Field Crops Research 149 (2013) 95–104

Contents lists available at SciVerse ScienceDirect

Field Crops Research

journal homepage: www.elsevier.com/locate/fcr

Prevention of pea lodging by intercropping barley with peas at different nitrogen fertilization levels

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ARTICLE INFO

Article history:
Received 5 September 2012
Received in revised form 24 April 2013
Accepted 25 April 2013

Keywords:
Barley–pea intercrop
Facilitation
Competition
Plant lodging
LER

ABSTRACT

Field pea (*Pisum sativum* L.) that is grown in pure stands tends to lodge, which may lead to decreased grain yields. Barley (*Hordeum vulgare* L.) intercropped with peas prevents lodging, but this facilitative effect of the cereal on the pea has rarely been examined. Two two-factorial experiments (Experiment 1 and Experiment 2) were conducted in 2005, 2006, and 2007 to study interactions between barley and a medium-tall, leafy field pea (Wiato cultivar) and between barley and a tall, leafy field pea (Fidelia cultivar). In both experiments, mineral N fertilizer was used at rates of 0, 30, and 60 kg of N ha^{-1}. Experiment 1 was conducted to evaluate plant lodging, grain yield, the intercrop yield advantage over pure stands and competition between the intercropped species. Experiment 2 was designed to separate the facilitative effect of the mechanical support provided to the peas by the barley in the intercrop from the effects of competition. In the experiment, groups of four pea plants were grown supported by an iron wire frame to prevent their lodging. The frames were kept in the plots until the peas flowered fully or reached full maturity. Similar groups of legumes were also grown in mixtures with nine barley plants. These treatments permitted the determination of the net benefits to the peas of the mechanical support provided by the added barley between pea flowering and maturity. In Experiment 1, there was little lodging of the pea cultivars in the intercrops, whereas the pure stands lodged severely. In all years, the barley–pea intercrops were more productive than the sole crops (LER > 1). The barley–Wiato mixture yielded more grain than the barley–Fidelia mixture in 2005 and 2006. Both mixtures transgressively overyielded in 2006 at the nitrogen fertilizer rate of 30 kg of N ha^{-1}, and the barley–Wiato mixture did so at 0 kg of N ha^{-1}. Experiment 2 showed that mechanical plant support (facilitation) was more important for the tall cultivar Fidelia than for the medium-tall cultivar Wiato, but Fidelia was the weaker competitor of the two with barley. Increasing the N fertilizer rates decreased the pea tolerance to competition from barley in the intercrop.

1. Introduction

Mixed cropping has been widely practiced in the traditional agriculture of developing countries because it is considered more efficient than sole cropping and because it reduces the risk to farmers (Altieri, 1999; Vandermeer, 1989; Zhang and Li, 2003). Legume–nonlegume intercrops have gained attention in developed countries, mainly in terms of the crop rotations of organic farming systems in which legumes play an important role as a source of N (Bulson et al., 1997; Hauggaard-Nielsen et al., 2009; Schmidtke et al., 2004).

The primary and most frequently reported type of interaction in such cropping systems is competition. It is particularly intense in the intercrops grown for yield maximization per unit area (Sobkowicz and Tendziagolska, 2005). In the barley–pea intercrop, the barley is often observed to be dominant. This dominance is attributed to the faster initial growth of the cereal and its high competitive uptake of soil N (Andersen et al., 2004; Corre-Hellou et al., 2006, 2007; Hauggaard-Nielsen et al., 2001a,b, 2009; Jensen, 1996a). Other authors found that the competitive ability of pea plants depends on their height. Tall pea cultivars are better able to compete with cereals than shorter ones (Hauggaard-Nielsen and Jensen, 2001; Rauber et al., 2001). Research also showed that the conventional leafy cultivars are better competitors than the semileafless ones (Rauber et al., 2001; Semere and Froud-Williams, 2001; Tofinga et al., 1993).

The competitive abilities of the components of the intercrop are influenced by nitrogen fertilizer inputs. In research with cereal–pea intercrops, increased N fertilizer increased the competitive ability of the cereal (Andersen et al., 2004; Chen et al., 2004; Corre-Hellou et al., 2006; Hauggaard-Nielsen and Jensen, 2001; Jensen, 1996a).

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http://dx.doi.org/10.1016/j.fcr.2013.04.023

The yield advantage of intercrops is attributed mostly to resource complementarity, which is an emergent property that occurs in mixtures of populations and stems from differences in resource acquisition by the component species. The mixture utilizes the limiting resource or resources more completely than the pure stands (Bulson et al., 1997). In legume–nonlegume mixtures, the two components use partially different nitrogen sources, and when the nutrient is limited, indices that assess intercrop production demonstrate the advantage of such intercrops over pure stands. This relationship was shown in experiments using different N fertilizer inputs (Andersen et al., 2004; Chen et al., 2004; Corre-Hellou et al., 2006; Hauggaard-Nielsen and Jensen, 2001; Jensen, 1996a).

