A desktop analysis of the economics of fixed N in Australian dryland cropping rotations

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Abstract

Grain legumes have played an important part in Australian agriculture providing an economic yield, a weed/ disease break and supplying nitrogen (N) to the cropping system via fixing atmospheric N. However, the potential opportunity cost (lost profit for not growing other crops) of growing legumes, means fixed N is not necessarily “free”. Furthermore, fertiliser may be a cost-effective alternative source of N. A desktop analysis was conducted to quantify the economic value of fixed N in three dryland legume-wheat rotation systems (WA-lupins, Vic-field pea, and NSW- chickpea) across Australia, by comparing legume-wheat to wheat-wheat rotations over 100 seasons with the APSIM simulation model. Scenarios included a range of soil N and fertiliser N rates applied to wheat. The economic values of the two rotations were analysed using a simple economic framework that accounted for commodity price and the value of residual fixed N. The results showed that the biggest driver of profitability to grow a grain legume crop was the economic return from the legume grain. Residual fixed N only accounted for a small component of the economic return except when fertiliser N was not applied to subsequent wheat crops. The value of residual fixed N was low because most of the fixed N was removed with the harvested legume grain and under current prices fertiliser N was a cheaper alternative. Therefore, farmers should integrate grain legumes in their rotations only if they are profitable compared to alternative crops, in terms of commodity price and weed/disease benefits.

Key words

Fertiliser N, grain price, grain legume, profit, pulses

Introduction

Soil nitrogen (N) is a common limiting factor to crop growth and yield. Ensuring that crops have access to sufficient N is central to productive farming systems (Sinclair and Rufty 2012). Historically, much of the N supplied to cropping systems came from the biological N fixation derived from the symbiotic relationship between legumes and rhizobia. Measurements have shown that quite large amounts of N can be fixed by legume crops. For example, the mean amount of measured N fixed by lupin, chickpea, field pea and faba bean is 136, 40, 84 and 90 kg N/ha respectively (Unkovich et al. 2010). Despite this, there has been a decline in the area of some legume crops in Australia, such as the area sown to lupin decreasing from 1.3 to 0.7 M ha between 1995 and 2011 (ABARES). In contrast, recently fertilizer N has been widely used in cropping systems and become a cost-effective alternative to supply N to crops. It is important to understand the triggers for such changes for developing profitable and sustainable agricultural systems in the future.

Biological N fixation has often been treated as a source of “free” N in cropping systems. However, when growing a legume crop there is a potential opportunity cost, i.e. the profitability that is foregone for not growing another crop, which needs to be considered. Taking account of the opportunity cost is vital in determining the economic value of fixed N. There is often a yield benefit to cereal crops grown after legumes (e.g. Seymour et al. 2012), which also needs to be considered. However, quantifying the economic value of fixed N to a cropping rotation is difficult. If the total economic value of residual fixed N following a legume crop and its contribution to following cereal crop is less than the opportunity cost, fixed N will not be a contributor to increased profitability. Here we report the results of a desktop analysis that quantified the economic contribution of legume fixed N to dryland cropping rotations in Australia. We used the APSIM simulation model (Holzworth et al. 2014) and constructed a bio economic framework to account for the yield benefits to a cereal following a legume crop, the value of the fixed N, but also the opportunity cost associated with growing a legume crop instead of a cereal.

Materials and methods

We constructed hypothetical cropping rotations at three representative sites throughout the Australian grain belt (Table 1). For each site simulations were run for 100 years (1912-2012) for both a wheat-wheat rotation and a legume-wheat rotation using APSIM, which has been shown to be able to adequately model the amount of N fixed by legume species (Chen et al. 2015). Standard sowing and harvesting rules were used for each crop. Various starting soil N and fertiliser N applied to wheat at sowing were simulated (Table 1). But no fertiliser was applied to the legume crops.

