The impact of lupins on nitrate leaching and wheat productivity

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Abstract

To explore the impact of narrow-leafed lupins in rotation with wheat in Western Australia, the simulation model APSIM was employed to analyse nitrate nitrogen (NO_3 N) leaching and wheat productivity in a range of lupin-wheat rotations on contrasting soil types, using long-term historical weather records from two rainfall locations. The simulated impact of lupins on wheat profitability and N leaching differed somewhat from that expected from agronomic experience. Soils with low plant available water-holding capacity did not necessarily leach more N than soils with higher plant available water-holding capacity, due to differences in organic material and mineralisation. N leaching in some years at a low rainfall location (with less average deep drainage) was as high as at a high rainfall location. When the proportion of lupins in rotation with wheat was increased, wheat yields increased as well as the financial returns from the wheat crops. However, returns from including lupins in rotation were reduced under high additional N fertiliser input to the wheat crop at a low rainfall location and in low rainfall seasons. To maximise benefits from lupins in rotation with wheat, the proportion of lupins in the rotation and N management need to be site and soil specific. Seasonal variability, in particular the combination of seasons in a sequence of years, will add a large level of uncertainty to the management of wheat-lupin rotations.

Media summary

Lupins in rotation with wheat are often beneficial to the financial returns of following wheat crops, but can also cause large amounts of nitrate N leaching out of the root zone in variable rainfall environments.

Key Words

wheat yield, grain protein, deep drainage, Mediterranean environment

Introduction

Eighty percent of Australia's 1M hectares of narrow-leafed lupins (*Lupinus angustifolius* L.) are grown in the Mediterranean environment of Western Australia. Lupins are well adapted to the coarse-textured and acidic soils in Western Australia and they have rotational benefits by breaking the disease cycles of cereals and adding significant amounts of fixed nitrogen (N) to the soil. However, the NO_3 N leaching potential after a lupin crop is large on sandy soils (Anderson et al. 1998b) and hence the N impact on the following wheat crop varies with annual rainfall amount and distribution. The rainfall parameters are a function of rainfall zone and seasonal rainfall variability. To explore the impact of lupins in Western Australia, a simulation model was employed to analyse NO_3 N leaching and wheat productivity in a range of lupin-wheat rotations on two contrasting soil types and at two contrasting rainfall locations with 45 years of historical weather records.

Methods

APSIM is a modelling framework that allows submodels (or modules) to be linked to simulate agricultural systems (Keating et al. 2003). Five modules, a specific crop module for wheat (NWHEAT) and lupin (LUPIN), a soil water module (SOILWAT2), a soil nitrogen module (SOILN2), and a residue module (RESIDUE2) were linked within APSIM (Keating et al. 2003) to simulate lupin (Lp)-wheat (W) rotations. The wheat model has been tested extensively in connection with the soil modules for growth (Asseng et al. 1998b), deep drainage (Asseng et al. 2001) and NO_3 N leaching (Asseng et al. 1998a). The lupin module has been recently developed and tested by Farre et al. (2004). The potential daily rate of nitrogen fixation in the lupin module is a function of crop biomass (i.e. the size of the crop) discounted for soil water stress, following the logic of Sinclair (1986) that N fixation rates are well-correlated with the amount of nodule material in the roots, which is in turn well-correlated with the size of the plants.?The potential rate of N fixation varies with crop growth stage, in order to account for low N fixing capacity while the nodules are developing, and also as a consequence of nodule senescence during pod-filling (Robertson et al. 2002). Other benefits from lupins in rotation, e.g. controlling weeds and diseases, were not considered in the simulation experiment. Wheat-lupin rotation simulations with APSIM were tested with detailed field measurements of a rotation experiment (I. Farre, unpubl.) conducted on a deep sand at Moora, in the northern wheat-belt of Western Australia, by Anderson et al. (1998a; 1998b) and by I.R.P. Fillery and G.C. Anderson (pers. comm.). Their results indicated that non-wetting soil characteristics, particularly at the beginning of the season, caused preferential water flow leaving NO_3 N behind in the top layers. APSIM currently does not allow for non-wetting characteristics and therefore soil N profiles were re-set to measurements at the beginning of each growing season. Hence, simulation experiments with APSIM imply non-wetting characteristics are absent which will over-emphasise leaching processes.

