EVALUATION OF GRAIN YIELD IN MIXED LEGUME-CEREAL CROPPING SYSTEMS

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Abstract: The aim of this study was to describe the combined corn yield of the mixed culture. Under the term of mixed culture, we understand the cultivation of two different crops at same field simultaneously, in particular mixture of leguminous and non-leguminous crops. This work deals with the evaluation of grain yield in mixed culture. Three replicates of 2 x 10 m plots per treatment were arrayed in blocked design. These variants were prepared: winter wheat (SC) - 140 kg N ha^{-1} yr^{-1} (100 %); mixed culture winter wheat + winter peas (IC) 112 kg N ha^{-1} yr^{-1} (80 %); mixed culture (IC) 70 kg N ha-1 yr-1 (50 %); mixed culture without fertilization - and Winter Peas (SC). Grain yield was evaluated by LER (Land Equivalent Ratio). The highest values of LER were found in mixed culture (IC 112 kg N ha^{-1} yr^{-1}; IC 70 kg N ha^{-1} yr^{-1}; IC 0 kg N ha^{-1} yr^{-1}).

Keywords: winter wheat, winter pea, grain yield, mixed culture.

1 Introduction

Modern agriculture is facing many problems: decline of soil fertility, compaction of soils, and contamination of water sources, which have different causes. In many countries throughout the world, agricultural soils are being degraded at an alarming rate by erosion, salinization, nutrient depletion and desertification. These problems can be solved only by a change of farming systems (Elbl et al., 2013). One of the major changes may be the inclusion of legumes in crop rotations. This system is known as a mixed culture.

Under the term of mixed culture, we understand the cultivation of two different crops in the same field (at the same time during a growing season) simultaneously, in particular mixture of leguminous and non-leguminous crops. The need to cultivate these crops for improving soil fertility and sustainability is often neglected, but positive influence of legumes in crop rotation is widely recognized (Hauggaard-Nielsen et al., 2008 and Ofori & Stern, 1986). Mixing species in cropping systems may lead to a range of benefits that are expressed on various space and time scales from a short-term increase in crop yield and quality to longer-term agro-ecosystem sustainability (Malezieux, et al., 2009).

For farming systems to remain productive, it will be necessary to replenish the reserves of nutrients which are removed or lost from the soil. In the case of nitrogen (N), inputs into agricultural systems may be derived from atmospheric N_2 via biological N_2 fixation (Peoples et al., 1995). Biological nitrogen fixation is an important aspect of sustainable and environmentally friendly food production and long-term crop productivity (Kessel & Hartley, 2000). Legumes can transfer significant amounts of symbiotically fixed N to neighboring plants, and a putative pathway for N transfer is decomposition of fine roots and nodules (Dubach & Russelle, 1994). The Figure 1 shows positive effect of mixed culture root system on soil fertility. Grain leguminous can cover their nitrogen demand from biological fixation of atmospheric N_2 (Hauggaard-Nielsen et al., 2001, Trenbath, 1976) and therefore, they compete less for soil Nmin in intercropping with cereals (Jensen, 1996).

Crop yield depends on ability to extract sufficient amount of nutrients (especially nitrogen) and water from soil. Uptake of nutrients and water is dependent on the availability of nutrients in rhizosphere. Nitrogen is a key element for all organisms, because it is an essential component of proteins and nucleic acids. Although the element nitrogen is extremely abundant, making up 78% of the Earth's atmosphere, it exists mainly as unreactive di-nitrogen (N_2). By contrast, to be useable by most plants and animals, reactive nitrogen forms are needed. These include oxidized and reduced nitrogen compounds, such as nitric acid, ammonia, nitrates, ammonium and organic nitrogen compounds, each of which is normally scarce in the natural environment. The most important kind of reactive nitrogen in the soil is the mineral nitrogen, which is formed by nitrate and ammonium nitrogen (Sutton, 2011).

The success of intercrop farming systems depends initially on effective nitrogen fixation and more importantly, on subsequent transfer of nitrogen to the non-legume (Stern, 1993). For example, Musa et al. (2010) state that, intercropping of barley and peas increased dry matter production and yield compared with either sole crop.

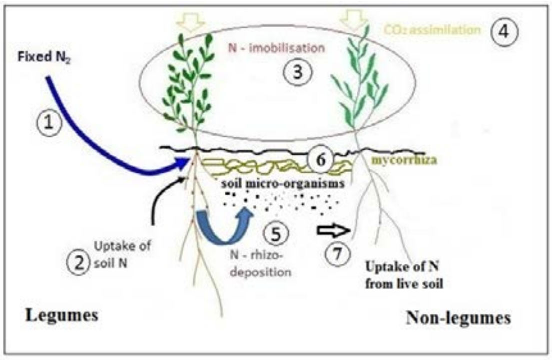

Fig. 1 Flows of nitrogen during the growing of mixed culture – benefits. 1.) Biological fixation of N_2. 2.) Uptake of N-min from the soil. 3.) Immobilization of nitrogen in plant biomass and in the corn. 4.) CO_2 assimilation. 5.) Nitrogen rhizodepozition - soil micro-organisms. 6.) Transport of nitrogen by mycorrhiza. 7.) Smooth reception of N_{min} from the soil.

