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Intercropping white (*Lupinus albus*) and Andean (*Lupinus mutabilis*) lupins with other annual cool season legumes for forage production

A. Mikić [a,*], B. Ćupina [b], V. Mihailović [a], Đ. Krstić [b], S. Antanasović [b], L. Zorić [c], V. Đorđević [a], V. Perić [d], M. Srebrić [d]

[a] Institute of Field and Vegetable Crops, Novi Sad, Serbia
[b] University of Novi Sad, Faculty of Agriculture, Department of Field and Vegetable Crops, Novi Sad, Serbia
[c] University of Novi Sad, Faculty of Sciences, Department of Biology and Ecology, Novi Sad, Serbia
[d] Maize Research Institute Zemun Polje, Belgrade, Serbia

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ABSTRACT

Small-plot trials were carried out during 2011 and 2012 on calcareous soils at the Experimental Field of the Institute of Field and Vegetable Crops at Rimski Šančevi near Novi Sad. The aim was to use white lupin (*Lupinus albus* L.) and Andean lupin (*L. mutabilis* Sweet) as supporting crops, and intercrop them with nine other annual cool season legumes, as supported crops. The highest two-year average total forage dry matter yield obtained was for the intercrop of white lupin with grass pea (11.2 t ha^{-1}). Intercropping white lupin with Ethiopian pea and French vetch had the highest two-year average values for land equivalent ratio (LER), given as LER_{FDMY} (both 1.20). The highest two-year average total forage dry matter yield came from the intercrop of Andean lupin with grass pea (9.8 t ha^{-1}). Intercropping Andean lupin with grass pea had the highest two-year average values of LER_{FDMY} (1.10). The overall average obtained for intercropping white lupin with other cool season annual legumes was 10.3 t ha^{-1} of forage dry matter yield and LER_{FDMY} of 1.15, while intercropping white lupin with other cool season annual legumes yielded 8.7 t ha^{-1} of forage dry matter and LER_{FDMY} of 1.04. In comparison to the traditional approach of intercropping annual legumes with cereals for forage production, the mutual intercropping of annual legumes provides farmers with higher quality forage and grain richer in protein and better utilisation of natural resources.

1. Introduction

Lupin (*Lupinus* L.) is a species-rich legume genus and comprises a few hundred species originating from both Old and New World, and cultivated on about 1,000,000 ha on a world scale (Mihailović et al., 2007a). The most important crops in this genus are white (*L. albus* L.), yellow (*L. luteus* L.), narrow-leafed (*L. angustifolius* L.) and Andean (*L. mutabilis* Sweet) lupins, that, like many other annual legumes, are multi-functional crops and are utilised in human consumption and animal feeding, in the form of green forage, forage dry matter, forage meal, mature grain, as well as green manure (Mikić et al., 2006).

Although the primary centre of both cultivated white lupin (*L. albus* L. var. *albus* Gladst.) and its wild progenitor (*L. albus* L. var. *graecus* (Boiss. and Sprunn) Gladst.) is most likely the southern Balkans (Cowling et al., 1998), this crop has remained mostly unknown in the central and northern parts of the Balkan Peninsula, such as Serbia (Mihailović et al., 2005). The first attempts to introduce white lupin as a forage and grain legume into Serbian agriculture occurred only relatively recently (Popović-Pecija, 1950), with no success. Today, the only collection of white and other lupins in Serbia exists at the Institute of Field and Vegetable Crops in Novi Sad (Ćupina et al., 2006). The Novi Sad collection of lupins contains about 200 accessions of 10 species, including 68 accessions of white lupin and eight accessions of Andean lupin of different geographic origin and status (Mihailović et al., 2007b).

