve many environmental problems associated with environmental pollution and loss of soil fertility due to the disruption of natural processes of ammonia, nitrification, nitrogen fixation (Pischik et al., 2016). Ecologists believe that weeds have a positive effect on the sustainability of agro-ecosystems under moderate presence. These species are natural components of agrocenoses and become harmful only by mass reproduction (Kaur, 2018). With regard to useful properties, weeds prevent water and wind erosion of the soil, promote the mobilization of minerals from the lower soil horizons into the arable layer due to a well-developed root system, which can reach a depth of 3–7 m (Zakharenko, 2000). Weeds also play a positive role in the formation of agrocenosis, soil health and improve other parameters of agroecosystems: they mitigate the effect of monoculture on agrophytocenosis, provide beneficial entomophages with a habitat that thus supports biodiversity (Mariushkina, 1990). The above-ground vegetative organs of weeds, after dying off, turn into green manures, which are necessary for the soil to maintain microbiological balance, without which its ability to produce crops is lost. Each segetal species is adapted to specific environmental conditions; it is a genotype with unique biological properties that have not been sufficiently studied and can be used as breeding material (Rahman, 2018). Weeds with a narrow ecological amplitude are indicators of soil fertility and physicochemical characteristics of the soil (Holzner, 1982). A number of specialists emphasize that weeds do not harm when their number in crops is below the biological and ecological thresholds of harm (Kosenko, 1971; Morozov, 2007).

Weeds and cultivated plants, when grown together, emit a wide range of physiologically active organic substances into the environment. These processes form a certain biochemical environment, a kind of protective environment. A general assessment of the allelopathic activity of agricultural crops indicates that the older the culture, the less active it is. For the control of weeds, crops with higher allelopathic activity are preferred. Therefore, their inclusion in agrophytocenosis is very important (Grodzinskiy, 1965). For example, the inclusion of crops from the *Brassicacia* family in the crop rotation after harvesting cereals can reduce the weediness of the fields by 90%–96% (Bell, 1970). Crop rotation is the most important biological factor in modern agriculture, which has an intensive regulating effect on the number and species composition of the weed component of agrophytocenosis (Tulikov, 1982).

Long-term studies (Nikitin, 1983) show that, according to the edifying effect, cultivated plants are divided into three groups: strongly edifying, i.e., crops of continuous sowing, the projective cover of which is 100%, e.g., winter rye, winter rape, vetch, alfalfa, sunflower for silage; average edificators, i.e., plants of solid and ordinary spring sowing, the projective cover of which is 75%–80%, e.g., spring crops like wheat, barley, rice, buckwheat, soybeans, cotton, sunflower, corn; weak edificatory, i.e., row-planted plants with wide aisles or undersized solid-planted plants, the projective cover of which is less than 40%, e.g., all melons, most vegetables like carrots, cabbage, onions, beets, as well as peas and flax.

In terms of beneficial properties, weeds prevent water and wind erosion of the soil, facilitate the mobilization of minerals from the lower soil horizons into the arable layer, mitigate the effects of monoculture on agrophytocenosis, provide beneficial entomophagous with habitats supporting in such a way the biodiversity. In this regard, it becomes relevant to study quantitative morphometry of growth and formation processes in segetal plants in the field based on modern methods.

To prevent negative forecasts in agricultural production, environmentally safe methods of controlling weeds and pests, such as phytocenotic ones, should be used. These methods allow us to regulate weed populations due to the edificatory properties of cultivated plants. Growth feature processes and development study of segetal plant species is a component of population analysis (McCall, 2017; Zlobin, 2009; Bondarieva et al., 2019). Particularly informative is the use of complex population analysis, the important components of which are the determination of weed population densities in agrophytocenoses, as well as their ontogenetic and vital structure. Determination of the latter, in turn, involves the use of morphometric analysis aimed at assessing the signs of vegetative and generative organs of plants (Tykhonova, 2012; Tykhonova et al., 2016).