Table 1. Locations and biophysical/economic variables applied in each analysis

	Dalwallinu, WA	Birchip, Vic	Moree, NSW
Legume crop	Lupin	Field pea	Chickpea
Starting soil N (kg N/ha)	20, 80	20, 80	25, 75, 150
Fertiliser N applied to cereal (kg N/ha)	0, 50, 100, 150	0, 50, 100, 150	0, 50, 100
Fertiliser N price ($/kg N)	1.00, 1.50, 2.00, 2.50, 3.00	1.00, 1.50, 2.00, 2.50, 3.00	1.00, 1.50, 2.00, 2.50, 3.00
Legume grain price ($/t)	200, 250, 300, 350	250, 300, 350, 400	200, 300, 400, 500

A simple economic framework was applied to each rotation taking into account both the value of grain from both crops and the extra N in the cropping system following the legume crop. The calculation of N in the system also included the saved N (N not applied) by the legume crop compared with wheat. Economic scenarios included various legume prices (depending on crop) and three fertiliser N prices ($1.00, $2.00, and $3.00/kg N) with a fixed wheat price ($300/t). For comparison, mean fertiliser N prices between 2003 and 2013 were $1.24/kg N with a range from 79 c/kg N to $1.91/kg N (ABARES). Fertiliser N price was used to calculate the cost of fertiliser N applied to the wheat crops but also the extra N contributed to the system from the N fixation of the legume crops. Residual fixed N from the legume was calculated as the difference in N in the cropping system at the beginning and end of the two year rotation. The mean difference in profitability between the two rotations over two years was used to evaluate the economics of fixed N.

Results

Birchip

Simulated mean yields for wheat and field pea were 2.6 t/ha and 2.3 t/ha, respectively. With a low starting soil N, the field pea crops fixed a mean of 99 kg/ha and removed 83 kg N/ha in grain, leaving a residual N benefit of 6 kg N/ha. With a high starting soil N, the field pea crops fixed a mean of 69 kg/ha and removed 83 kg N/ha in grain, leaving a residual N deficit of 14 kg N/ha. The actual value of this residual N depended on the price of N. Field pea-wheat rotations were generally more profitable than wheat-wheat rotations (Figure 1). The biggest driver of profitability were changes in the price received for field pea. At a low field pea price of $250/t many of the field pea-wheat rotations had lower returns than a wheat-wheat rotation. Under all scenarios where the field pea price was $400/t a field pea-wheat rotation had the highest return. The amount of N applied to the wheat crop was also a big determinant of profitability. As more N was applied to wheat crops the value of fixed N decreased and therefore the relative profitability of this rotation fell. N fertiliser price was only a small driver of the difference in returns between these two rotations.

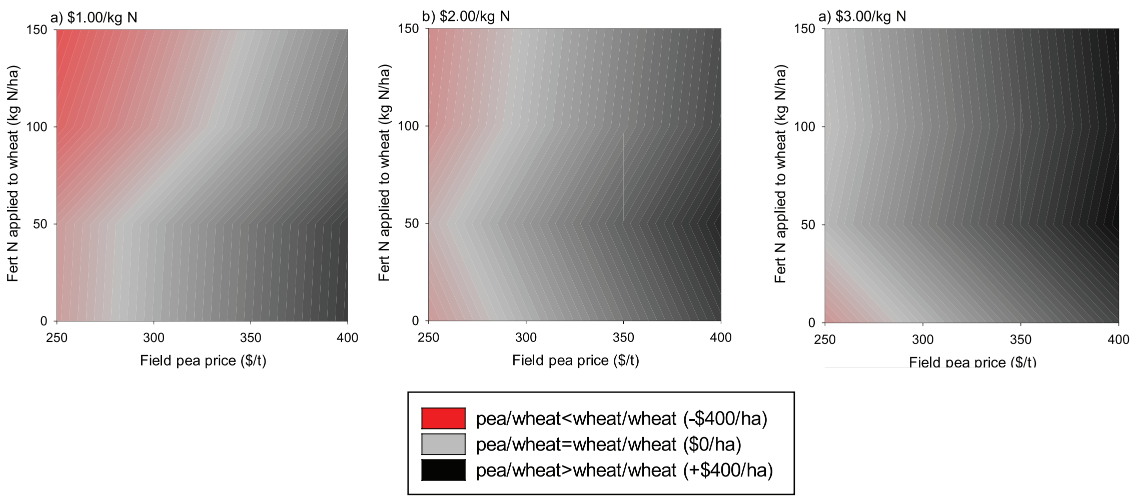

Figure 1. Effect of applied fertiliser N, Field pea price and fertiliser N price on difference in profit from field pea-wheat rotations and wheat-wheat rotations at Birchip for a low N soil (20 kg N/ha).