The main obstacle to the successful growing of white lupin in Serbia may be the predominance of chernozem, officially designed as aridic Kastanozem (FAO, 1974), soil in the fertile northern parts. The term *chernozem* comes from the Russian languages and literally means "black soil", referring to its colour. It is dominant in southern Russia, the Ukraine, Slovakia, Hungary, western Romania and northern Serbia and is generally considered one of the best soil types for cultivating a large majority of field crops since its richness in organic matter such as humus. White lupin may be tolerant of slightly calcareous soils with pH values between about 5 and 8, but a high soil pH and a presence of lime, often found in chernozem soils, can cause chlorosis in white lupin, mainly due to a lack of iron (Duthion, 1992). However, the wide genetic variation of white lupin, present in accessions of different origin, has been found useful as a base for the establishment of the first Serbian white lupin breeding programme (Mikić et al., 2010). It was aimed at

* Corresponding author at: Institute of Field and Vegetable Crops, Maksima Gorkog 30, 21000 Novi Sad, Serbia. Tel.: +381 21 4898 376, +381 64 8706 059; fax: +381 21 4898 377.
E-mail address: aleksandar.mikic@nsseme.com (A. Mikić).

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developing the cultivars tolerant of calcareous soils and with a potential for high quality forage, protein-rich grain and higher biomass yields, resulting in the registration of two cultivars, 'Vesna' and 'Panorama', in the Serbian national list of December 2008 (Mikić et al., 2011). In a preliminary trial in 2009 in Helsinki, Finland, 'Vesna' produced more than 18 t ha^{-1} of forage dry matter in a single cut at the stage of first flowering (Stoddard, pers. comm.).

One of the clearest definitions of intercropping is that it represents the simultaneous cultivation of at least two crops in the same field (Willey, 1979). In a more complex context, it may be regarded as a practical application of ecological principles with respect to biodiversity, plant interactions and other natural regulation mechanisms (Vandermeer et al., 1998). While intercropping legumes with cereals (Bedoussac and Justes, 2010) or brassicas (Cortés-Mora et al., 2010) is well-studied, little is known on intercropping legumes with each other. Some annual legumes are companion crops in establishing perennial forage crops such as red clover (*Trifolium pratense* L.), alfalfa (*Medicago sativa* L.) or sainfoin (*Onobrychis viciifolia* Scop.), where they act as bioherbicides (Ćupina et al., 2011). Regarding the mutual intercropping of annual legumes for forage production, we established four main principles (Fig. 1, left): 1) same time of sowing; 2) similar growth habit; 3) similar cutting time; and 4) combinations of crops with good standing ability, acting as supporting crops, with others that are susceptible to lodging, acting as supported crop (Mikić et al., 2012).

The aim of this study was to assess the feasibility and potential benefits of intercropping white and Andean lupins with other temperate annual legumes for forage production.

2. Materials and methods

Small-plot trials were carried out during 2011 and 2012 on chernozem soils at the Experimental Field of the Institute of Field and Vegetable Crops at Rimski Šančevi near Novi Sad. All the treatments were designed according to the said four basic principles of mutual annual legume intercropping. Following the model of intercropping white and Andean lupins with other annual cool season legumes (Fig. 1, right), white and Andean lupins played the role of supporting crops, while nine other cool season annual legume species, namely red vetchling (*Lathyrus cicera* L.), winged vetchling (*Lathyrus ochrus* (L.) DC.), grass pea (*Lathyrus sativus* L.), Ethiopian pea (*Pisum abyssinicum* A. Braun), tall pea (*Pisum sativum* L. subsp. *elatius* (Steven ex M. Bieb.) Asch. & Graebn.), common pea (*Pisum sativum* L. subsp. *sativum*), Narbonne vetch (*Vicia narbonensis* L.), French vetch (*Vicia serratifolia* Jacq.) and common vetch (*Vicia sativa* L.), acted as supported crops. All eleven crops were represented by one accession of different status and geographic origin from the collection of the Institute of Field and Vegetable Crops (Table 1) and were also sown as sole crops.