Methods

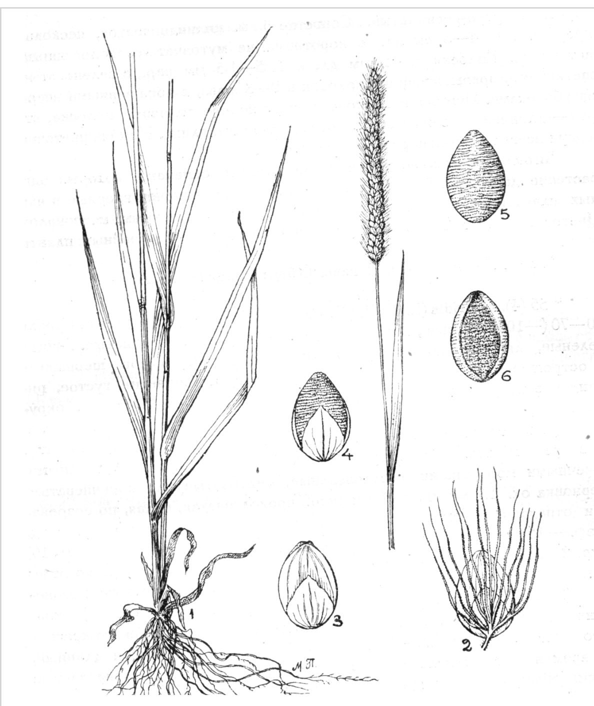
The object of the study is populations of the monocarpic late spring segetal species *Setaria glauca* (L.) P. Beauv. It is a widespread weed of cereals and croplands, an archaeophyte of Indo-Malay origin (Protopopova, 1991). The modern area of species is cosmopolitan. The species is characterized by a high diversity of ecological types, easily adaptable to different growth conditions. *S. glauca* populations are widespread in the segetal conditions of the forest-steppe of Left-Bank Ukraine (Tykhonova, 2011). The height of the plant is from 4 to 50 cm. At the base of the leaves, there are tufts of long twisted hairs. The root system is of mock type. It penetrates the soil to a depth of 30 cm to 80 cm. The inflorescence is a cylindrical sultan (Fig. 1). Spikelets are of 3 mm long and 2 mm wide with bristles of brown-red color, unbearded. It blooms in June. Inbreeding prevails. Fruits are ovoid grains of 2–3 mm long. They ripen in July or August. The average weight of 1000 pieces of seeds is 2.5 g. They maintain germination in soil up to 10–15 (30) years. They do not lose their germination even with prolonged stays in the water. Myrmecochory is observed, but it is not significant under seeding. The plant is thermophilic. The seedlings appear in late spring when the soil warms to the temperature of 15–20°C. The minimum temperature at which germination of grains is possible is 6–8°C, and the maximum is 42–44°C. The period of seedling rise is extended from late spring to autumn. Seeds come from a depth of 5 cm. Fresh seeds have a ripening period, which lasts on average for 15 months (Vasilchenko, 1979).

Analysis of vitality parameters of populations of late spring monocarpic segetal species *S. glauca* was performed under the conditions of agrocenoses of cereals and legumes on the experimental fields of the educational and scientific production complex of Sumy National Agrarian University.

The farm is located within the Sumy administrative district of the Sumy region, which corresponds to the forest-steppe natural zone. The climate of the study area is temperate continental. The average annual temperature is +6°C. The average annual rainfall is 510 mm. The soil of the experimental field that is black soil is typical, deep, slightly humus leached medium-loam. The reaction of the soil solution is neutral with pH 7.0, and the total humus content is 4%. The content of readily hydrolyzable nitrogen is 9.0 mg/kg, the content of mobile forms of phosphorus and exchangeable potassium are 14.0 and 6.7 mg/kg, respectively. Groundwater lies at a depth of 24 m. Therefore, the natural and climatic conditions of the study area are favorable for growing crops.

Scientists have studied populations of *S. glauca* in agrophytocenoses of frumentaceous, grain legume crops, and cereal crops such as winter rye, winter wheat, barley, buckwheat, and peas. In the experiment, all cultures were grown using classical technologies without herbicides. Potatoes were the predecessor in all experimental areas. The population status of *S. glauca* has been assessed using conventional population methods (Didukh, 2018; Gibson, 2014). Analysis of vitality parameters of populations was performed based on phytocenology methods outlined in the works of Zlobin (2018).

