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RESEARCH ARTICLE

Growing lupine and vetch in mixed crops

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Abstract

This paper aimed to determine the efficiency of growing spring vetch and narrowleaf lupine in mixed crops to produce grain forage. Further, the paper evaluated the influence of seeding quantities, component ratios, and weather conditions on yield and reaction in agrophytocenosis. Field tests and results processing complied with the appropriate methods. The paper examined weather conditions, quality of grain forage, yield, land equivalent ratio, competitiveness, and aggressivity of crops. Land equivalent ratio (LER) reached 1.41 to 1.77 when planting mixed legume grains at seeding quantity of 0.9 to 1.4 germinating seeds per hectare, where vetch amounts to 32%–42% of lupine content (0.38–0.45). The research demonstrated the resilience of crops to lodging and their suitability for thrashing. Under favorable humidification (Selyaninov hydrothermal coefficient (SCC) at 1.6), narrowleaf lupine grains constitute the bulk of the yield (65%), while at less favorable humidification (SCC 0.62), spring vetch generates most of the yield (80%). Neither crop demonstrates a significant advantage under moderately arid conditions. under unfavorable weather conditions, the competitiveness of vetch (CRba) relative to lupine elevates from 1.8 to 7.3, while its aggressiveness (CAba) decreases from 4.9 to 1.6. This suggests that there is positive alleopathy and environmental tolerance in lupine and vetch agrophytocenosis. The research demonstrated the possibility of efficiently growing spring vetch and narrowleaf lupin in mixed crops in the Middle Urals to produce high-protein grain concentrate. Further, the research established the optimal seeding quantity and component ratio and evaluated the influence of weather conditions on yield and changes in the proportion of harvested crops.

Keywords

Narrow-leaved lupine, spring vetch, agrophytocenosis, land equivalent ratio, competitive ratio, coefficient aggressivity

Introduction

The intensive production of plant-based proteins for animal farming and the food processing industry remains one of the main tasks for global agriculture. However, since soil and climatic zones impose limitations on soy cultivation, other legume crops should be grown to ensure stable and profitable grain crop production where such unfavorable conditions prevail. Only innovative legume crop cultivation methods can help address this issue.

Effective production of grain crops with high protein content, namely narrowleaf lupine and spring vetch (*Lupinus angustifolius* L.; *Vicia sativa* L., 1753), is possible in the Middle Urals and other climatically similar regions. These grain crops surpass pea in terms of content and quality of seed protein. Nevertheless, there is only small-scale cultivation of lupine and vetch despite the availability of new grain forage cultivars, animal feeding, and protein concentrate processing technologies (Tyurin, Kosolapov 2013, 2016; Tyurin et al. 2013; Zotikov et al. 2018). Forage lupine grain is much cheaper than soybean protein meal and is comparable in quality (Privalov, Shor 2015).

Legume grains take 2.8% of the Russian cultivated areas and 5% of the grain cultivated areas (Toshkina, Ambartsumova (2019). However, this proportion is insufficient for providing protein-rich forage to agriculture. At the same time, soy is primarily responsible for the increase in grain cultivated areas.

Both narrowleaf lupin and spring vetch are versatile crops with significant biological and economic potential. These crops are a major resource of highly digestible unprocessed protein for animal farming. The introduction of modern cultivars into agricultural production should aid import phase-out and increase animal farming forage resources in the most cost-efficient way (Ageeva, Pochutina 2017).

Modern agricultural production features the single grain cultivation of narrowleaf lupine and spring vetch, along with their cultivation in communities (agrophytocenosis) with wheat, barley, and oats. However, these cultivation methods are economically inferior to the production of wheat and barley. Today, profitability is an essential criterion in agricultural crop production. Therefore, an increase in grain and forage lupine and vetch can only occur with the introduction of more profitable techniques than spring wheat production.

Plants compete for space in natural and artificial agrophytocenosis. As a result, some become prospering and dominating, while others are inhibited and underdeveloped. In natural agrophytocenosis, favorable conditions lead to a complex community of species without dominating ones. Conversely, strongly unfavorable conditions diminish the importance of competition, while environmental conditions become the main inhibiting factor (Ramenskiy 1938).

Competition may be different in artificial agrophytocenosis with few species. For the agrophytocenosis to be successful, plants should have the following characteristics: root and vegetation layering, weak competition, different vegetative phases, similar or compatible cenotype, no lodging during the vegetative phase, guaranteed yield in any weather conditions, enhanced tillage productivity.

The relationship between plants in mixed agrophytocenosis is characterized by the overall plant survival rate. This rate is based on the seeding quantity, germinating power, the safety of plants during the vegetative phase, all defining population at harvest (Toshkina, Ambartsumova 2019).