All eighteen intercrops and all eleven sole crops were sown on 24 March 2011 and 22 March 2012. The plot size was 5 m^2 and the experimental design was a split-plot with three replicates. The sowing rates in sole crops were 100 viable seeds m^{-2} for white and Andean lupins, all three vetchlings and all three peas and 120 viable seeds m^{-2} for all three vetches. In all the intercrops, the sowing rate of each component was one half of its sowing rate when sown as a sole crop.

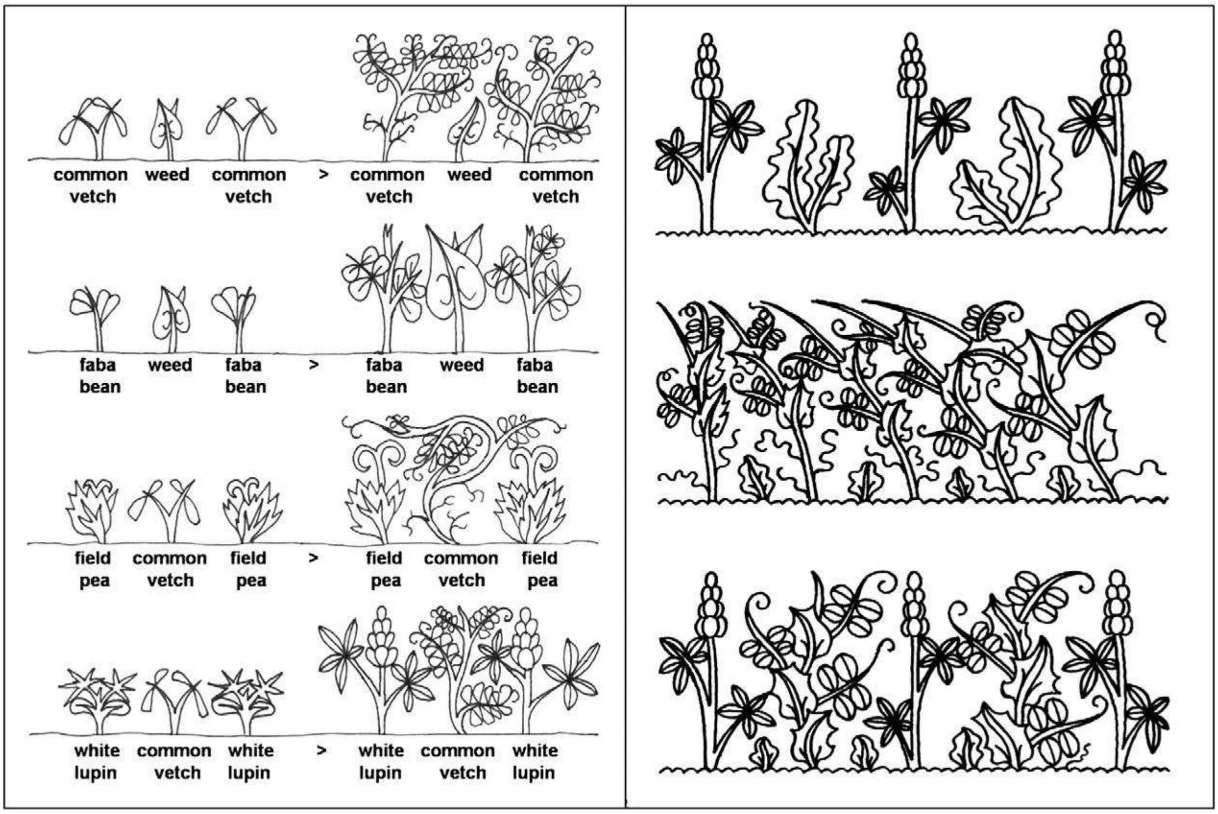

Fig. 1. (Left) Different aspects of the mutual intercropping of annual legumes (Mikić et al., 2012): (first row from above) in the pure stand of a lodging-susceptible crop such as common vetch, weeds are suppressed but lower leaves in vetch are mostly lost; (second row from above) in the pure stand of a lodging-resistant crop such as faba bean, weeds have favourable conditions; (third row from above) semi-leafless field pea and common vetch are less-beneficial choice since different growing habit; (fourth row from above) white lupin and common vetch are appropriate choice respecting all basic principles. (Right) Model of intercropping white or Andean lupins with other annual cool season legumes: (top row) white or Andean lupin has a good standing ability, but is heavily infested by weeds; (middle row) some annual cool season legumes are highly susceptible to lodging, such as pea, and easily match weeds but significantly suffer from losing lower leaves; (bottom row) intercropping white or Andean lupin with some annual cool season legumes, such as pea, is beneficial to both by suppressing weeds and increasing forage yield and improving its quality.

Table 1
Selected passport data of the accessions included in the trial with of intercropping white or Andean lupins with other annual cool season legumes at Rimski Šančevi in 2011 and 2012.

Species	Accession name	Status	Country of origin
White lupin	Vesna	Cultivar	Serbia
Andean lupin	LUP 509/83	Local landrace	Peru
Red vetchling	SA22083	Local landrace	Portugal
Winged vetchling	SEL 547	Local landrace	Cyprus
Grass pea	Sitnica	Cultivar	Serbia
Ethiopian pea	MG 101785	Wild	Ethiopia
Tall pea	K-2524	Wild	Lebanon