Fig. 1. *Setaria glauca* (L.) Beauv. *1 - general view, 2 - spikelet, 3–4 – spikelet in different positions, 5–6 – grain in different positions (by Keller, 1935)*



The first stage involved the morphometric analysis of individuals of weed populations under different agrophytocenotic conditions. The set and the number of morphological parameters were determined by the peculiarities of the morphology of the species. From the obtained number of quantitative traits that characterized the life condition of individuals, key parameters were selected that provided an integral assessment of the vitality of individuals (Zlobin et al., 2009). For the species studied, the following parameters were plant height (H, cm), total phytomass (W, g), a mass of generative organs (Wg, g), and leaf area (A, cm^2).

The second stage was the evaluation of the population vitality. To identify the characteristics of weed development, samples of plants in the amount of 80–90 pcs were taken from the experimental fields. Morphometry methods developed by Harper (Harper & White, 1974) were used to determine indices of the production process, growth, and formation of the investigated species. With the benefit of methods of statistics, the data obtained for each field were analyzed.

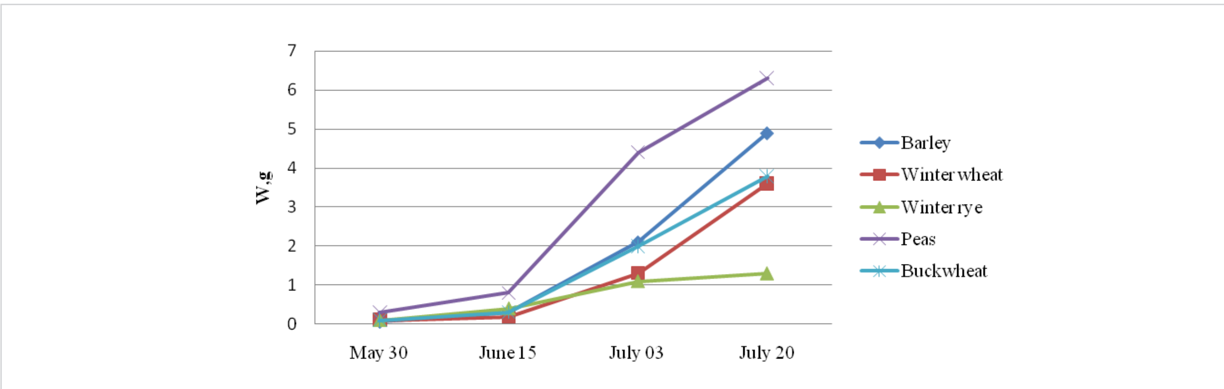
Reproductive efforts have been identified as the fate of the organism's resources aimed at the reproduction process. This indicator is a dynamic parameter that covers favorable or unfavorable conditions of plant growth. Therefore, the mass of plant reproductive organs was weighed in one ontogenetic state that is fruiting. The phytomass was calculated in the dry state. The most informative indicator is the reproductive effort, which is the ratio of the mass of generative organs to the total phytomass. The dynamics of the growth morphometric parameters of *S. glauca* during the growing season in different crops planted areas was observed, based on the data of different terms of measurement. During the growing season, the main growth parameters of individuals were recorded 4 times. Based on these measurements, we calculated the dynamics of growth in weed plants by the most important indicators. Based on the basic morphometric parameters, the generalization characteristics of the growth process were calculated: absolute growth rate, reproductive effort, recovery index, generative index.

Results and Discussion

The results of the main morphoparameters estimation values of *S. glauca* in the studied agrophytocenoses are presented in Tables 1–4 and in Figs. 2–5. It is established that at the time of the ripening of cultivated plants, in the second half of July, the conditions of pea agrocenosis were the most favorable, and the crops of winter rye were the least favorable. If we trace the dynamics of the growth processes of *S. glauca* on the agrophytocenotic gradient, we can see that the rapid recruitment of phytomass occurs in spring crops, i.e., peas and barley, weeds grow slowly in winter crops and buckwheat (Fig. 2). The species shows the maximum W-value in the last measurement period before the harvesting of the cultivated plant in crops of peas, i.e., 6.3 ± 0.7 g, and the minimum in cenoses of rye, i.e., 1.3 ± 0.05 g, where populations of *S. glauca* are rarefied and formed from weakened low plants without lateral shoots with narrow leaf blades.

Plant height (H) in the crops of *S. glauca* peas was 2.6 times higher than in the crops of rye and almost twice higher than in the crops of winter wheat and buckwheat.