Between 1976 and 1978, mixed crops of lupin and vetch were planted in Belarus. However, their productivity was lower than mixed vetch, mustard, oats, and single crops (Kukrash, Lukashevich 1989).

Researchers from the Ural Research Institute of Agriculture, a branch of the Ural Federal Agricultural Research Center of the Ural Branch of the Russian Academy of Sciences, explored effective cultivation of vetch-lupine agrophytocenosis conducting a study in 2001–2003 (Vyatkina, Matern 2005). The All-Russian Research Institute of Grain Legumes and Cereals (Orel, Russia) independently conducted similar research between 2007 and 2008 (Glazova, Zotikov 2010). Growing vetch and lupine in the environment of Novgorod Region was researched between 2013 and 2018 (Toshkina, Ambartsumova 2019).

In mixed crops with oats, barley, and wheat, spring vetch acts as a cenotype-E plant. It has low competition power, tends to be inhibited, but can overtake cleared space at an extremely high rate. At the same time, when growing in agrophytocenosis with narrowleaf lupine, spring rapeseed, and white mustard, vetch acts as a cenotype-V, vigorous development and overtake of territory, or cenotype-P, tolerance to extreme conditions (permanent or temporary), plant (Bezgodov, Yalunina 2016; Bezgodov et al. 2020a, 2020b; Glazova, Zotikov 2010; Kukrash, Lukashevich 1989; Zotikov et al. 2012).

Streamlining of lodging legume crops cultivation which accounts for the specific environmental conditions and biological characteristics of a cultivar, can help reduce the deficit of plant-based protein. In addition, mixed crops can increase plant-based protein production due to reduced loss at harvest (Lukashevich et al. 2018)].

Using white lupin and Andean lupin along with other annual legume crops during the cold season can help achieve a greater yield of forage and grains, as well as can be economically justified by high land equivalent ratios (LER) at 0.96–1.16 and more efficient use of natural resources (Mikić et al. 2013).

Studying the impact of lupin-vetch agrophytocenosis on grain crop yield at various weather conditions during the vegetative phase is relevant. Such knowledge would help further develop the necessary technology for cultivating lupine and vetch crops and enhance their productivity.

Material and methods

Research on cultivating grain lupine-vetch mixed crops was conducted in 2001–2003, 2016–2017, and 2020. The objective was to explore the possibility of growing spring vetch and narrowleaf lupine in mixed crops for grain forage. The research problem was determining the influence of seeding quantity, component ratio, and weather conditions on yield and cultivar response in agrophytocenosis.

The Ural Research Institute of Agriculture, a branch of the Ural Federal Agricultural Research Center of the Ural Branch of the Russian Academy of Sciences, conducted the research under the Government order of the Federal Agency for Scientific Organizations on "Creating and improving adaptive cultivation technologies of economically important crops based on optimization of biotic and abiotic factors".

Test samples were planted in dark-gray heavy loam soil. Agrochemical profile of test sites: pH 4.8–5.4; humus 3.5%–4.3%; the sum of bases 12–26 mEq/100g of soil; easily hydrolyzable nitrogen 80–104 mg/kg; phosphorus pentoxide 150–270 mg/kg, potassium oxide 80–190 mg/kg of soil. Agricultural engineering was typical for the Middle Urals area. The experiment featured fourfold replication of plots with systematic layered positioning. The plot area was equal to 10–13.5 square meters. The predecessor was cereal (barley). Mineral fertilizers were introduced during preplanting cultivation at a ratio of 30–60–90 (2001–2003) and 30–30–30 (thereafter) kg of active ingredient per hectare. Crops were planted in early May (on May 14 in 2016 and 2017). The soil was rolled after planting. In 2016, 2017, and 2020, the soil was treated with the herbicide "Algoritm" (clomazone) at a ratio of 200 g/ha.

Test crops included: narrowleaf lupine cultivars Dikaf 14 (2001–2003), Vityaz (2016–2017), Ladny (2020); spring vetch cultivars Lgovskaya 22 (2001–2003), Assorti (2016–2017), Mega and Ugolek (2020).

Weather conditions during the vegetative phase greatly varied across the years of the study. For example, the years between 2001 and 2003, as well as the year 2017, were favorable in terms of humification. Similarly, the years 2001, 2003, and 2017 were favorable in terms of temperature. Conversely, the years 2016 and 2020 were arid and hot, and the year 2002 had heavy precipitation combined with low temperatures during the vegetative phase (Table 1, Fig.1).