Common pea	Jantar	Cultivar	Serbia
Narbonne vetch	Chicharo	Local landrace	Spain
French vetch	Novo Hopovo	Wild	Serbia
Common vetch	Perla	Cultivar	Serbia

All the plots with sole crops were cut at the full bloom or early pod stage, while the intercrops were cut when the first intercrop component reached the full bloom or early pod stage. The green forage yield in all intercrops was measured immediately after cutting. The forage dry matter yield in each was determined on the basis of forage dry matter proportion in the green forage samples taken after the cutting and dried until constant mass at a room temperature.

The reliability of forage dry matter yield in all intercrops of both white and Andean lupins was determined by calculating the land equivalent ratio (LER_{FDMY}) as:

$$LER_F = FY(sg)_{IC}/FY(sg)_{SC} + FY(sd)_{IC}/FY(sd)_{SC},$$

where $FY(sg)_{IC}$ is the forage dry matter yield of the supporting component in the intercrop, $FY(sg)_{SC}$ is the forage dry matter yield of the supporting component when grown as sole crop, $FY(sd)_{IC}$ is the forage dry matter yield of the supported component in the intercrop and $FY(sd)_{SC}$ is the forage dry matter yield of the supported component when grown as sole crop.

The results of the study were processed by analysis of variance (ANOVA) with the least significant difference (LSD) test applied and using the computer software MSTAT-C.

3. Results and discussion

The analysis of the weather data during the growing seasons of white and Andean lupins and other cool season annual legumes shows that the average monthly temperature in both growing seasons was slightly higher in comparison to a long-term average (Table 2). However, both growing seasons of white and Andean lupins and other cool season annual legumes had less precipitation than a long-term average. In general, the sowing layer of the chernozem soils at Rimski Šančevi in both growing seasons of white and Andean lupins was well provided with the most important nutrients (Table 3).

Table 2
Weather data during the growing season of white and Andean lupins and other annual cool season legumes at Rimski Šančevi in 2011 and 2012 as compared to a long-term average.

