



Contribution of legumes to wheat productivity in Mediterranean environments of central Chile

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ABSTRACT

The potential benefits of using a legumes have not been evaluated in the rainfed, cropping systems of central Chile where wheat (*Triticum aestivum*) is typically grown in rotation with oats (*Avena sativa*) using high rates of nitrogen (N) fertilizer. Two experiments were initiated to compare unfertilized legume-wheat cropping sequences to the current oat-wheat system without and with applications of N fertilizer (160 or 207 kg N ha⁻¹). One experiment was located in the interior dryland of central Chile (average annual rainfall 650 mm), and the other in the Andean foothills (average annual rainfall 1200 mm). Treatments were established in different areas of the same two experimental sites in consecutive years (2008 and 2009) resulting in four separate trials evaluating legume effects on wheat yield (2009 or 2010). Estimates of N₂ fixation determined using the ¹⁵N natural abundance technique indicated that around 21 kg shoot N was fixed for every tonne (t) of shoot dry matter accumulated by either narrow-leaf lupin (*Lupinus angustifolius*), field peas (*Pisum sativum*), yellow lupin (*Lupinus luteus*), or white lupin (*Lupinus albus*) grown for grain, and by vetch (*Vicia atropurpurea*) grown in association with oats for green manure. When the amounts of N₂ fixed were adjusted to account for N in the nodulated roots, narrow-leaf lupin was calculated to have returned the lowest average net inputs of fixed N to the system following grain harvest (26 kg N ha⁻¹) and field pea the highest (192 kg N ha⁻¹). By comparison vetch in the green manure treatments where all above-ground biomass were incorporated into the soil returned 67 kg fixed N ha⁻¹. Depending upon location and year, growing grain legumes increased the subsequent N uptake by wheat by up to 60 kg N ha⁻¹ (average 35 kg N ha⁻¹) and vetch + oats green manure up to 103 kg N ha⁻¹ (average 50 kg N ha⁻¹). Wheat yields after grain legumes ranged from 2.4 to 3.0 t ha⁻¹ in the interior dryland and 5.4–6.4 t ha⁻¹ in the Andean foothills which were respectively 72–110% (90% average) and 69–83% (75% average) of the yields achieved by N fertilized wheat. Wheat yields after the vetch + oats green manure were 1.8 and 7.9 t ha⁻¹ representing 60% and 102% of the yield of N fertilized wheat. In the absence of N fertilizer or legumes wheat yields after oats were around half that of the N fertilized wheat. It was concluded that grain legumes or legume-based green manures provide opportunities to greatly reduce the reliance of wheat production upon N fertilizer.

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1. Introduction

Many cropping systems traditionally utilized legumes to regenerate the nitrogen (N) fertility of soils through the legume's unique ability to fix atmospheric N₂ in a symbiotic relationship with the soil bacteria rhizobia. However, the practice declined drastically following the wide-spread availability of low-cost synthetic fertilizers such as urea in the early 1960s (Crews and Peoples, 2004). In the dryland (rainfed) cropping areas of the Mediterranean climatic region of central Chile, bread wheat (*Triticum aestivum*) is

predominantly grown in rotation with oats (*Avena sativa*) and relies heavily upon N fertilizers applied at sowing and tillering to support growth. Nitrogenous fertilizers represent >25% of wheat's total production costs, and the dramatic increases in the price of fertilizers and other agricultural inputs that has occurred in recent years, combined with the recognition of the high energy costs and green-house gas emissions associated with the production, transport and use of N fertilizers (Crews and Peoples, 2004; Jensen et al., 2011) has stimulated the interest of both researchers and farmers to reconsider what role legumes may have in providing a reliable and renewable source of N for food production.

The formation of root-nodules, the process of N₂ fixation within those nodules, and the legume's subsequent reliance upon N₂ fixation for growth (proportion of N derived from atmospheric N₂;

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%Ndfa) depends on many variables such as the presence and effectiveness of rhizobial strains in soil, soil pH, nutritional deficiencies or toxicities, concentrations of soil nitrate, and temperature or water stress (Howeison and Ballard, 2004; Chalk et al., 2010). The amounts of N_2 fixed on the other hand tend to be related to legume biomass production (Peoples et al., 2009a; Unkovich et al., 2010b), and in dryland agriculture one of the most likely factors to influence legume productivity is growing season rainfall. To our knowledge only two publications provide data on the amounts of N_2 fixed by grain legumes in Chile. Estimates of N_2 fixation by narrow-leaf lupin (*Lupinus angustifolium*) and white lupin (*Lupinus albus*) growing in southern Chile (1200 mm rainfall zone) indicated that 85% of the plant N came from N_2 fixation and 197–282 kg shoot N were fixed per ha^{-1} , respectively (Barrientos et al., 2002). Elsewhere in Chile Urzúa (2000) reported that between 100 and 300 kg N ha^{-1} were fixed by faba bean (*Vicia faba*), 50–270 kg N ha^{-1} by field pea (*Pisum sativum*), 40–300 kg N ha^{-1} by white lupin and 25–100 kg N ha^{-1} by common bean (*Phaseolus vulgaris*) although neither details of levels of %Ndfa achieved, or the factors responsible for the stated range of values were provided.

It has been demonstrated in different regions of the world that legumes can play a major role in: (i) providing net additions of N into cropping soils (Evans et al., 2001; Walley et al., 2007), (ii) increasing the concentrations of soil mineral N (Herridge et al., 1995; Evans et al., 2003a; O'Connor et al., 2010), and contributing directly to the N nutrition of wheat (Janzen et al., 1990; Jensen, 1994; Fillery, 2001), and (iii) improving the grain yield of following cereal crops (Evans et al., 2003b; Kirkegaard et al., 2008; Seymour et al., 2012). However, the only available Chilean data on the effects of legumes on wheat come from the high rainfall regions of southern Chile where wheat grain yields grown after legumes have been reported to be 55–140% greater than wheat following wheat (Rouanet, 1989; Novoa et al., 1995). The potential impact of introducing grain legumes or green manure crops into the wheat-based cropping systems has never been quantified for the Mediterranean-type climatic environments of central Chile where close to 60% of the total area of Chilean dryland wheat is sown (INE, 2007).

