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Nitrogen uptake, use and utilization efficiency by oat–pea intercrops

Reinhard W. Neugschwandtner*, Hans-Peter Kaul

Division of Agronomy, Department of Crop Sciences, University of Natural Resources and Life Sciences Vienna (BOKU), Konrad Lorenz-Straße 24, 3430 Tulln, Austria

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ABSTRACT

Cereal–legume intercropping in sustainable arable farming systems in temperate regions is of increasing interest for increasing productivity. This study assessed the influence of sowing ratio and N fertilization on nitrogen uptake, use and utilization efficiency of oat (*Avena sativa* L.) and pea (*Pisum sativum* L.) in intercrops. A two-year field study was carried out in eastern Austria with oat and pea sown in three substitutive sowing ratios and at different nitrogen levels.

Oat was the dominant partner in the mixtures strongly outcompeting pea. Total grain yields were generally lower in intercrops than in pure stands. Consequently, nitrogen use and the partial factor nitrogen use efficiency for grain production were lower in intercrops. Nitrogen utilization efficiency was highest in pure oat stands and decreased with higher pea shares.

Grain N concentration of oat and pea increased with N fertilization. In intercrops, grain N concentrations of oat increased with lower oat share whereas those of pea were not affected by cropping system. Due to higher grain N concentrations of oat in intercrops, intercrops could attain a higher grain N yield in unfertilized treatments. Thus, growing oat–pea intercrops can be reasonable for producing grain feed at low N input level.

1. Introduction

Intercropping is a traditional farming technique, which is important in farming systems of developing countries but far less widespread in mechanized systems (Lithourgidis et al., 2011). But there is an increased scientific interest in intercropping systems in temperate regions for developing sustainable farming systems for forage (Anil et al., 1998) or grain production (Neugschwandtner and Kaul, 2014; Zając et al., 2013, 2014). Yields of grain legumes are generally more variable than those of many other crop species (Jeuffroy and Ney, 1997). Thus, Jensen (1996) has shown that intercropping barley with pea resulted in a higher yield stability of intercrops than of pea pure stands. Yield and yield components (Neugschwandtner and Kaul, 2014) and yield per plant (Echarte et al., 2011) as well as concentrations and uptake of nutrients (Li et al., 2001) of individual crops may be affected in intercrops compared to pure stands. Higher yields can be obtained by intercropping through an improved water and radiation capture as shown for maize–soybean intercrops compared to soybean sole cropping (Coll et al., 2012). Thereby, intercropping can be an alternative under rainfed conditions for reducing farm risk (Monzon et al., 2014). Further one, biological and chemical soil characteristics are positively influenced by intercropping (Oelbermann and Echarte, 2011); e.g. intercropping contributes to the long-term immobilization of N compared to sole cropping as shown for maize–soybean intercrops and, thus, could help to curb the currently growing reliance on N fertilizers (Regehr et al., 2015).

Cereal–legume intercrops may allow for the optimal use of soil and atmospheric nitrogen sources to maintain high production and quality levels with low fertilizer N inputs to minimize potential environmental impacts, which may occur in intensive agricultural systems (Pelzer et al., 2012). Soil inorganic and atmospheric N sources can be complementarily used by the intercrop components. Cereals are more competitive than legumes for inorganic soil N (Jensen, 1996) due to a faster and deeper root growth of the cereal (Corre-Hellou and Crozat, 2005). In substitutive cereal–pea intercrops, the cereal has an even better access to soil N than in pure stands due to a lower plant density but at a similar amount of available N per unit area (Bedoussac and Justes, 2010). Legumes save the soil N pool due to their symbiotic N_2 fixation (Chalk et al., 1993; Hauggaard-Nielsen et al., 2001). The portion of N derived through fixation by pea is further increased in intercrops as the higher soil mineral N acquisition of the cereal fosters symbiotic N_2 fixation due to low NO_3 concentrations; symbiotic N_2 fixation is negatively affected by that chemical compound (Corre-Hellou et al.,

* Corresponding author. Tel.: +43 1 47654 3311; fax: +43 1 47654 3342.
E-mail address: reinhard.neugschwandtner@boku.ac.at (R.W. Neugschwandtner).

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2006; Hauggaard-Nielsen et al., 2009). Thus, the share of symbiotically fixed N in relation to the N uptake of the legume in intercrops can be increased due to competition for soil mineral N by the non-legume, especially with low N fertilization (as shown in barley–pea intercrops by Andersen et al., 2005). Nevertheless, the total amount of fixed nitrogen per unit area is often lower in intercrops than in pure legume stands due to lower plant density of the legume and competition by the non-legume accompanying plant (Van Kessel and Hartley, 2000).

Intercropping is mostly practiced under low soil fertility and low input conditions (Vesterager et al., 2008); under these conditions intercropping shows the highest yield increase compared to pure stands (Ofori and Stern, 1986; Hauggaard-Nielsen et al., 2009) due to the high level of complementary N use between the two species compared with highly fertilized systems (Bedoussac and Justes, 2011). Thus, nitrogen fertilization is a critical topic in intercropping. The reliance on soil mineral N for achieving a high grain yield is different for the partners in cereal–legume intercrops with a high demand for cereals and a low demand for legumes (Cochran and Schlentner, 1995). Nitrogen fixation is considerably reduced with a high rate of nitrogen fertilization (Jensen, 1986). The inhibitory effect of N fertilization on nodulation and N_2 fixation of legumes in intensive farming systems can be alleviated by intercropping non-legume partner (as shown in faba bean/maize intercrops by Li et al., 2009). Several studies have highlighted that N fertilization of cereal–legume intercrops affects competition between crops, yield and nitrogen yield of individual crops and of the total system (Ghaley et al., 2005; Naudin et al., 2010; Pelzer et al., 2012).