Month	March	April	May	June	July	Average/sum
Year	Average monthly temperature (°C)					
2011	6	13	17	20	22	16
2012	8	13	17	23	25	17
Long-term average	6	11	17	20	21	15
Year	Precipitation sum (mm)					
2011	28	23	65	87	62	265
2012	4	23	51	31	48	157
Long-term average	38	47	59	85	70	299

Table 3
Chemical composition of the soil layer up to a depth of 30 cm during the growing season of white and Andean lupins and other annual cool season legumes at Rimski Šančevi in 2011 and 2012.

pH (H_2O)	pH (KCl)	N (%)	P_2O_5 (mg 100 g^{-1})	K_2O (mg 100 g^{-1})	$CaCO_3$ (%)	Humus (%)
7.90	7.41	0.196	17.99	21	5.61	2.97

There were significant differences in the two-year average values of forage dry matter yield at both levels of 0.05 and 0.01 in the sole crops of both white and Andean lupins and other cool season annual legumes (Table 4). The average forage dry matter in white lupin was higher than in Andean lupin. All sole crops had similar or mostly higher forage dry matter yield in comparison to the results of the previous trials in the same agroecological conditions, such as red vetchling, with 5.0 t ha^{-1} (Mikić et al., 2013a), grass pea, with 6.7 t ha^{-1} (Mihailović et al., 2013), common pea, with 6.4 t ha^{-1} (Ćupina et al., 2010), French vetch, with 6.3 t ha^{-1} (Ćupina et al., 2012), Narbonne vetch, with 5.0 t ha^{-1} (Mikić et al., 2009) and common vetch, with 8.8 t ha^{-1} (Mikić et al., 2013c).

In the intercrops of white lupin with other cool season annual legumes (Table 5), white lupin had the highest two-year average individual contribution to the total forage dry matter yield in the intercrop with Ethiopian pea. The highest two-year average total forage dry matter yield was in the intercrop of white lupin with grass pea. Intercropping white lupin with common pea had a similar agronomic performance as in a previous trial in the same agroecological conditions, with 11.0 t ha^{-1} (Krstić et al., 2011). Regarding the two-year average forage dry matter yield of the intercrops of white lupin with three tested genera, the highest two-year average of forage dry matter was with vetchlings.

Intercropping white lupin with Ethiopian pea and French vetch had the highest two-year average values of LER_{FDMY}, while intercropping white lupin with common vetch had the lowest two-year average values of LER_{FDMY} (Table 5). Intercropping white lupin with grass pea proved more economically reliable in comparison with a trial in the same agroecological conditions (Ćupina et al., 2009).

In the intercrops of Andean lupin with other cool season annual legumes (Table 6), Andean lupin had the highest two-year average individual contribution to the total forage dry matter yield in the intercrop with Narbonne vetch. The highest two-year average total forage dry matter yield was in the intercrop of Andean lupin with grass pea. Intercropping Andean lupin with other annual cool season legumes had a poorer agronomic performance than in a previous trial with the intercrops of white lupin (Krstić et al., 2011).

Intercropping Andean lupin with grass pea had the highest two-year average values of LER_{FDMY}, while intercropping Andean lupin with common pea had the lowest two-year average values of

Table 4
Two-year average values of forage dry matter yield (t ha^{-1}) in the sole crops of white and Andean lupins and other annual cool season legumes at Rimski Šančevi for 2011 and 2012.

Sole crop	Forage dry matter yield
White lupin	8.8
Andean lupin	7.6
Red vetchling	8.9
Winged vetchling	9.6
Grass pea	10.2
Ethiopian pea	6.7
Tall pea	9.3
Common pea	9.6
Narbonne vetch	7.2
French vetch	6.2
Common vetch	9.0
$LSD_{0.05}$	1.3

Table 5
Two-year average values of forage dry matter yield (t ha^{-1}) and its land equivalent ratio (LER_{FDMY}) in the intercrops of white lupin with other annual cool season legumes at Rimski Šančevi for 2011 and 2012.

