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AGROBIOLOGICAL BASES OF VETCH (*Vicia sativa* L.) CULTIVATION FOR SEEDS IN THE CENTRAL RUSSIA USING HETEROGENEOUS AGROCENOSES

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Abstract

Common vetch (*Vicia sativa* L.) is widely cultivated in the Russian regions with different climate and edaphic conditions, whereupon a significant plant polymorphism and specific adaptation to environment and cultivation technologies are observed. Recently, a new breeding approach is being developed to created vetch varieties for grain forage use. Since 2002, a new such variety, the Lugovskaya 98, is recorded in the State Register of Selection Achievements of the Russian Federation. This variety differs significantly from those cultivated for green fodder. Particularly, there is no hydrocyanic acid which is the main anti-nutrienent, and the level of trypsin inhibitors is reduced allowing the seeds of Lugovskaya 98 vetch to be used as protein source in animal feeds with no extra processing. In vetch pure stands a significant lodging occurs due to peculiar architectonics and biological peculiarities of plant growth under temperate climate. This necessitates vetch cultivation in the mixes with support crops. A complementary support crop and its stand density must be selected specifically in accordance with local soil and climatic conditions. We compared vetch Lugovskaya 98 seed yield formation in binary agrocenoses with different crops under stand density gradients and found those mostly complementary to vetch with regard to seed yield and quality. Plant allelopathic interactions were shown to begin during early ontogenesis. At high sowing rate of oats (*Avena sativa* L.) the vetch plant death increased up to 7-9 % compared to 3-4 % in the vetch pure stands. Vetch young growth was also 6 to 7 % suppressed in the mixes with white mustard (*Sinapis alba* L.). In contrary, *Phacelia tanacetifolia* had no effect on vetch young growth and juvenile plants. Generally, the vetch generative development was the best in the mixes with oat and mustard plants when the sowing rates of the support crops were low (i.e., not more than 1.00-2.00 and 1.50-2.25 million seeds per hectare, respectively). In these cenoses the bean number averaged 8.8-9.1 per plant, or 714-758 per square meter. As sowing rates of a support crop increased, the bean number reduced by 7-12 %. The highest vetch seed biological yield (283.6 g per square meter) was discovered in the mixes with the white mustard at sowing rate of 1.50 million seeds per hectare, and rather high yield of 260.5-267.5 g per square meter was recorded with phacelia and oat plants when their sowing rates were the lowest. Completeness of harvesting and seed quality in vetch are known to depend significantly on lodging. Before harvesting, in vetch pure stands the lodging was 74 %, and in mixes with oat, mustard and phacelia plants it was 22-42 % (depending on the cereal sowing rates), 37-45 %, and 54-56 %, respectively. Actual vetch seed yield was the highest (1.51-1.57 ton per hectare) when the white mustard or oat plants were used in mixes at sowing rates of 1.50 and 3.00 million seed per hectare, respectively. Under excess rainfall during vegetation vetch/oat ensured a complete harvesting vetch seeds due to less lodging, and at low rainfalls the vetch/mustard mixes were more convenient. According to vetch seed germination of 93-96 % and vigor of 77-83 %, the vetch/oat and vetch/mustard mixes ensured the highest seed quality. In lodged pure vetch these parameters were reliably lower (85 % and 65 %, respectively).

Keywords: common vetch (*Vicia sativa* L.), mixed stands, supporting crops, sowing rate, yield, seeds, seed quality

Common vetch (spring cultivar) (*Vicia sativa* L.) has a long, thin, easily lodging stem. Architectonic specificity and biological features of common vetch necessitates vetch cultivation in the mixes with support crops. Selection of complementary support crops and their proportions in vetch stands are defined by competitiveness of species and varieties, soil and climatic conditions, and herbage purposes. Abroad, common vetch is cultivated with grain cereals. Mixes with oat (*Avena sativa* L.) are most common [1-6]. In this, the mixing ratio varies considerably — from 25 % (oat) + 75 % (vetch) [6] to 75 % (oat) + 25 % (vetch) [4]. There is a tendency of the vetch proportion in the mix to be the greater the drier the climate is. Vetch cultivation in the mixes with (*Hordeum vulgare* L.), wheat (*Triticum aestuvum* L.), triticale (*Triticosecale* Wittm. ex A. Camus) is practiced as well [1, 7-9].