The aim of this study were to assess oat–pea intercrops grown on a fertile soil in temperate conditions of eastern Austria as affected by sowing ratio and N fertilization with focus on (a) nitrogen yield and (b) nitrogen use and utilization efficiency of oat–pea intercropping systems as compared to pure stands of both crops.

2. Material and methods

2.1. Experimental site and environmental conditions

The experiment was carried out in Raasdorf (48°14′ N, 16°33′ E) in eastern Austria on the experimental farm Gross-Enzersdorf of BOKU University in the years 2010 and 2011. The soil is classified as a chernozem of alluvial origin and rich in calcareous sediments (pH 7.6, silty loam, 2.2–2.3% organic substance). The mean annual temperature is 10.6 °C, the mean annual precipitation is 538 mm (1980–2009). The temperature in both growing seasons was generally above the long-term average with higher temperatures in 2011 than in 2010 (except for July). Monthly precipitation in 2010 was highly above average during the growing season from April until July whereas the vegetation period 2011 was comparatively dry. For detailed information on weather data during the growing seasons see Neugschwandtner and Kaul (2014).

2.2. Experimental treatments and measurements

Pure stands of oat (cv. Effektiv) and pea (cv. Lessna, semi-leafless) were established with 350 (oat) and 80 (pea) germinable seeds m^{-2}, respectively. Three substitutive oat–pea intercropping mixtures consisted of the following sowing ratios (oat:pea, based on the pure stands of each crop in %): 75:25, 50:50 and 25:75. The nitrogen fertilizer calcium ammonium nitrate (CAN, 27% N) was applied at two fertilization levels (6 and 12 g N m^{-2}) complemented by an unfertilized control. Fertilizer was applied in two equal splits, right after sowing and at end of tillering of oat, on May 2, 2010, and on May 5, 2011.

The preceding crops were winter barley (2010) or spring barley (2011). Seedbed preparation was done with a tine cultivator to a depth of 20 cm. Sowing of both crops was performed simultaneously in one pass-over with an Oyjard plot drill at a depth of 4 cm on March 19, 2010, and on March 14, 2011. Individual plots had an area of 15 m^2 (10 × 1.5 m) and comprised 10 rows at 12.5 cm spacing. Soil mineral N in 0–0.9 m depth at sowing was 15.8 (March 24, 2010) or 16.8 (March 16, 2011) g N m^{-2} (at 0–0.9 m depth). Mechanical hand weeding was performed throughout the experiment; plants were sprayed against pests when necessary [with the insecticide deltamethrin, 7.5 g a.i. ha^{-1} (Decis®)]. Plants were harvested manually by cutting on the soil surface at full ripeness on 1.2 m^2 per plot on July 21, 2010, and on July 19, 2011, and dried at 70 °C for 3 d. Thereafter, plant samples were divided into grain and residue.

For nitrogen determination, grain and residue samples were first ground to pass through a 1 mm sieve. Nitrogen concentrations were determined as average of duplicate samples of about 50 mg each by the Dumas combustion method (Winkler et al., 2000) using an elemental analyzer (vario MACRO cube CNS; Elementar Analysensysteme GmbH, Germany).

Grain and residue N yield were calculated by multiplying yield figures with N concentrations and from these the N harvest index (NHI) was derived. N use efficiency (NUE), partial factor N use efficiency (PFNUE) and N utilization efficiency (NUtE) were calculated according to Sinebo et al. (2004) and Anbessa and Juskiw (2012) as follows:

$$\mathrm{NUE}\,(\mathrm{g\ g^{-1}}) = \frac{YLD}{N_{MIN} + N_f} \tag{1}$$

$$\mathrm{PFNUE}\,(\mathrm{g\ g^{-1}}) = \frac{YLD_f}{N_f} \tag{2}$$

$$\mathrm{NUtE}\,(\mathrm{g\ g^{-1}}) = \frac{YLD}{NY_{AGDM}} \tag{3}$$

where *YLD* is the grain yield and NY_{AGDM} the nitrogen yield of the above-ground dry matter; N_{MIN} represents soil mineral *N* at sowing and N_f the fertilizer level; the subscript $_f$ stands for fertilizer *N*.

The land equivalent ratio for nitrogen yield (LER_N), which indicates a possible N yield advantage of intercrops, was calculated modified according to Mead and Wiley (1980) as follows:

$$\mathrm{LER_N} = \mathrm{NY_{Oic}}/\mathrm{NY_{Ops}} + \mathrm{NY_{Pic}}/\mathrm{NY_{Pps}} \tag{4}$$

where NY_{Ops} and NY_{Pps} are the crop N yields for oat (O) and pea (P) grown in pure stands (ps) and NY_{Oic} and NY_{Pic} are the yields of the crops grown in intercrops (ic). A LER_N >1 shows an N yield advantage of the intercropping system whereas a LER_N <1 indicates an N yield disadvantage. The LER_N is the sum of the partial LER_N of the individual crops in the mixture. The partial LER_N indicates the relative competitive ability of individual crops regarding N yields in mixtures.

2.3. Statistics

The experiments were in a randomized complete block design with three replications. Statistical analyses were performed using SAS version 9.2. Analysis of variance (PROC GLM) with subsequent multiple comparisons of means were performed. Means were separated by least significant differences (LSD), when the *F*-test indicated factorial effects on the significance level of $p < 0.05$. Based on analysis of variance results, data are mainly presented for N fertilization (main effect) and interactions of crop × year. Other interactions are presented occasionally in case they were significant and relevant.