Table 1. Conditions during the vegetative phase

Year	$\Sigma t>10\ ^0C$	Precipitation amount, mm	SCC
Average	1772	272	1.53
2001	1814	298	1.64
2002	1582	294	1.59
2003	1966	283	1.44
2016	2102	130	0.62
2017	1851	297	1.60
2020	1683	163	0.97

Source: Compiled by the authors.

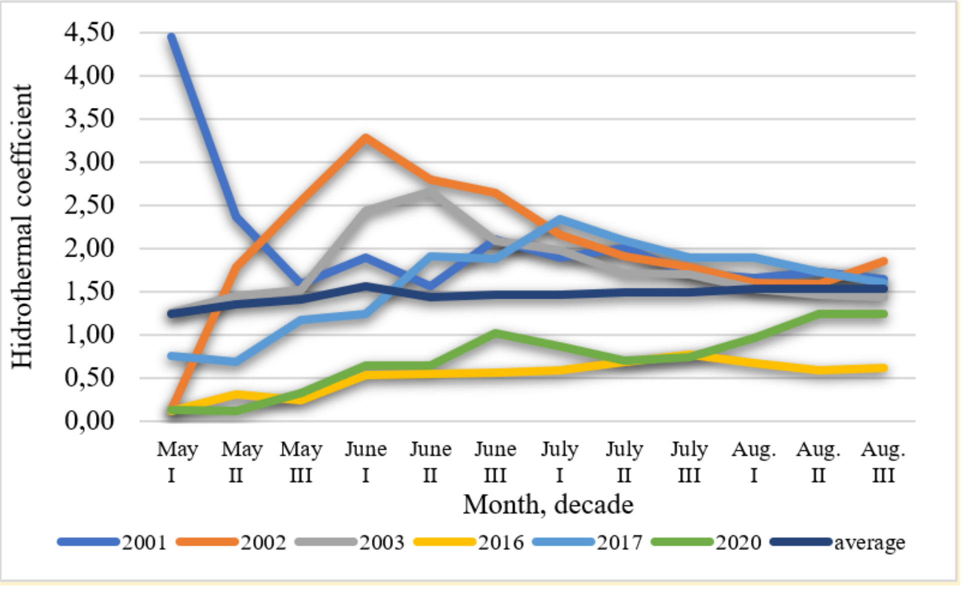

Figure 1. Characteristics of the level of moisture supply of the growing season, Selyaninov hydrothermal coefficient (SCC). Source: Compiled by the authors.

Results

Under favorable weather conditions, vetch yielded 2.6 to 3.6 tons per hectare (Table 2) in the Middle Urals. However, single-crop crops lodge significantly, which causes considerable yield loss at threshing.

Table 2. Yield and component ratio in agrophytocenosis

Variant, seeding quantity	Yield, t/ha			Mean yield	
	2001	2002	2003	t/ha	% to vetch
Barley 5.5 mln.	3.55	4.70	5.00	4.42	141
Oats 6.5 mln.	3.01	4.00	4.70	3.90	125
Vetch 1mln. + oats 3 mln.	1.85	4.20	4.58	3.54	113
Vetch 1млн. + oats 1.5 mln. + barley 1.5 mln.	3.17	4.90	4.50	4.19	134
Vetch 2.0 mln.	2.59	3.60	3.19	3.13	100
Lupine 1.2 mln.	2.18	1.75	2.64	2.19	70
Lupine 85% + vetch 15%	3.26	3.88	3.30	3.48	111
Lupine 75% + vetch 25%	3.53	4.35	3.40	3.86	123
Lupine 50% + vetch 50%	3.51	3.77	3.80	3.69	118

Variant, seeding quantity	Yield, t/ha			Mean yield	
	2001	2002	2003	t/ha	% to vetch
Lupine 25% + vetch 75%	3.48	3.52	3.81	3.60	115
HCP05	0.30	0.18	0.27		

Source: Compiled by the authors.

The area under this crop has decreased so much that vetch, like peas, could not be a protein filler for balancing concentrated forage. The high labor intensity and the lack of cost-effective technologies for the available cultivars contributed to this decrease.

In terms of mechanical composition, Sverdlovsk Region soils are medium to heavy loams, limiting the potential of narrowleaf lupine. As a result, its yield is just 70% of spring vetch yield and 50%–56% of cereal yield. At the same time, growing a mix of vetch and lupine for forage resulted in unlodging or slightly lodging agrophytocenosis, while its productivity was 11.2 to 23.3% higher than single crops of vetch and reached that of cereals.

Like other researchers growing vetch in mixed crops with cereals, we have noted a decrease in yield compared with single crops. Specialists recommend this technique (Mednov et al. 2018; Rakhimova, Khramoy 2018) for obtaining vetch seeds.