In Russia, regional methods have been developed for vetch cultivation for seeds in the mixes with various crops — spring cereals (oat, barley, triticale, wheat); cabbage crops (white mustard *Sinapis alba* L., rapeseed *Brassica napus* var. *napus*); legumes (broad bean *Vicia faba* L., narrowleaf lupin *Lupinus angustifolius* L., pea *Pisum sativum* L.) [10-12]. In commercial crops common vetch is mainly cultivated in oat mixes (the recommended seeding rate for pure live seeds for the Central Black Earth Region is 3.7-4.5 million pcs/ha) [12]. The advantage of oat as support crop against other cereals is, in particular, due to the fact that the use of sorting machines to separate vetch, barley, and wheat seeds is difficult because of their close biometric parameters [13].

The main objective of using mixed agrophytocenoses of vetch cultivated for seeds with support crops is crop regulation and formation of herbage suitable for high-quality mechanical harvesting, which requires learning the basics of such cenoses functioning. In turn, the state of mixed cenoses is defined by the quantitative ratio of their components based on agro-biological and agrocenose properties, as well as technological and varietal characteristics of the crops used.

Due to the wide distribution and cultivation in all 12 agricultural regions of Russia, that results in heterogeneous genotypes, common vetch varieties are considerably polymorphic in traits with individual responses to biotic and abiotic factors, including machinery, and unequal plasticity and homeostasis in the years of different (including extreme) weather conditions [10, 14-17]. There is evidence that vetch genotypes are adapted to place of origin and differ in the yields, with the realization of their potential depending on the growing conditions [18-22]. The reason is that, due to directional selection for a particular phenotype, the genotypic variability of cultivated species is narrowed and adapted to the breeding conditions [23].

Along with traditional vetch breeding for green fodder, specialized varieties for grain forage with high yield, increased protein levels and the absence or low levels of anti-nutrients in grain is currently under development in Russia [24]. Thus, since 2002, variety Lugovskaya 98 (originated from All-Russian Research Institute of Forages) was first registered as a grain forage variety. In this variety, the grain contains no hydrocyanic acid, and the trypsin inhibitory activity is 24-40 mg per 100 g dry matter only, being several times lower compared to MPC. The protein level in seeds is 31.8 %, protein biological value is 59.4 % indicating good quality [24, 25]. The variety Lugovskaya 98 was developed by hybridization and has specific morphological and biological features and economically important traits which distinguish it from a green forage variety. In particular, the plant architectonics has been changed to generative development in the upper part of the stem with converged fertile nodes, also the intensive growth and drought resistance until bloom, enhanced competitiveness in mixed stands, larger seeds of 80 g or more in weight per 1000 seeds are characteristic [13, 24]. All the above requires variety specific cultivation.

We first studied the biological peculiarities of plant development and herbage formation in grain forage vetch Lugovskaya 98 grown in binary cenoses at different abundance of support components. The most complementary support crops and the optimum proportion of the basic and support crops for the highest seed yield were estimated under the Central Black Earth Russia. A certain support crop was evaluated using argophytocenoses approach based on the study of plant competitiveness in heterogeneous agrophytocenosis and estimation of the support crop edificator ability by quantitating parameters of both components with special attention to yielding and yield structure of the legume component.

The purpose of this study was to determine the effect of support crop sowing density and the vetch grain forage variety on plant growth, yield, and seed quality in the main binary agrocenosis crop.

Technique. The field experiments have been conducted in 2006-2012 (All-Russian Research Institute of Forages) with oat variety Skakun, white mustard variety Lugovskaya, and lacy facelia (*Phacelia tanacetifolia* Benth.) variety Ryazanskaya used as support crops for common vetch variety Lugovskaya 98 at various seeding rates. Vetch was grown according to the recommendation for mixed crop in the Central region, at seeding rate of 1.3 million viable seeds per 1 ha [12]. Conventional row seeding was used for all crops studied. Vetch seeds were pre-inoculated with nodule bacteria *Rhizobium leguminosarum* bv. *viceae*, strain 145 (rizotorfin formulation).

Seed yields were assessed after threshing the entire plot area using Sampo 130 (Sampo Rosenlew Ltd., Finland) (2006-2009) and Classik (Wintersteiger AG, Austria) harvesters (2010 and 2012). Records and monitoring were carried out according to the accepted Guidelines for the Conduct of Field Studies with Forage Crops (Moscow, 1997). Crop phenology, sprouting of seedlings, plant growth dynamics, stand height, and crop lodging were studied, and the values of individual crop structure components, biological yield and sowing quality of harvested seed were estimated. An experimental plot area was 25 m^2. Experiments were conducted in four replications at a andomized crop location.

Data statistical processing was performed by variance analysis [26].