Fig. 2. *Growth dynamics of aboveground phytomass (W, g) Setaria glauca in the different crops planted areas*



In the rye planted area, weed populations were most depressed, and pea agrocenosis conditions were most favorable for *S. glauca* growth processes. The H-value at the last measurement dates in the crops of peas was 80 cm, and in barley it was 48.2 cm, while in the crops of winter crops and buckwheat, this indicator was in the range of 31–38 cm (Table 1). The absolute growth rate of *S. glauca* in barley crops was 0.16 g/day, for wheat it was 0.12 g/day, for rye it was 0.03 g/day, for peas it was 0.2 g/day, and for buckwheat it was 0.13 g/day.

Table 1. *Setaria glauca plant height according to the variants of the experiment, cm*

Crop	30.05	15.06	3.07	20.07
Barley	6.0 ± 0.5	12.0 ± 1.1	30.1 ± 2.5	48.2 ± 2.3
Winter wheat	8.7 ± 1.4	8.9 ± 0.9	15.5 ± 1.8	36.2 ± 0.9
Winter rye	9.4 ± 1.2	20.8 ± 3.8	30.3 ± 1.9	31.2 ± 3.2
Peas	13.5 ± 0.3	17.6 ± 0.7	38.1 ± 4.1	80.7 ± 5.5
Buckwheat	4.6 ± 1.3	13.6 ± 1.1	34.2 ± 3.4	38.2 ± 3.5

Leaf-area duration (A) was chosen as an additional parameter in the study of the species. Planted areas of peas and spring barley had the best conditions for the formation of photosynthetic organs in *S. glauca* plants in which the average area of the leaf-area duration (A) of weeds reached 156.4 cm^2 and 151.2 cm^2, respectively. Planted areas of buckwheat and winter rye were the worst for the *S. glauca* leaf-surface development, where the leaf-area duration of one weed plant appeared to be insignificant and was 37.6 and 77.8 cm^2, which is about 3–5 times less than in favorable conditions (Table 2). Consequently, winter rye and buckwheat exerted considerable edificatory pressure on the development of the leaf-area development of *S. glauca.*

The most important biological processes include reproduction (Gibson, 2014). Annual weeds are propagated in an exclusively generative way. In *S. glauca*, units of generative reproduction are grains. Seed productivity of this species according to literary data (Vasilchenko, 1979) is 2000–3500 pieces, sometimes 5500 pieces of grains from a plant (as a maximum 13 800 grains were registered). In the conditions of the investigated agrophytocenoses, this indicator varied within 280–1300 pieces/plant. Observations revealed that in the conditions of research, seeds of this species begin to sprout at a soil temperature of 7–10°C and germination continues in the second half of spring and early summer in the forest-steppe of Ukraine.

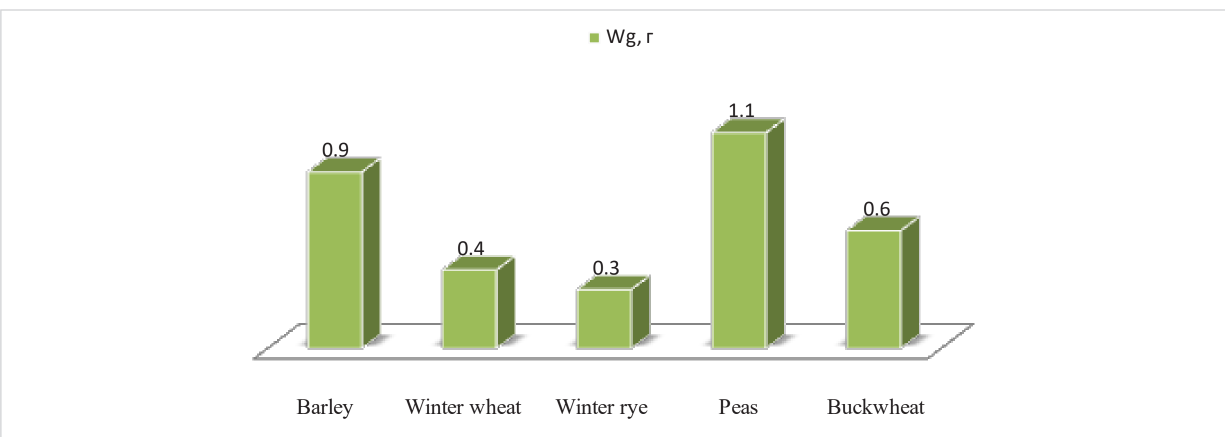
Table 2. *The leaf-area duration value of Setaria glauca according to the variants of the experiment, cm²*