Several authors have noted that the intercrop advantage may also result from interspecific facilitation, the positive influence of plants of one species on plants of another species (Hauggaard-Nielsen and Jensen, 2005; Vandermeer, 1989). Facilitation and competition have been extensively studied by plant ecologists who emphasize that because both interactions operate in plant communities, the results of many experiments show only the net outcome of the two phenomena (Bruno et al., 2003; Callaway, 1995; Callaway and Walker, 1997; Holmgren et al., 1997). In the cereal–legume intercrop, the direct transfer of fixed N from the legume roots to the cereal roots is an example of facilitation (Brooker et al., 2008). Although the process has not been adequately demonstrated under field conditions (Cochran and Schlentner, 1995; Hauggaard-Nielsen and Jensen, 2005; Jensen, 1996a), fixed N can be released from the mineralizing roots of the legume plant and taken up by cereal plant roots (Jensen, 1996b; Stern, 1993). Hauggaard-Nielsen and Jensen (2005) and Zhang and Li (2003) reviewed several other underground facilitation mechanisms existing in intercrops and indicated that these mechanisms should be taken into consideration when assessing intercrop efficiency.

Callaway (1995) demonstrated a facilitation mechanism in which some plant species use the stems of other species as mechanical support for their growth. This situation is similar to that observed in cereal–legume intercrops in which the second component is a climbing plant, such as pea or vetch, which needs support for its successful growth. The legumes attach to the stiff culms of the cereal by tendrils. In this way, the cereal facilitates the growth of the legume, but the weight of the legume interferes directly with the growth of the cereal. This mechanism allows the legume to gain access to light and possibly to more effectively compete for the resource. Because it is taller than barley, Iptas (2002) found that triticale instead of barley intercropped with Hungarian vetch resulted in higher vetch growth and yields. Although this type of facilitative interaction is directly visible in the legume–nonlegume intercrop, it may be recognized as facilitation in agronomic terms only when the facilitated species yields more because of such support than when it grows unsupported. In other words, the interspecific facilitation has to be greater than the intraspecific facilitation that exists in the pure legume stand.

Research clearly documents that the susceptibility of pea to lodging results in decreased yields. Annicchiarico and Iannucci (2008) found a negative correlation between susceptibility to lodging and grain yield among 37 pea cultivars. Schouls and Langelaan (1994) suggested that the main reasons for grain yield losses in pea were the worsened light penetration into a lodged canopy and the lack of assimilates for later-forming pods. A decrease in the grain yield of pea resulting from lodging was also demonstrated by Wang et al. (2006) in an experiment in which one treatment artificially prevented lodging of the pea canopy. Other research showed that leafy pea cultivars were more prone to lodging than semileafless ones (Annicchiarico and Iannucci, 2008; Schouls and Langelaan, 1994; Uzun and Açıkgöz, 1998; Uzun et al., 2005; Wang et al., 2006). According to Uzun et al. (2005), tall pea cultivars lodged more than shorter ones. Consequently, lodging has biological meaning being inherent in the growth of pea. Thus, when the legume is grown in mixed stands with cereal, aboveground facilitation operates in the intercrop.

In intercropping experiments with pea, plant lodging has rarely been examined. Corre-Hellou et al. (2011) attributed the greater weed infestation of pure pea stands than barley–pea mixtures to lodging of the legume. Kontturi et al. (2011) observed severe lodging of certain semileafless pea cultivars in pure stands and demonstrated that even small numbers of oat plants effectively reduced lodging in an oat–pea intercrop. Rauber et al. (2001) found a high-yield advantage when intercropping oats with conventional tall, leafy pea cultivars and suggested that the advantage occurred because the cereal prevented lodging of the pea. The importance of this type of facilitation has also been shown in research with other crops. Revilla-Molina et al. (2009) questioned the role of resource complementarity in a varietal rice mixture. They demonstrated that the yield advantage of the mixture over the pure stands resulted from the support that one cultivar provided to another.

Based on the available studies, it may be assumed that the aboveground facilitation of pea by barley is yet another interaction apart from competition that exists in the intercrop mixture. Observation of the canopy of such an intercrop, where the attachment of the pea tendrils to the barley allows the legume to climb to the top of the canopy and gain more light, suggests that the phenomenon may positively affect pea yields.

The aims of the present research were to determine the grain production of intercrops of barley with two cultivars of field pea and to analyze the interactions between the component species at different levels of N fertilization. For the purpose of this study, two experiments were conducted: a field experiment (Experiment 1) and a microplot experiment (Experiment 2). The field experiment was designed to evaluate the effects of N fertilizer input on plant lodging, grain yield, the intercrop yield advantage and interspecific competition. The microplot experiment was designed to assess the importance of the supportive function of barley against pea lodging, which is understood to be a facilitative interaction, and the role of N fertilizer input in modifying this facilitative interaction and in interspecific competition.

2. Materials and methods

A pair of two-factorial experiments was conducted in 2005–2007 in Wrocław at the Swojec Agricultural Experimental Station of Wrocław University of Environmental and Life Sciences. Both experiments were conducted in the same field on alluvial loamy sand soil of 5.5–5.6 pH containing 0.5 g kg^{-1} of total N in the 0–20 cm layer. Oats was the preceding crop before both experiments each year. After harvesting the oats and collecting the straw, the soil was tilled shallowly. Before winter, the field was plowed to a depth of 25–27 cm. In spring, the field was harrowed with a spike-tooth harrow and fertilized each year with triple superphosphate and potassium chloride at a rate of 22 kg of P ha^{-1} and 66 kg of K ha^{-1}.

2.1. Weather conditions

The weather conditions varied during the experimental period (Fig. 1). The rainfall was highly variable during the 2005 growing season. In May, the rainfall was more than two times the 37-year average, whereas June precipitation approached only half of the monthly long-term average. A prolonged period of snow cover in March 2006 due to low air temperatures caused a two-week delay in sowing the experiments. Adverse water conditions in May and July 2006 together with a high air temperature in July accelerated