The success of intercrop farming systems depends initially on effective nitrogen fixation and more importantly, on subsequent transfer of nitrogen to the non-legume (Stern, 1993). The productivity of crops (sole crops and intercrops – mixed culture) depends on the species of individual crops and varies between different experimental sites, soil properties and cultivation conditions (Kadžiulienė et al., 2011). Cultivation of mixed culture has these benefits: improvement of soil fertility, increase of the quality and health of arable soils and higher resilience of agricultural land to various erosion phenomena. In addition to these positive benefits, the mixed legume-cereal system allows more efficient use of land, the same plot can be used for cultivating two crops at the same time and thus higher total grain production (Hauggaard-Nielsen et al., 2008; Kessel & Hartley, 2000 and Ofori & Stern, 1986).

The aim of the project will be to find effect of two field crops cultivated in mixed culture on grain yields. Hypothesis, which claims that cultivation of winter wheat and winter pea together has positive effect on total grain production, was tested.

2 Materials and Methods

The present experiment is sub-section of a larger experiment, which was focused on monitoring of the impact of mixed culture cultivation on soil fertility, leaching of mineral nitrogen from arable soil, soil microbial activities and content of available nutrients (P, K, Mg) in rhizosphere soil.

Area of our interest is the agricultural region, which is located 8 km north of the city Prostějov. Experimental site is situated in the protection zone of underground drinking water source "Kvartér řeky Moravy". This site is located, according

Quitt (1975), in the climatic region T2, where annual climatic averages are of 350-400 mm of precipitation in growing season, 200-300 mm of precipitation in winter and 8-9 °C of mean annual air temperature. The experiment was based on the black earth, moderate, loess without skeleton (BPEJ 30100).
At both variants, seeds of mixed culture were sown mixed in the rows in the same depth on the 10th of October 2012. Four replicates of 2 x 10 m plots per treatment were arrayed in blocked design. These variants were prepared: winter wheat (SC) - 140 kg N ha^{-1} yr^{-1} (100 % of recommended dose). Mixed culture winter wheat + winter pea (IC) - 112 kg N ha^{-1} yr^{-1} (80 %), IC - 70 kg N ha^{-1} yr^{-1} (50 %) and IC without fertilization.

Fig. 2 Mixed legume-cereal cropping system at experimental site

The crops were harvested at full maturity on the 23rd of July 2013. The samples of grain were dried at 70 °C to constant weight and total dry matter production for each plot was determined separately for grain legumes and wheat.
Combined intercrop yield is the sum of yields of both the components in the intercrop. Evaluation of grain yields was performed by the land equivalent ratio (LER) for each variant of experiment. LER is defined as the relative (land) area of growing sole crops (SC) that is required to produce the yields (Y) achieved when growing intercrops (IC), the values of LER were calculated according Willey (1979):

$$LA = Y_{A,IC}/Y_{A,SC} \quad (1)$$
$$LB = Y_{B,IC}/Y_{B,SC} \quad (2)$$

Where: $Y_{A,IC}$ and $Y_{A,SC}$ are the yields of intercropped and sole winter wheat and $Y_{B,IC}$ and $Y_{B,SC}$ are the yields of intercropped and sole winter pea.

$$LER = LA + LB \quad (3)$$

LER values > 1 indicate an advantage from intercropping in terms of the use of environmental resources for plant growth compared with sole crops. When LER is < 1, resources are used more efficiently by sole crops than by intercrops (Knudsen, 1999).
Potential differences in grain yield were analyzed by one-way analysis of variance (ANOVA) in combination with the Tukey`s test.

3 Results and Discussion

The results of grain yield were determined during the first year of the present experiment, which were carried out in 2012. The main objective of this work is evaluation of grain yield from individual variants of IC and SC. Crops in mixed legume-cereal cropping system were harvested together at the same moisture of plant biomass.

Fig. 3 Grains of winter wheat and winter pea (condition after harvest – winter wheat and winter pea were harvested together)
Grain yield of the winter wheat SC and winter pea SC are higher than individual components in the intercropping. The amount of yield is an important indicator of efficiency of agricultural production. The complete overview of grain yield is shown in the Table 1. The values stated in the Table 1 indicate the possibility of using of one parcel (site) to grow two crops in mixed culture. The highest values were found in variants SC (winter wheat and winter pea), but this difference was significant only between SC winter wheat and other variants.