Crop	30.05	15.06	3.07	20.07
Barley	5.5 ± 1.1	13.1 ± 4.6	64.5 ± 7.2	151.2 ± 15.3
Winter wheat	7.3 ± 3.1	10.9 ± 2.4	54.0 ± 14.0	98.0 ± 12.8
Winter rye	11.9 ± 0.7	18.9 ± 5.1	72.0 ± 6.9	77.8 ± 10.9
Peas	21.3 ± 1.4	36.0 ± 3.3	123.9 ± 21.3	156.4 ± 27.4
Buckwheat	6.2 ± 0.9	15.9 ± 1.8	29.5 ± 2.6	37.6 ± 5.2

The pea agrocenoses, in which *S. glauca* formed the largest number of seeds, were significantly distinguished on the gradient of cereals and legumes (Fig. 3). The total mass of inflorescences from one plant was 1.1 g. The optimal conditions for seed development were also formed in the spring barley planted area, where the Wg-value was 0.9 g. In planted areas of other crops, this rate was much lower, e.g., the Wg-value in winter wheat was 0.4 g, in buckwheat it was 0.6 g, and the lowest Wg-value which was 0.3 g was formed in the area planted with winter rye crops.

One of the characteristics of generative reproduction of segetal plants is the reproductive effort, i.e., the proportion of phytomass expressed as a percentage that the plant spends directly on the formation of organs of generative reproduction. This indicator may differ from others due to the significant ecological plasticity of the species. In areas planted with pea crops, the reproductive effort made 17%, barley made 18%, winter wheat made 10%, winter rye made 20%, and buckwheat had only 16%. In extreme conditions, winter rye coenosis was found to be the highest rate of reproductive effort. An important component of population research is the assessment of individual vitality and populations in general. In botanical works, it can be carried out based on vital analysis, in which the qualitative characteristics of plants and, as a result of the whole population, are determined based on the complex of dimensional characteristics of genets (ramets) presented in its composition (Zlobin, 2018; Tykhonova, 2011). To more fully represent the impact

Fig. 3. *Setaria glauca mass of the generative organs at the time of the cultivated plant harvesting, g*



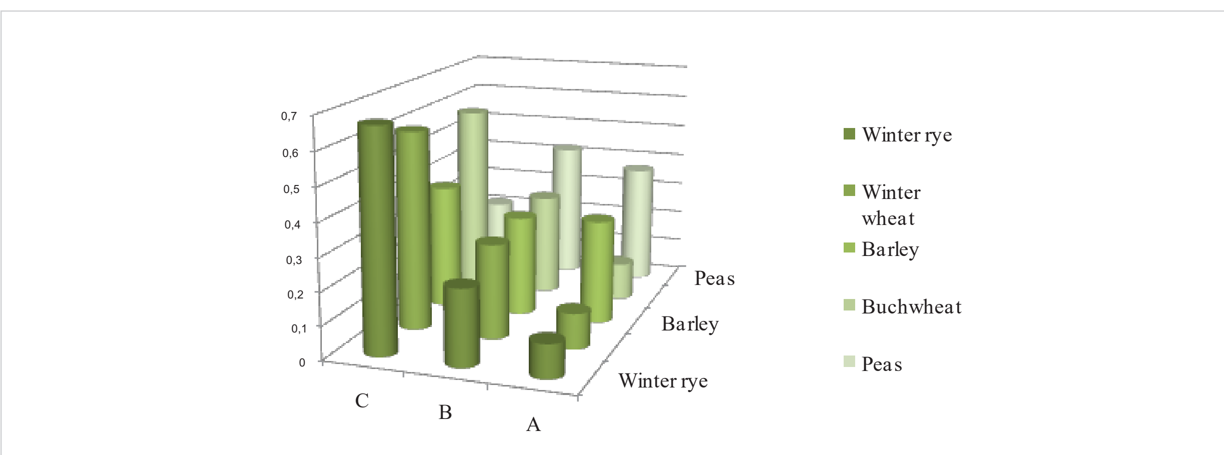
of different coenotic conditions on the development of *S. glauca* populations, their vitality analysis was conducted, which provides valuable information on the status of weed communities in planted areas of different crops separately and in combination with a comprehensive population analysis. The vitality analysis assesses the viability of populations of one or another plant species on the basis of morphometric indices followed by the establishment of population quality by the ratio of plants of high class "a", middle class "b" and low class "c". The population quality index allows us to generalize the concept of the state of a population under different phytocenotic conditions. If its value is less than 0.17, the population is depressed; if its value is more than 0.33, the population is prosperous; and if its value is within these two values, it is equilibrium. To analyze *S. glauca* population vitality structure, plants were sampled in a generative state in each of the investigated agrophytocenoses. Indicators characterizing the vitality of populations of this species are total phytomass, leaf area duration, and a mass of reproductive organs. The results of the vital analysis are presented in Table 3.