Results. Compatibility of vetch varieties with different grain cereals varies. Compared to wheat and barley, oat was a stronger vetch competitor [13]. In mixed crops, coexisting species share the habitat with a specific ecological capacity. As a result of allelopathic effects of biologically active substances excreted by viable seeds since the early ontogeny, oat may inhibit sprouting some vetch varieties [13]. Different vetch tolerance is manifested in the change of biometric parameters of seedlings, juvenile plants and, ultimately, in crop yielding. To diminish the negative impact on the vetch plants, it is recommended to reduce the oat seeding rate in proportion to the decrease of sprouting growth in a legume [13].

A comparison of the copmleteness of sprouting showed that vetch stand density decreased from 86 to 78 pcs/m^2 as the oat seed rate increased from 1 to 4 million pcs/ha (Table). In this, considerable crop deterioration and elimination of vetch plants, with sprout death increased up to 7-9 % compared to 3-4 % in the control, was observed with oat seeding rates of 3.00 and 4.00 million/ha, that is, at a higher cereal crop sowing density.

Compared to vetch, white mustard seeds germinated faster impacting negatively the legume sprouting. Thus, in the years of adequate soil moisture in post-seeding period, i.e., 120 % of normal rainfall in May decade II (2007), 141 % monthly rainfall in May (2008), and 166 and 121 % rainfall in May decades II and III, respectively (2009), the mustard plants entered the full seedling phase 3-4 days earlier than vetch plan ts. As a result of advanced mustard development, vetch sprouting reduced to 6-7 % (sample area 5 m^2) compared to pure stands (see Table).

Phacelia, with its longer sprouting period and decelerated growth in the first month as compared to mustard plants, had no negative impact on vetch stand density.

Yield structure and seed yielding in common vetch (*Vicia sativa* L.) variety Lugovskaya 98 depending on the support crop (Moscow Province, field experiment, mean values for the years of 2006-2010 and 2012)

Crop, viable seed seeding rate, million pcs/ha	1	Beans		4	5	Seed yield			9	10
		2	3			6	actual, tons/ha 7	actual, tons/ha 8		
Pure stand										
Vetch	69	786	76	6.5	74	281.0		0.70	74.74	85
Vetch mixed with support crop										
Phacelia (*Phacelia tanacetifolia* Benth.)										
2.10	69	747	82	6.4	54	260.5	0.13	1.16	74.10	88
3.10	67	667	84	6.3	54	245.8	0.20	1.21	73.32	88
4.10	68	684	85	6.2	56	219.9	0.22	1.02	73.11	90
Mustard (*Sinapis alba* L.)										
1.50	63	744	84	6.5	37	283.6	0.25	1.51	78.56	94
2.25	62	714	86	6.4	39	252.5	0.28	1.37	77.85	94
3.00	63	694	86	6.2	45	230.9	0.35	1.20	78.42	96
Oat (*Avena sativa* L.)										
1.00	66	758	83	6.6	42	267.5	0.65	1.25	76.55	93
2.00	65	744	84	6.5	36	240.2	0.94	1.42	74.95	95
3.00	62	708	86	6.4	27	221.3	1.32	1.57	73.62	94
4.00	60	670	86	6.4	22	206.4	1.60	1.40	73.58	94
LSD_{05}	–	60.20	–	0.30	–	23.72	–	0.11	2.77	3.4

N o t e. 1 — sprouting, %; 2 — total per m^2; 3 — mature, %; 4 — seeds per bean, 5 — lodging by harvesting, %; 6 — biological, g/m^2, 7 — support crop; 8 — vetch, 9 — weight of 1000 seeds, g; 10 — seed germination, %. The dashes indicate that statistical processing was not performed because of the large sample size.

Heterogeneous sowing which included different crops provided a much more complicated phytocenotic system in agrocenose hierarchy compared to pure stand crop cenoses. Vetch stand yields and structure in the mixes with support crops are determined by their growth biological characteristics and dependent on the specific soil and climatic, agronomic and phytocenotic factors, among which sowing densities of support crops and their ratio to that of the legume component are the most significant ones.

Quantitative parameters of vetch seed herbage elements in mixed crops varied in different ways depending on the abundance of the support crop. Thus, the bean number changed substantially (from 667 to 758 pcs/m^2, or by 14 %), whereas their seed yields changed to a lesser extent (6.2 to 6.5 seeds, or within 5 %) (Table). At the same time, generative development in the legume component was greatly influenced by support crop species and proportion [4, 13].