Table 1 Grain yield in mixed culture and sole crops (mean values ± standard error are shown, n = 4, different letters indicate a significant differences at the level 0.05 – ANOVA, P < 0.05)

Variants	Grain yield (g/m^2)	±SE
Winter wheat		
Sole crops – 140 kg N ha^{-1} yr^{-1}	416.66^{a}	47.81
Inter cropping – 112 kg N ha^{-1} yr^{-1}	$295.33^{b,c}$	7,85
Inter cropping – 70 kg N ha^{-1} yr^{-1}	320.33^{b}	12,41
Inter cropping – 0 kg N ha^{-1} yr^{-1}	212^{c}	18.44
Sole crops – 0 kg N ha^{-1} yr^{-1}	0	0
Winter pea		
Sole crops – 140 kg N ha^{-1} yr^{-1}	0	
Inter cropping – 112 kg N ha^{-1} yr^{-1}	$259.23^{b,c}$	19.45
Inter cropping – 70 kg N ha^{-1} yr^{-1}	197.64^{c}	8.99
Inter cropping – 0 kg N ha^{-1} yr^{-1}	195.88^{c}	17.51
Sole crops – 0 kg N ha^{-1} yr^{-1}	$265.43^{b,c}$	8.79

There are significant differences between SC (winter wheat) and IC (winter wheat and winter pea), but smaller doses of mineral fertilizers were applied at sites with IC and this means a great savings in financial costs. Moreover, cultivation of mixed culture has positive effect on agro-ecosystem and it is essential for more efficient use of agriculture land. Positive influence of mixed culture cultivation on soil properties and soil fertility was confirmed by Dakora (2002) and Kessel & Hartley (2000). Peoples et al. (1995) and Willey (1979) state cultivation of mixed culture can be economically profitable.

Table 2 Representative data for calculation of LER (winter wheat – A, winter pea – B)

Variants	LA	LB	LER
Sole crops – 140 kg N ha^{-1} yr^{-1}	0	0	0
Inter cropping – 112 kg N ha^{-1} yr^{-1}	0.71	0.98	1.69
Inter cropping – 70 kg N ha^{-1} yr^{-1}	0.77	0.74	1.51
Inter cropping – 0 kg N ha^{-1} yr^{-1}	0.51	0.74	1.25
Sole crops – 0 kg N ha^{-1} yr^{-1}	0	0	0

The Land Equivalent Ratio (LER) was used to evaluate intercrop efficiencies in grain yield and was calculated according Eq. 3 (originally Willey, 1979). Calculation is presented in the Table 2 and values of LER are shown in Figure 4.

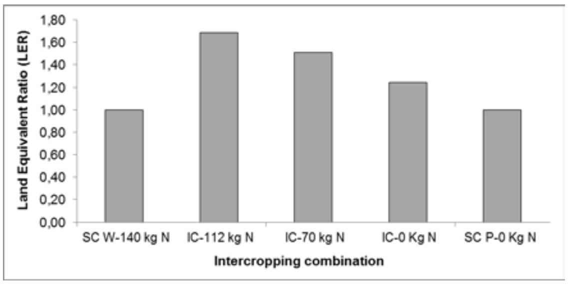

Fig. 4 LER for grain yield as affected by intercropping combination (SC W – sole crop winter wheat; SC P – sole crop winter pea)

The above Figure 4 shows values of LER. Maximum and minimum LERs (1.69 and 1.25) were attained by intercropping – 112 kg N ha^{-1} yr^{-1} and intercropping – 0 kg N ha^{-1} yr^{-1}.

Dariush et al. (2006) state: a total LER of higher than 1.0 indicates the presence of positive interferences among the varieties or crops components of the mixture, and also means that any negative interspecific interference, that exists in the mixture, is not as intensive as the intraspecific interference that exists in the monocultures.

The total values of LER were higher than 1 in all variants of IC. Detected values at the winter wheat and winter pea intercrops indicate advantage in grain yield from intercropping compared with sole cropping. The relationship between the values of LER and profitability of mixed culture cultivation was confirmed by Knudsen (1999).

Conclusions

This contribution presents the first results of long-term field experiment. Therefore, these results must be interpreted with caution. The measured values of grain yield and LER indicate possibility of mixed culture cultivation at one site. This possibility was demonstrated by analysis of grain yield. Based on these results, we conclude that mixed culture cultivation can be used in conditions of Czech agriculture. We assume the inclusion of legumes in crop rotations will have several positive effects for Czech farmers: improvement of soil fertility, diversification of production and increase of the resistance of soil against erosion.

Abbreviation

N_{min} – Mineral nitrogen
N_2 – Atmospheric nitrogen
SC – Sole crop
IC – Inter crop (mixed culture)

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