Table 3. *Setaria glauca populations' vital structure in planted areas of different crops*

Crop	Percentage of units by classes of vitality			Population quality index Q	Population type
	A	B	C		
Winter rye	0.102	0.231	0.667	0.16	Depressive
Winter wheat	0.108	0.288	0.604	0.20	Equilibrium
Barley	0.316	0.305	0.379	0.31	Equilibrium
Buckwheat	0.115	0.310	0.575	0.21	Equilibrium
Peas	0.368	0.421	0.211	0.39	Prosperous

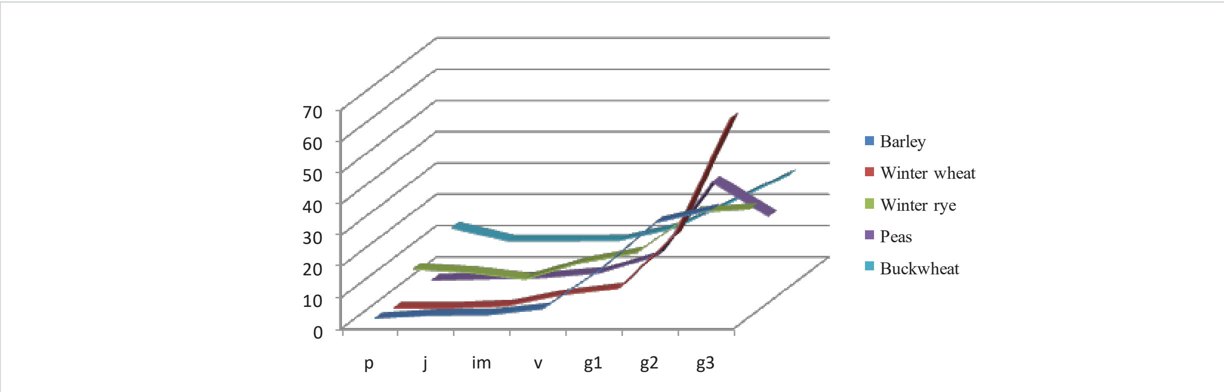
Vitality analysis of populations of vegetative plants shows a frank heterogeneity of individuals in terms of their development level and in the ratio in populations of individuals of different classes of vitality. Depending on the species of cultivated plant, vitality structure of weed populations varies from depressive to prosperous. The study found that flourishing populations of *S. glauca* with a quality index of 0.39 develop in areas planted with pea crops; in areas planted with winter wheat and buckwheat crops equilibrium populations form with quality indices of 0.20 and 0.21, respectively; weeds of all classes are represented in summer barley in equal shares that allow forming an equilibrium population with signs of prosperity with a sufficiently high-quality index of 0.31. Depressive populations with a quality index of 0.16 are formed in coenoses of winter rye (Fig. 4).

Fig. 4. *Setaria glauca vitality spectra in planted areas of different crops*



Growth processes are described by so-called growth curves. They can be built for the body so as for its parts. The growth of a plant as a whole and the development of its organs are unequal and it is not easy to determine these inequalities directly through the growth curves. Therefore, it is customary to assess the unequal growth of the plant and its organs by their size at a certain stage of ontogeny.