Intercrop	Forage dry matter yield			LER_{FDMY}
	Supporting crop	Supported crop	Total	
White lupin + red vetchling	6.0	4.2	10.3	1.16
White lupin + winged vetchling	5.3	5.1	10.4	1.14
White lupin + grass pea	5.0	6.2	11.2	1.18
White lupin + vetchlings average	5.5	5.2	10.6	1.16
White lupin + Ethiopian pea	6.7	2.9	9.7	1.20
White lupin + tall pea	5.2	5.5	10.7	1.18
White lupin + common pea	5.0	5.6	10.6	1.15
White lupin + peas average	5.7	4.7	10.3	1.18
White lupin + Narbonne vetch	6.2	2.8	9.0	1.09
White lupin + French vetch	5.9	3.3	9.2	1.20
White lupin + common vetch	5.0	4.4	9.4	1.06
White lupin + vetches average	5.7	3.5	9.2	1.12
White lupin intercrops average	6.0	4.2	10.3	1.15
$LSD_{0.05}$	1.8			0.05

LER_{FDMY} (Table 6). Intercropping Andean lupin with grass pea proved more economically reliable in comparison with a trial in the same agroecological conditions, where white lupin intercropped with grass pea had a LER_{FDMY} of 1.04 (Ćupina et al., 2009).

The overall average yield obtained by intercropping white lupin with other cool season annual legumes was 10.3 t ha^{-1} of forage dry matter yield and LER_{FDMY} of 1.15, while intercropping white lupin with other cool season annual legumes had 8.7 t ha^{-1} of forage dry matter yield and LER_{FDMY} of 1.04. Their performance was similar to intercrops of autumn-sown annual legumes and brassicas, with the two-year average forage dry matter yield of 8.6 t ha^{-1} (Ćupina et al., 2013a), and intercrops of spring-sown annual legumes and brassicas, with the two-year average LER_{FDMY} of 1.15 (Mikić et al., 2013b). It was also similar to intercropping autumn-sown legumes and cereals, with the two-year average LER_{FDMY} of 1.05 (Mihailović et al., 2011), better than intercropping lentil with other cool season annual legumes, where the two-year average forage dry matter yield was 8.6 t ha^{-1} (Ćupina et al., in press) and comparable to intercropping vetches with other cool season annual legumes, with the two-year average forage dry matter yield of 9.4 t ha^{-1} and LER_{FDMY} of 1.10 (Ćupina et al., 2013c).

Table 6
Two-year average values of forage dry matter yield (t ha^{-1}) and its land equivalent ratio (LER_{FDMY}) in the intercrops of Andean lupin with other annual cool season legumes at Rimski Šančevi for 2011 and 2012.

Intercrop	Forage dry matter yield			LER_{FDMY}
	Supporting crop	Supported crop	Total	
Andean lupin + red vetchling	4.0	4.6	8.7	1.05
Andean lupin + winged vetchling	3.3	5.1	8.4	0.97
Andean lupin + grass pea	4.2	5.6	9.8	1.10
Andean lupin + vetchlings average	3.9	5.1	9.0	1.04
Andean lupin + Ethiopian pea	4.9	2.9	7.8	1.09
Andean lupin + tall pea	4.1	5.0	9.1	1.07
Andean lupin + common pea	4.0	4.2	8.2	0.96
Andean lupin + peas average	4.3	4.0	8.4	1.04
Andean lupin + Narbonne vetch	5.0	3.0	8.0	1.07
Andean lupin + French vetch	4.5	2.9	7.4	1.05
Andean lupin + common vetch	4.4	3.6	8.0	0.98
Andean lupin + vetches average	4.6	3.2	7.8	1.03
Andean lupin intercrops average	4.0	4.6	8.7	1.04
$LSD_{0.05}$	1.5			0.04

4. Conclusions

Intercropping white and Andean lupins with other cool season annual legumes may lead to higher forage and grain yields and can be economically justified by high LER values and better utilisation of natural resources. In comparison to the traditional intercropping of annual legumes with cereals for forage production, the mutual intercropping of annual legumes provides farmers with high quality forage and grain richer in protein. Further research on the same subject will focus on forage and grain quality aspects, such as the crude protein and crude fibre content in forage and grain dry matter and other less examined aspects such as forage yield, grain yield and crop physiology.

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