In general, the mixed stands with mustard and oat plants at their reduced sowing rates (1.00-2.00 and 1.50-2.25 million/ha, respectively) were the most favorable to develop generative organs in vetxh. This was manifested in a larger number of beans per plant (8.8-9.1 pcs.) and total bean number per unit area (714-758 pcs/m^2). As seeding rates of a support crop increased, the vetch bean number reduced by 7-12 % (see Table).

Completeness of harvesting and seed quality in common vetch are known to depend significantly on lodging: potential crop yield losses can reach 50 % or more with greater lodging [30]. According to our data, the timing and extent of mixed stand lodging varied considerably depending on the plant species, seeding rate, and weather. So, the growth of vetch variety Lugovskaya 98 was relatively slow from the phase of full shoots to the beginning of budding, with an average daily growth of 1.2-1.5 cm. Then, entering the reproduction period, the growth was accelerated to 2.5 cm/day or more, until the green bean formation. High crop lodging is most likely in the same period. In particular, lodging in vetch pure stands before harvesting was 74 % (see Table). At the same time, the beginning of the lodging was observed as early as the branching occurred. As a result, despite high biological yield in pure crops (281 g/m^2), vetch seed harvesting completeness was minimal and amounted just to 25 %.

Linear daily growth gain in oat plants in the first 5 weeks averaged about 1.7 cm. And in the first two decades after the full shoot phase, oat was superior to vetch in its height by 50-76 %, and then in the flowering phase, vetch was 12 % superior to the support crop. In oat paniculation phase, both components were aligned in height, but later the growth in vetch was superior to oat in case of enough soil moisture. The most intensive growth of vetch plants was observed in 2008, when rainfall was over 142 % of norm during the growing season, including 110-138 % in June and July. Active vetch growth was observed in 2009 under the 2.1-fold rainfall excess in July decade I compared with the average annual value.

The mixed stand lodging decrease with an increase of cereal crop proportion in vetch/oat mixes was found as a general regularity (see Table). In vetch/oat stands, the lodging was 22-42 % depending on the abundance of bluegrass support component, i.e. it differed by 2 times. Stem type lodging prevailed in the seasons of typical weather conditions, and additional root lodging was observed under excessive moisture.

The growth of white mustard plants was decelerated to 0.8 cm/day, being 38-39 % less than in vetch, in the decade I. Starting from pentad III and throughout the following month, mustard plants had the highest growth of about 2.7 cm/day, and by the vetch budding the supporting plants were superior to vetch in stem height by 34 %.

Crop resistance to stem lodging is determined by the development of intercalary meristem, mechanical tissue layer and vascular bundles in the parenchyma, and by the thickness of sclerenchyma ring, which affects the diameter of internodes and the thickness of stem walls [27]. Lodging depends on the morphological and anatomical parameters of support crop stem corresponding to the load the stem is exposed to. Mustard stem stiffness was 26.9 kg/cm^2, with bending strength of 26.3 kg/cm^2 and fracture resistance of 1.45 kg/cm^2, and in oat plants the values were 16.3; 20.3, and 1.0 kg/cm^2, respectively [28]. In vetch-mustard mixed stands lodging was 37-45 % increasing with the increased cabbage component proportion. A disadvantage of vetch/mustard mixes was their high lodging at excessive moisture due to mustard bolting and thin stem formation. Under these conditions, bolting and reflorescence were observed in vetch, too. This was most pronounced in 2008, when due to an increased rainfall in June and July (110-138 % of norm), crop mix lodging reached 68-73 %. Higher lodging (42-52 %) was observed in 2006 with secondary vetch growth in the maturity phase due to excessive rainfall in August at 75.3 % excess compared to the average long-term value.

Compared to other species studied, in phacelia the growth was the slowest in the first 2-3 weeks with an increase in plant length of 1.1 cm/day, being by 58-70 % behind vetch in the first post-sprouting decade. Then, phacelia growth accelerated (first up to 1.8 cm/day, then to 2.6 cm/day), and by the beginning of vetch budding, the components of the mix were aligned in the plant length. Phacelia has upright ribbed stems up to 80-100 cm, and, therefore, seems to be a promising support crop for vetch. However, compared with mustard and oat, phacelia/vitch mixes were most affected lodging which, under temperate climate with enough and excessive moisture, reached 54-56 % with more pronounced root type.