Vetch growing in mixed crops with oats and barley is not technologically sound and does not help significantly increase forage protein. At the same time, vetch-lupine agrophytocenosis can yield 914 to 1111 kg/ha yield of raw protein with grain protein content between 28 to 31.6% (Table 3).

Table 3. Yield and protein content in agrophytocenosis component grains

Variant, seeding quantity	Raw protein kg/ha				Raw protein g/kg			
	2001	2002	2003	Mean	2001	2002	2003	Mean
Barley 5.5 mln.	362	432	445	413	102	92	89	94
Oats 6.5 mln.	373	345	550	436	124	116	117	119
Vetch 1 mln. + oats 3 mln.	407	625	594	542	220	149	130	166
Vetch 1 mln. + oats 1,5 mln. + barley 1.5 mln.	643	526	660	610	203	107	147	152
Vetch 2.0 mln.	763	1027	971	920	295	285	304	295
Lupine 1.2 mln.	370	371	499	413	170	212	189	190
Lupine 85% + vetch 15%	914	1067	984	988	280	275	298	284
Lupine 75% + vetch 25%	1027	1249	1075	1117	291	287	316	298
Lupine 50% + vetch 50%	1052	1058	1111	1074	300	281	292	291
Lupine 25% + vetch 75%	973	977	1111	1020	280	278	292	283

Source: Compiled by the authors.

In 2001–2003, the lupine and vetch agrophytocenosis with 75+25% and 50+50% rates of the total seeding quantity were the most productive.

The past experiences of cultivating lupine and vetch agrophytocenosis (Kukrash, Lukashevich 1989; Toshkina, Ambartsumova 2019; Zotikov et al. 2018) highlight the need to evaluate reactions of vetch and lupine to growing in mixed crops, as well as the influence of seeding quantity and weather conditions during vegetative phase on agrophytocenosis.

In the Middle Urals, under favorable weather conditions (SCC 1.4–1.6), spring vetch yielded 2.5 to 3.13 tons per hectare, while narrowleaf lupine yielded 2.19 to 3.59 tons per hectare. However, with unfavorable and arid conditions (SCC 0.62–0.97), the yield reduced significantly, up to 58% for vetch and 65% for lupine (Table 4).

The agrophytocenosis component ratio and yield directly depend on weather conditions during the vegetative phase. When weather conditions change from favorable to arid, the portion of lupin in yield decreases while the portion of vetch grows. In 2016, the portion of lupin in mixed lupin and vetch crops was 20.2% to 30.7% (SCC 0.62). In 2020, it was 45.2% to 51.6% (SCC 0.97). In 2017, the portion of lupine was 64.7% to 82.8% (SCC 1.6).

Table 4. Field performance and agrophytocenosis component ratio

Variant, seeding quantity	Yield, tons/ hectare	%		LER
		Lupine	Vetch	
2001–2003, SCC 1.4 to 1.64				
Vetch 2 mln.	3.13	-	100	1.0
Lupine 1.2 mln.	2.19	100	-	
Lupine 85% + vetch 15%	3.48	-	-	1.49
Lupine 75% + vetch 25%	3.86	-	-	1.57
2017, SCC 1.60				
Vetch 1.5 mln.	2.50	-	100	1.0
Lupine 2.0 mln.	3.53	100	-	
Lupine 85% + vetch 15%	3.56	82.8	17.2	1.08
Lupine 70% + vetch 30%	4.78	64.7	35.3	1.56
HCP05	0.29	-	-	-
2020, SCC 0.97				
Vetch 1.25 mln.	1.37	-	100	1.0
Lupine 1.25 mln.	1.67	100	-	
Lupine 75% + vetch 25%	2.10	48.4	51.6	1.41
HCP05	0.15	-	-	-

Variant, seeding quantity	Yield, tons/ hectare	%		LER
		Lupine	Vetch	
2016 SCC 0.62				
Vetch 1.5 mln.	1.54	-	100	1.0
Lupine 2.0 mln.	1.22	100	-	
Lupine 85% + vetch 15%	1.72	30.7	69.3	1.20
Lupine 70% + vetch 30%	2.58	20.2	79.8	1.77
HCP05	0.12	-	-	-

Source: Compiled by the authors.

At the same time, under any weather conditions, lupine and vetch agrophytocenosis yielded more than a single crops plot. For example, plots where lupin and vetch were planted in 75 to 25 and 70 to 30 ratios to the total seeding quantity demonstrated stable annual growth of field performance from 41% to 77%. Such performance allows characterizing mixed lupine and vetch crops as an efficient, self-regulating agrophytocenosis. Furthermore, vetch lodges significantly less in mixed lupine and vetch crops, while grain harvesting is possible with threshing and ensures yield.