A simulation experiment has been carried out for the same deep sand as the Moora rotation experiment (55 mm plant available water-holding capacity to maximum root depth (PAW)) and for a contrasting soil, a deep sandy loam with more than twice PAW (130 mm), in two contrasting rainfall locations with long-term historical weather records (1957-2002). One location was at Buntine (north of Moora) with 332 mm average annual rainfall. The second location was in the southern part of the wheatbelt at Kojonup with 492 mm average annual rainfall. In both locations, about 80% of average annual rainfall falls between April and October. The mean temperature is 3.9 ?C higher at Buntine than Kojonup. The simulations were run without any re-setting. The rotation treatments included different proportions of lupins (WW, LpWWW, LpWW and LpW). Each year, lupins were sown between 25 April and 31 July after the first occurrence of 15 mm rainfall over 10 consecutive days. Wheat was sown between 5 May and 5 June after a minimum of 25 mm during the period, or after 10 mm between 5 June and 31 July. A later maturing wheat variety was chosen between 5 May and 5 June and an early maturing wheat variety was used afterwards. Treatments of nil, 50 kg N/ha (at sowing), 100 kg N/ha (50 at sowing and 50 at 40 days after sowing) and 150 kg N/ha (50 at sowing, 50 at 40 days after sowing and 50 at 70 days after sowing) were applied to the wheat crops. Deep drainage and NO_3 N leaching were recorded at the maximum potential rooting depth of a soil (150 cm for the deep sand and 230 cm for the deep loamy sand).

Results

Testing of the rotation model indicated that APSIM can reproduce the observed dynamics of soil water and soil N (data not shown). The observed and simulated growth patterns for a LpW rotation on a deep sand at Moora from 1995 to 1998 is shown in Figure 1. While the lupin crop was reproduced well, the wheat crop tended to be over-estimated in 1995 and underestimated in 1997.

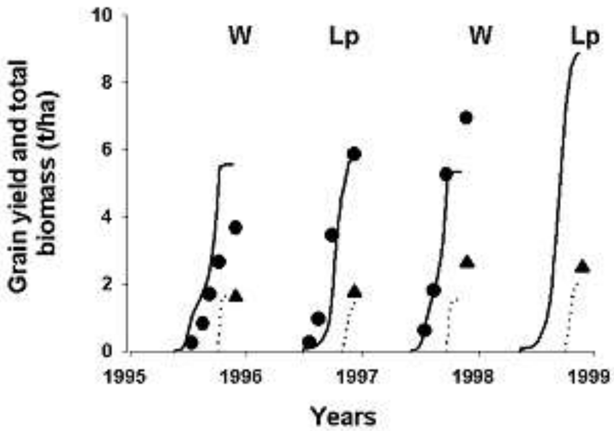

Figure 1. Simulated (lines) and observed (symbols) grain yields (▲,····) and total biomass (●, —) for Moora, Western Australia for wheat (W) and lupin (Lp). Note, no measurements for total lupin biomass in 1998 were available. The observed data were provided by Anderson et al. (1998) and Fillery and Anderson (pers. comm.).

The output from the APSIM model using the long-term historical weather records at Kojonup and Buntine showed that average NO_3 N leaching was, as expected, in average higher at the high rainfall location (Kojonup) than at the low rainfall location (Buntine). Nitrate N leaching, which occurred mainly during the wheat crops,

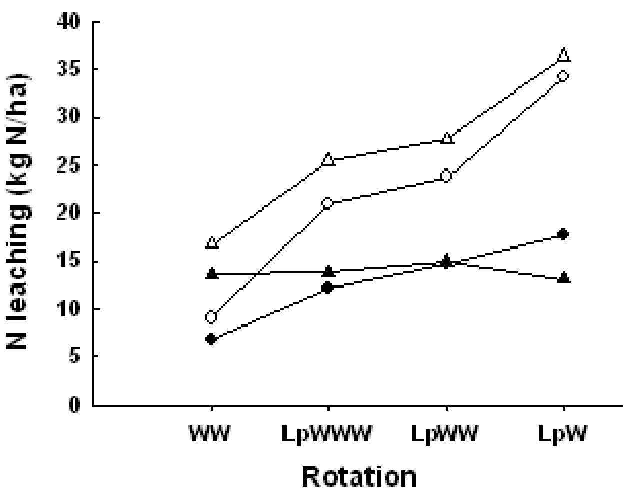

Figure 2. Simulated average (45 years) annual NO_3 N leaching in a sandy soil at Buntine (●), and Kojonup (?) and a loamy sand at Buntine (▲), and Kojonup (△), Western Australia, for lupin (Lp) – wheat (W) rotations with no additional fertilizer N.