In the mixed crop, plants interact physiologically and biochemically due to root excretions. As a result of *Rhizobium leguminosarum* bv. *viceae* nodule bacteria activity on the root system, common vetch contributes to soil enrichment with biological nitrogen up to 74-109 kg/ha, thus increasing soil fertility [29]. An important feature of annual legumes is their active symbiotrophic nitrogen nutrition which is 1.7-2.5 times higher under mixed cultivation with cereals. The reason is that a cereal crop which absorbs the available soil nitrogen intensely stimulates nodule bacteria activity. Moreover, the cereal component absorbs part of nitrogen fixed by rhizobia, which is indirectly indicated by an increased nitrogen levels in seeds and straw in mixed crop [30]. Vetch inoculation with specific symbiotic strains enhances symbiotic nitrogen fixation, thus considerably increasing the yield and its quality [31]. Here, vetch varieties are genotypically differentiated for their responses to inoculation. Lugovskaya 98 variety is characterized by wide amplitudes and high efficiency of complementary symbiotic interaction with natural and selected root nodule bacteria strains [32, 33].

The effectiveness of bluegrass interaction with legumes in mixed stands depended on its abundance. Thus, vetch had a favorable effect on oat growth in a mixed stand at a ratio of 1:1-1:2 only. In such stands, compared to pure cereal crops, an increase in oat plant height of 9 %, in the number of leaves of 15-17 %, in the number of spikelets per inflorescence of 10-13 %, and in the average absolute dry mass per plant of 18-20 % were observed [34]. With the vetch/oat abundance ratio to 1:3-1:4, the positive impact of legumes on morphological and biological traits of cereals was negligible and within the experimental error, compared to those in pure cereal crops [34]. Consequently and as a result of the increasing intraspecific competition in denser crops, oat reproduction rate in the mixed stand was 20 and 15 % at seeding rates of 1.00 and 2.00 million pcs/ha, respectively, even at higher lodging (42 and 36 %, respectively), and 14 and 12 % only when the seeding rates were 3.00 and 4.00 million pcs/ha with 27 and 22 % lodging (see Table).

The actual and biological grain yields are the most objective criteria for evaluating biological effectiveness of mixed crops and the reflection of the aggressiveness of competitive component interference [35]. A comparison of these figures in two-component agrocenoses demonstrated the highest vetch seed biological yield (283.6 g/m^2) in the mixes with white mustard plants at the seeding rate of 1.50 million pcs/ha, and with phacelia and oat plants (260.5-267.5 g/m^2) when the support crop seeding rates were the lowest (see Table).

The main purpose of creating mixed agrophytocenoses is managing the crop quality and yield, and technological suitability for mechanical harvesting. As a result of support crop seeding rate and lodging balance, actual vetch seed yield was the highest (1.51-1.57 ton/ha) when mustard or oat plants were used in mixes at seeding rates of 1.50 and 3.00 million pcs./ha, respectively. Compared to mustard, more intensive transpiration is characteristic of oat plants. Mustard is less resistant to lodging at excessive moisture. The efficiency of support crops varied depending on the moisture during the growing seasons and the associated crop lodging: in 2006 with 175 % of normal rainfall in August, and in 2008 with 130 % rainfall in June and July, vetch/oat mix was by 22-51 % superior to vetch/mustard mix for actual yields. In 2007 and 2009, at low, 72 and 91 %, rainfalls from June to August, respectively, and elevated temperatures, the vetch/oat mix yield was, on the contrary, by 18-50 % inferior to the vetch/mustard mix.

Seed sowing qualities are integrated indicators which reflect the peculiarities of physiological and biochemical processes of seed formation depending on the fluctuations of exogenous and endogenous imperative factors. Cultivation and harvesting technology has a great influence on vetch seed sowing qualities [36, 37]. When threshing at full maturity of 82-86 % of beans, the most mature seeds with a significant excess in the weight of 1000 seeds (by 3.08-3.82 g at LSD_{05} of 2.77 g) compared to control were obtained in vetch/mustard mixes (see Table). As to seed germination (93-96 %), the highest vetch seed quality conformed the state standards for the original and elite seeds (GOST 11230-95), was provided in heterogeneous agrocenoses with mustard and oat plants (see Table). In this, seed vigor was 77-83 %. At the same time, lodged pure vetch seeds, though met GOST conditioning requirements, had significantly lower germination (85 % at LSD_{05} of 3.4) and vigor (65 % at LSD_{05} of 5.0).

Thus, common vetch variety Lugovskaya 98 is advisable to be sown for seeds in the Central Black Earth Region of Russia at seeding rate of 1.30 million pcs/ha in mixes with support crops differentially selected for the species and seeding rates. The use of white mustard support crop at seeding rate of 1.50 million live seeds per ha is more efficient in the areas with less rainfall and in upland areas. Vetch/oat crops at a bluegrass seeding rate of 3.00 million pcs/ha should be used in the lower areas and at excessive moisture.

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