Fig. 5. *Ontogenetic spectra of Setaria glauca in planted areas of different crops*



Analysis of the periodization of the ontogeny of monocarpic *S. glauca* was performed according to the method of Makrushina et al. (2008). Ontogenetic spectra are known to carry important information about the general state of populations under different conditions of existence (Tykhonova et al., 2016). Assessment of the ontogenetic composition of *S. glauca* populations was performed immediately before harvesting. According to the Beideman scale, this corresponded to the following phases: in areas planted with cereals, it was 3.4–4.4; in areas planted with peas, it was 4.2–4.4; in areas planted with buckwheat, it was 3.2–4.3, and according to the BBCH scale, it corresponded to stages 66–77, respectively. This approach allowed us to obtain valid comparative material for the group of species studied. Recovery and generativity indices were calculated for each weed population in each type of agrophytocenosis (Fig. 5).

The index of generativity in the agrophytocenoses of barley, winter wheat and peas was at the level of 86%–95%, while in the cenoses of buckwheat and rye, it was at the level of 62%–68%. The index of weed population recovery in barley, winter wheat, and pea crops was 5%–13% in amplitude, and in areas planted with rye and buckwheat crops, it was 27%–29% (Table 4).

Table 4. *Ontogenetic spectra of Setaria glauca populations in different agrophytocenoses at the time of harvesting*

Crop	Certain ontogenetic state plants, part (%)							Recovery index,%	Generative index,%
	p	j	im	v	g_1	g_2	g_3		
Winter rye	2.0	3.1	3.2	5.1	17.3	32.6	36.7	13.3	86.7
Winter wheat	0.7	0.7	1.4	4.9	7.0	23.9	61.3	7.7	92.3
Barley	8.5	7.4	5.3	10.6	13.8	26.6	27.7	31.9	68.1
Buckwheat	0.4	0.8	1.2	2.7	8.1	31.7	55.2	5.0	95.0
Peas	12.5	8.3	8.3	8.4	12.5	20.8	29.2	37.5	62.5

Studies of areas planted with non-herbicidal crops have shown that the type of agricultural crop, which always acts as an edificator of agrophytocenosis, significantly affects the development of the *S. glauca* populations. Analysis of the vitality and ontogenetic structure of the weeds showed that this species is well adapted to growth, development, and reproduction in different conditions. *S. glauca* vividly illustrates the life strategy of the explerent, which is best suited to sustainable living in crop planting conditions (Kurdukova, 2018). The expressed ability to adapt to various environmental factors in both vegetative and ruderal conditions and to form viable seeds was noted in other species of the *Poaceae* family (Cheplick, 2014; Jarić et al., 2015).

Conclusions

Depending on the agrophytocenotic conditions, statistically significant changes in reproductive indices and a complex of population characteristics in *S. glauca* occur. This indicates the feasibility of using population analysis in weed research. An edificatory crop plant has a significant phytocenotic effect on the status of *S. glauca* populations in agrophytocenoses. The study proved that this species is well adapted to growth, development, and reproduction of vegetative conditions. *S. glauca* is an explerent according to its life strategy. Particularly favorable phytocenotic conditions for weed development are in coenoses of winter wheat and peas. In these cultures, the share of weed generative individuals at the time of harvest is 55%–62%. The vital analysis showed that in pea crops, flourishing weed populations develop; in winter wheat and buckwheat crops, equilibrium populations are formed; and depressive populations with a quality index of 0.16 are formed in coenoses of winter rye.

According to the ontogenetic analysis, agrophytocenoses of buckwheat and winter rye influence considerable phytocenotic pressure on the development of *S. glauca* populations, the generative plants share of which decreases to 28%–30% in the ontogenetic spectrum, and the juvenile plants share increases to 12%–18%. It has been established that in the agrophytocenoses of barley, winter wheat, and pea, the ontogenetic spectra of *S. glauca* have a pronounced right-sided nature with predominance in the populations of individuals of the state g_1, g_2, g_3, which indicates the optimal ecological conditions for *S. glauca*. In areas planted with buckwheat and winter rye crops, the ontogenetic spectra are isomerous indicating a moderate coenotic pressure of edificatory plants on the weed population. On the whole, the ontogenetic spectra of *S. glauca* are fully component and definitive, which indicates the normal process of weed generative restoration in the agrocenoses of the studied cultures.

The results of population analysis as a whole and the revealed the pattern of growth and development of *S. glauca* in various agrophytocenoses can be used in production in the preparation of weed crop rotations, which can suppress weed development and effectively regulate its number. The urgency of including such crops as buckwheat and winter rye before crop rotation to inhibit the development of *S. glauca* populations has been proved.

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