The objectives of the present study were to: (a) quantify and compare the inputs of fixed N by either narrow-leaf lupin, field peas, and yellow lupins (*L. luteus*), or white lupin grown for grain, and vetch (*Vicia atropurpurea*) grown in association with oats for green manure, and (b) determine the subsequent impact of including a legume in a cropping sequence on wheat N uptake and grain yield in two different rainfall regions of central Chile. This investigation differs from many previous rotation experiments undertaken elsewhere in the world which have generally focused on examining the impact of growing one legume genotype at a single location, usually for a single end purpose (either grain, forage or green manure), in a single year on the yield of a following wheat crop. Our study aimed to evaluate four different legume species, three grown for grain and one for green manure, in two different environments, and compared the grain yields and N-uptake characteristics of wheat after legumes with standard farmer practice of applying N fertilizer to wheat grown following oats. Furthermore, the experimental treatments were re-imposed on new areas of land in two consecutive years so that the performance of the legumes and the rotational benefits for wheat could be quantified at both trial locations over more than one growing season.

2. Materials and methods

2.1. Description of experimental sites

Two experiments were undertaken at two locations in central Chile between 2008 and 2010, namely the interior dryland and the

Andean foothills, which represent 23% and 68% of the total area sown to wheat in central Chile, respectively (INE, 2007).

Experiment I was conducted at the Experimental Center of Cauquenes-INIA (35°58'S, 72°17'W; 140 m above sea level), Maule Region, in the eastern part of the coastal mountain range of Chile in the interior dryland. The average annual temperature in this region is 14.7 °C, the minimum average is 4.7 °C (July) and the maximum 27 °C (January). Long-term average annual precipitation is 695 mm, with a six-month (November–April) dry season (del Pozo and del Canto, 1999).

Experiment II was conducted in a farmer's field in Yungay (37°10'S 71°58'W; 297 m above sea level), Biobío Region, in the Andean foothills. The average annual temperature is 14 °C, the minimum average is 3.5 °C (July) and the maximum 26 °C (January). Long-term mean annual rainfall is 1200 mm, with a 4-month (December–March) dry season (Novoa and Villaseca, 1989; del Pozo and del Canto, 1999).

The soil at the Experiment I trial site was a granitic Entisol, of sandy clay loam texture, classified as Ultic Palexeralfs (Stolpe, 2006). At the beginning of the study, soil pH (1:5 in water, 0–20 cm) was 7.0, the organic matter content was 1.6% and the concentrations of available mineral N (2 M KCl), P (0.5 M $NaHCO_3$) and K (1 M NH_4OAc) in the top 20 cm were 2.3 mg kg^{-1} , 12 mg kg^{-1} and 185 mg kg^{-1} , respectively. The soil at Experiment II was an Andisol of volcanic origin, Typic Haploxerands (CIREN, 1999). Topography was slightly hilly. Soil pH (1:5 in water, 0–20 cm) was 5.8, the organic matter content was 15% and the concentrations of available mineral N, P and K (0–20 cm) were 4 mg kg^{-1} , 9 mg kg^{-1} and 49 mg kg^{-1} , respectively.

2.2. Treatments

Both experimental sites were under naturalized pasture prior to the commencement of the study, although in the case of the Cauquenes trial, the land had been subject to regular cereal cropping every second year for at least the previous decade. The soil was prepared one month before sowing various legume species or oats using a chisel plow and disc harrows. Since the outcomes of rotational studies in dryland systems can be influenced by the patterns or amounts of rainfall that occur in either the treatment year or the following wheat phase, the two experiments were repeated in consecutive years. Legume and oats treatments were established at both sites in 2008 which were followed by wheat in 2009, and the same treatments were applied again in an area beside the 2008 trial in 2009 and these plots sown to wheat in 2010. This effectively resulted in four separate data sets evaluating the effects of legumes on wheat performance.

The treatments used in Experiment I at Cauquenes in the interior dryland included narrow-leaf lupin (*Lupinus angustifolius*, cv. Wonga; sown at 120 kg seed ha^{-1}), yellow lupin (*L. luteus*, cv. Motiv; 120 kg ha^{-1}), field peas (*P. sativum*, cv. Rocket; 220 kg ha^{-1}), and oats (*A. sativa*, cv. Urano; 120 kg ha^{-1}) grown for grain, and a mixture of vetch (*V. atropurpurea*, unnamed local cultivar; 60 kg ha^{-1}) + oats (cv. Urano; 40 kg ha^{-1}) to be used as green manure.

Treatments used in Experiment II at Yungay in the Andean foothills included narrow-leaf lupin (cv. Wonga; 120 kg ha^{-1}), white lupin (*L. albus*, cv. Rumbo; 140 kg ha^{-1}), field peas (cv. Rocket; 220 kg ha^{-1}), and oats (cv. Urano; 120 kg ha^{-1}) grown for grain, and a mixture of vetch (unnamed local cultivar; 60 kg ha^{-1}) + oats (cv. Urano; 40 kg ha^{-1}) to be used as green manure. No N fertilizer was applied to any of the legumes or vetch + oats treatments at either of the two experimental sites.

Oat (cv. Urano; 120 kg ha^{-1}) treatments were also sown as a grain crop with (+N fertilizer) and without N fertilizer (nil N fertilizer) at both experimental sites to represent the standard farmer

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