Dalwallinu

Simulated mean yields for wheat and lupin were 2.7 t/ha and 1.3t/ha, respectively. With a low starting soil N, the lupin crops fixed a mean of 113 kg/ha and removed 71 kg N/ha in grain, leaving a mean residual N benefit of 42 kg N/ha. With a high starting soil N, the lupin crops fixed a mean of 95 kg/ha and removed 71 kg N/ha in grain, leaving a mean residual N benefit of 24 kg N/ha. The biggest driver of profitability was changes in the amount of fertiliser applied to wheat crops. In most situations with no fertiliser lupin-wheat rotations were more profitable than wheat-wheat rotations (Figure 2). However, when any rate of fertiliser N was applied the lupin-wheat rotations were less profitable than wheat-wheat rotations, especially with low fertiliser N prices (Figure 2a). Lupin prices had only a small impact on relative profitability. Overall, N fertiliser prices needed to triple to $3.00 kg/N to make a marked change in the return difference (Figure 2c).

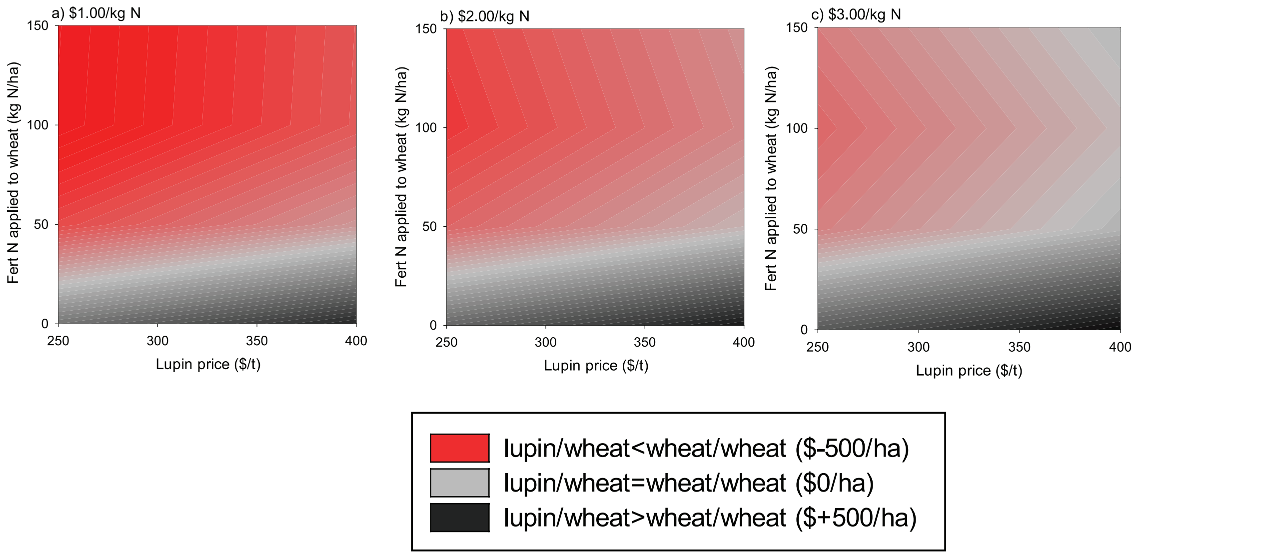

Figure 2. Effect of applied fertiliser N, lupin price and fertiliser N price on difference in profit from lupin-wheat rotations and wheat-wheat rotations at Dalwallinu for a low N soil (20 kg N/ha).

Moree

Simulated mean yields for wheat and chickpea were 2.6 t/ha and 1.6t/ha, respectively. With a low starting soil N, the chickpea crops fixed a mean of 66 kg/ha and removed 57 kg N/ha in grain, leaving a mean residual N benefit of 9 kg N/ha. With a medium starting soil N, the chickpea crops fixed a mean of 39 kg/ha and removed 57 kg N/ha in grain, leaving a mean residual N deficit of 18 kg N/ha. With a high starting soil N, the chickpea crops fixed a mean of 25 kg/ha and removed 96 kg N/ha in grain, leaving a mean residual N deficit of 71 kg N/ha. In most situations where chickpea price was $300/t or greater, the chickpea-wheat rotation was more profitable than a wheat-wheat rotation (Figure 3). The difference in return between the two rotations was equally sensitive to both chickpea price and the amount of N fertiliser applied to wheat. There was very little change in the difference in return between the rotations when fertiliser price doubled to $2/t (Figure 3b). However, there was a shift in favour of the chickpea-wheat rotation when fertiliser N price tripled to $3/t (Figure 3c).