Land equivalent ratio (LER), competitive ratio (CR), and coefficient aggressivity (CA) are used to characterize mixes and changes that occur within mixed crops (Laman et al. 1996). The higher the LER is, the more effective is field use. In mixed crops, lupine has an advantage during humid years with moderate temperature, while vetch has an advantage during arid and hot weather conditions (Table 5).

Table 5. The influence of growing conditions on efficiency, competitiveness, aggressivity, and changes within mixed crops

Variant, seeding quantity, mln. (seed ratio)	SCC	LERa lupine	LERb vetch	CRab lupine	CRba vetch	CAab lupine	CAba vetch
Lupine 1.4 + vetch 0.45 (1:0.32)	1.6	0.88	0.68	0.6	1.8	-4.9	4.9
Lupine 0,88 + vetch 0.38 (1:0.42)	0.97	0.61	0.80	0.3	3.9	-2.4	2.4
Lupine 1.4 + Vetch 0.45 (1:0.32)	0.62	0.43	1.34	0.1	7.3	-1.6	1.6

Source: Compiled by the authors.

Competitive ratio (CR) is a ratio of each component's LER respective of planting proportion. The research of these proportions in agrophytocenosis shows decreasing competitiveness of lupine and dominating vetch under poorer precipitation and temperature conditions during the vegetative phase. For instance, under favorable conditions during the vegetative phase and sufficient humidification (SCC 1.6), the competitiveness of vetch (CRba) was three times that of lupine, suggesting optimal planting lupine and vetch at a three to one ratio. Vetch does not entirely dominate under extreme weather conditions when planting at this ratio, while lupine maintains a supportive function in agrophytocenosis.

When grown in mixed crops, the aggressiveness of spring vetch (CAba) and dominance capability surpasses lupine. At the same time, while under unfavorable conditions competitiveness of vetch increases from 1.8 to 7.3, its aggressiveness decreases from 4.9 to 1.6. Thus, the data suggests that there is positive alleopathy and environmental tolerance in lupine and vetch agrophytocenosis.

Discussion

The research on growing lupine and vetch in mixed crops both advises for and against this method. Some papers (Kukrash, Lukashevich 1989; Toshkina, Ambartsumova 2019) showed that both legume crops mutually inhibit when growing mixed crops, with lupine being most affected. Thus, vetch was observed to supplant lupine completely. Due to the vining and the absence of supporting crops, vetch lodged regardless, while the seeding method did not affect grain yield. Those studies used vetch as the main component at a seeding quantity of 5.2 million per hectare and lupine at 1.2 million (Toshkina, Ambartsumova 2019). In other words, the vetch to lupine ratio was five to one.

Other studies (Zotikov et al. 2012) used the following seeding quantities: 1.1 million vetch seeds and 0.5 million lupine seeds; 0.55 vetch seeds and 0.75 lupine seeds. These studies determined that sustainable yield of vetch grains under arid conditions developed in legume agrophytocenosis where the lupine to vetch ratio was between 2.2 and 0.7 to one.

Our research used mixed crops with seeding quantities of lupine between 0.9 and 1.7 million seeds per hectare and vetch between 0.23 and 0.5 million seeds per hectare. In other words, the lupine to vetch ratio was either two, three, or 7.5 to one. The mixed crops have produced stable yields across the years and varying weather conditions. These results can be explained by the higher competitiveness and aggressivity of vetch and its dominance compared to lupine.

Concluding, our research suggests that vetch and lupine agrophytocenosis can be cultivated to produce grains when the vetch to lupine ratio is three to one, or two to one (by millions of seeds per hectare). The lupine to vetch ratio can even be higher and reach seven to one. However, more research is needed to evaluate this possibility.

Conclusion

The study of lupine and vetch agrophytocenosis has established that the portion of grains in the yield depends on the weather conditions during the vegetative period.

Under favorable humidification, narrowleaf lupine grains comprise the bulk of the yield, while vetch produces more grain under more arid conditions. Thanks to the absence of lodging and high crops performance, this agrophytocenosis ensures the production of 2.1–2.85 to 3.86–4.78 tons per hectare with the combine harvesting.

Independent of the weather conditions, LER elevates 1.41 to 1.77 times when using a mix of grain legumes where vetch amounts to 32%–42% of lupine content. However, under unfavorable weather conditions, the competitiveness of vetch (CRba) relative to lupine elevates from 1.8 to 7.3, while its aggressiveness (CAba) decreases from 4.9 to 1.6.

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