Nitrate N leaching on the loamy sand at the low rainfall location Buntine was about the same across the different lupin proportions (12-13 kg N/ha) as a result of a combination of the higher PAW of 130 mm with less drainage and lower rainfall. At Kojonup there was less NO_3 N leaching on the sand, even with the low PAW of 55 mm and higher drainage rates, due to less organic material, lower N mineralisation and poorer lupin growth on the sand as compared to the loamy sand. However, with 50% lupins in the rotation at Buntine the simulations suggested that the sand leached more N than the loamy sand. Average lupin grain yields were 2.3 t/ha on the loamy sand and 1.5 t/ha on the sand at Kojonup and 1.8 t/ha on the loamy sand and 0.9 t/ha on the sand at Buntine.

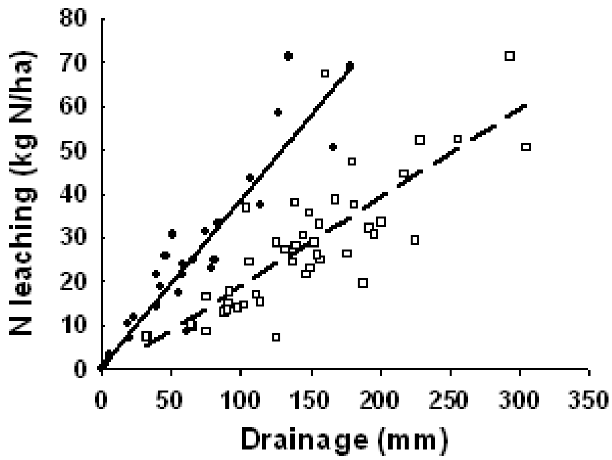

Figure 3. Simulated annual NO_3 N leaching versus deep drainage for a lupin–wheat– wheat rotation (LpWW) for a loamy sand at Buntine (●) and at Kojonup (□), Western Australia, with no additional fertilizer N. Regression lines are shown.

When comparing annual NO_3 N leaching at Buntine with Kojonup for a LpWW rotation, NO_3 N leaching in some years at the low rainfall location was as high as at the high rainfall location, although deep drainage was in general less at Buntine (Figure 3). Indeed, there was more NO_3 N leaching simulated for each mm drainage at Buntine compared to Kojonup, due to the accumulation of N in the soil in dry seasons, less crop utilisation of N under water deficit and less frequent drainage events. High rates of simulated NO_3 N leaching are often caused when mineral N is built up in the soil during dry seasons and then followed by a wet season; therefore the sequence of seasons becomes critical.

Taking into account the grain yield and protein content of the wheat, the financial return from wheat crops in rotations with lupins increased with a larger lupin proportion in the rotation, as shown for Buntine in Figure 4. However, the benefit from lupins became less with increasing N fertiliser rates and was even negative with 100 kg N/ha at Buntine. Overall, across the different proportions of lupins in the rotation, the wheat yield benefits from lupins averaged about A$100-150 per wheat crop at Buntine and were about A$150-200 at Kojonup.

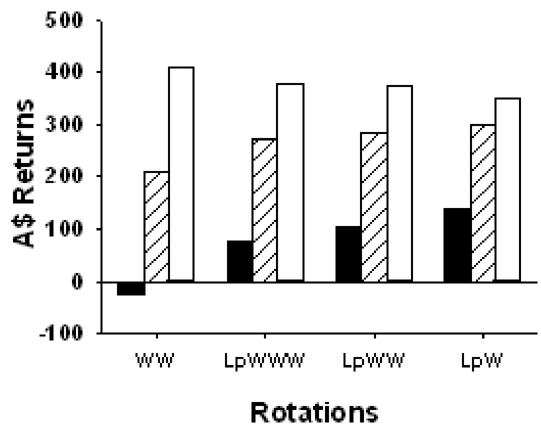

Figure 4. Simulated average (45 years) annual A$ returns for wheat grown on loamy sand in lupin (Lp) and wheat (W) rotations at Buntine, Western Australia. The wheat crops had N – fertilizer of nil (filled bars), 50 kg N/ha (crossed bars) and 100 kg N/ha (open bars). Grain yield and protein at 11% moisture. Operating costs of $113/ha and $0.80/kg N have been subtracted. The base rate for wheat was assumed at A$170/t.

Conclusions

The simulation results of the rotation experiment indicated that crop sequence, soil type, location and seasonal rainfall interactions complicate the analysis of the impact of lupins in rotations on wheat profitability and NO_3 N leaching, with some results not necessarily expected from agronomic experience. To maximise benefits from lupins in rotation with wheat, the proportion of lupins in the rotation and N management of wheat need to be site and soil specific. However, seasonal variability, in particularly the combination of seasons in a sequence of years, will add a large level of uncertainty to the management of wheat-lupin rotations.

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