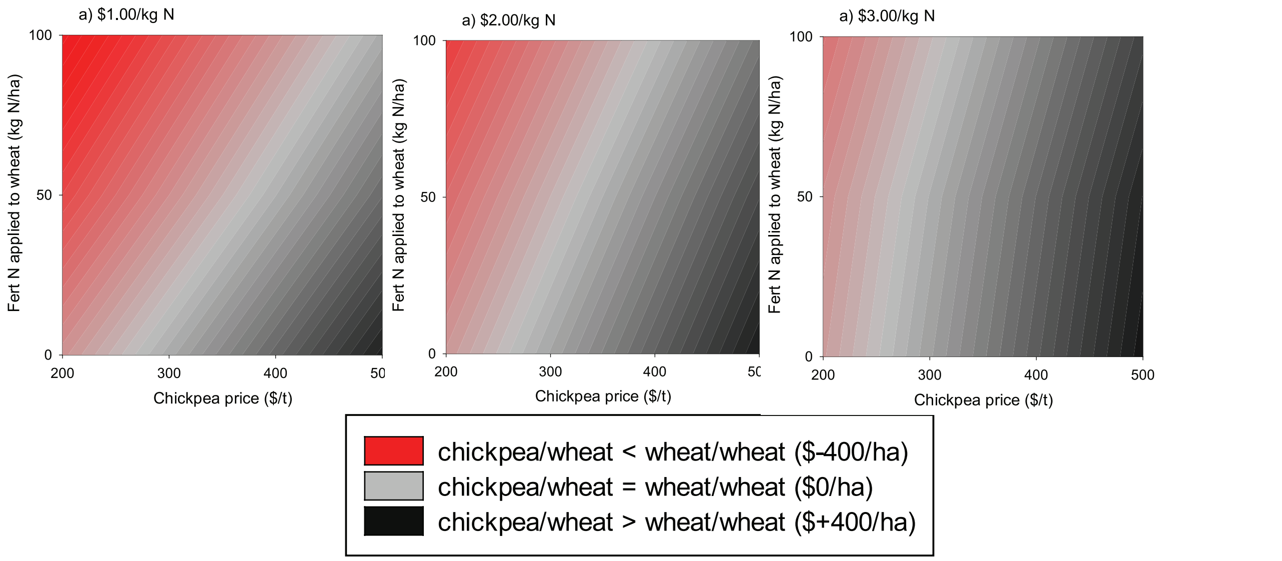

Figure 3. Effect of applied fertiliser N, chickpea price and fertiliser N price on difference in profit from chickpea-wheat rotations and wheat-wheat rotations at Moree for a medium N soil (75kg N/ha).

Discussion

The value of fixed N from the legume component of these rotations was small compared to the economic return from legume grain. There are 2 reasons to explain why the economic value of fixed N was low. The first was that under current prices fertiliser N was a cheaper alternative than fixed N. This was highlighted by the relative insensitivity of economic return to fertiliser N price (which also determined the value of fixed N) (Figures 1-3). This was further highlighted by the response of relative to applied fertiliser N. When no fertiliser N was applied to wheat crops any residual N from the legume had a large effect on profitability due to the extra wheat yield. This was most pronounced for the lupin-wheat rotation in WA (Figure 2) due to the larger amounts of residual N following lupins compared to the other two legumes. However, when N fertiliser was applied the lupin rotations were less profitable. The second reason was that a large proportion of fixed N was contained in legume grain, which was removed from the system after harvest of the legume crop and therefore was of no value to following crops.

The difference in return was always sensitive to legume grain price. This highlights the importance of the opportunity cost for growing (or not) these legumes. In some situations there was a large opportunity cost (e.g. Figure 2) and the legume-wheat rotations had a lower return than the wheat-wheat rotations. While in other some scenarios there was no or only a small opportunity cost (e.g. Figure 1) and the legume-wheat rotations had a higher return than the wheat-wheat rotations.

Conclusion

We are not advocating for or against including legumes in crop rotations in Australia, but rather analysing the possible economic values of N fixed by legumes. If they are profitable (based on yield and commodity price) compared with other alternative crops farmers should include legumes in their rotations. For all three rotations simulated residual N benefit following a legume crop was only a minor contributor to profitability. While fertiliser prices remain relatively low fixed N should not be a major driver in the decision to grow a legume or not. Our analysis did not consider the other benefits provided by legume crops in crop rotations such as weed and disease breaks. These considerations may be important drivers in the decision to grow a legume break or not. However, once the decision to grow a legume has been made then the amount of residual N following that legume crop will need to be considered in the N fertiliser applied to subsequent non-leguminous crops.

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