Australia's declining crop yield trends II: The role of nitrogen nutrition.

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Abstract

From comparison with world benchmark yields and in light of the fact that the average crop receives very much higher inputs than it did 20 years ago but does not yield any more, indications are that Australian wheat yields are in real decline. Reasons for this declining trend are examined, particularly with respect to the likely impact of nitrogen as a primary driver of yield. This trend coincides with an intensification of cropping, a reduction in the use of rotational legume leys and an increased use of fertiliser as an N source. However, as fertiliser sales show, this is not replacing what is being used by the crop; the balance being met from depletion of the soil N bank. Implications of this declining soil reserve and means to reverse the decline and consequently restore and improve system productivity, sustainability and profitability are discussed.

Key Words

Australian crop yield trends, rotations, productivity, sustainability, nitrogen nutrition, ley farming,

Introduction

In the first paper in this series (Lake 2012) it was found that average Australian wheat yields show a distinct plateau and probable real decline since about 1990. This is despite increased farmer inputs, advanced production technologies and variety genetics and contrasts continuing growth in world average wheat yields over the last three decades (ABARES 2012). As the onset of this plateau and decline period coincides with increased cropping intensity and decreased use of legume leys in crop rotations, this paper examines the possibility that nitrogen (N) previously supplied via pasture legume fixation (Crawford *et al* 1989) has become deficient and is a likely major cause for the observed deterioration in crop performance.

Methods

Data sources

Data on total domestic nitrogen fertilizer usage and total Australian crop production for the period 1989-90 to 2008-09 were obtained either directly or by estimation from official statistics (ABARES 2010).

Overall methodology

N balance figures for each year since 1989 were estimated by calculations of total N removed via crop product less the net amount (ie with allowance for estimated losses via volatilization, denitrification and leaching) added via fertilizer. While actual losses vary widely, an average figure of 30% of applied N is assumed lost. The balance is assumed to be derived from (or added to) the soil N pool.

Assumptions and scenarios

The data available from ABARES with respect to N fertilizer usage are effectively limited to total N used in Australian agriculture, so that two different scenarios were developed using different assumptions with respect to the proportion of total N used on temperate broad acre crops versus on pastures, horticultural and other crops. Both scenarios assume that prior to 1990 only about 15% (60kt elemental N equivalent, mainly as mono- and di-ammonium phosphate) to temperate crops. This is because most N prior to then came from fixation via commonly used legume leys (Crawford et al 1989). That application (60 kt p.a.) is assumed to continue on as a base rate for both scenarios for the post 1990 period.

In Scenario 1, this 60 kt plus all additional N fertilizer above the basal 1990 level is assumed applied to temperate broad acre crops. This provides a best case scenario for N balance in these crop soils. Scenario 2 assumes that the 60 kt plus 70% of the increased N fertilizer consumption since 1990 has been applied to temperate broad acre crops. Other allowances and assumptions for purposes of simplification included;

- Legume crops are 10% of total crop production by weight, and are system N neutral;.
- Wheat averages 10% protein by weight or 16 kg of elemental N equivalent per tonne of grain.
- All other crops were assumed to likewise have 16 kg of elemental N equivalent per tonne of grain.

While data available are not entirely consistent across the full period due to differing means of collection and presentation by ABS and ABARES, from examination of the data (some time overlap of differing data sets allowing same year comparisons) the likely resulting variations are small.

Results and discussion

Crop area, production and N fertiliser use.

Both area sown to crops and total crop production have grown significantly since the late 1980s; the former by 60% and the latter by about 50%. However, while crop area has grown fairly steadily throughout the period, peak total production occurred in the late 1990s and has since declined (Figure 1). This reflects previous findings that average crop yields per hectare are not growing as should be expected (Lake 2012).

Since the late 1980s, total N fertiliser use in Australia has also grown significantly from 440 kt to 900 kt (elemental N equivalent) p.a. in the decade to 2008-09 (Figure 2). This growth (mainly in urea consumption) occurred almost entirely in the mid-late 1990s, and after allowing for droughts, has since roughly stabilised.

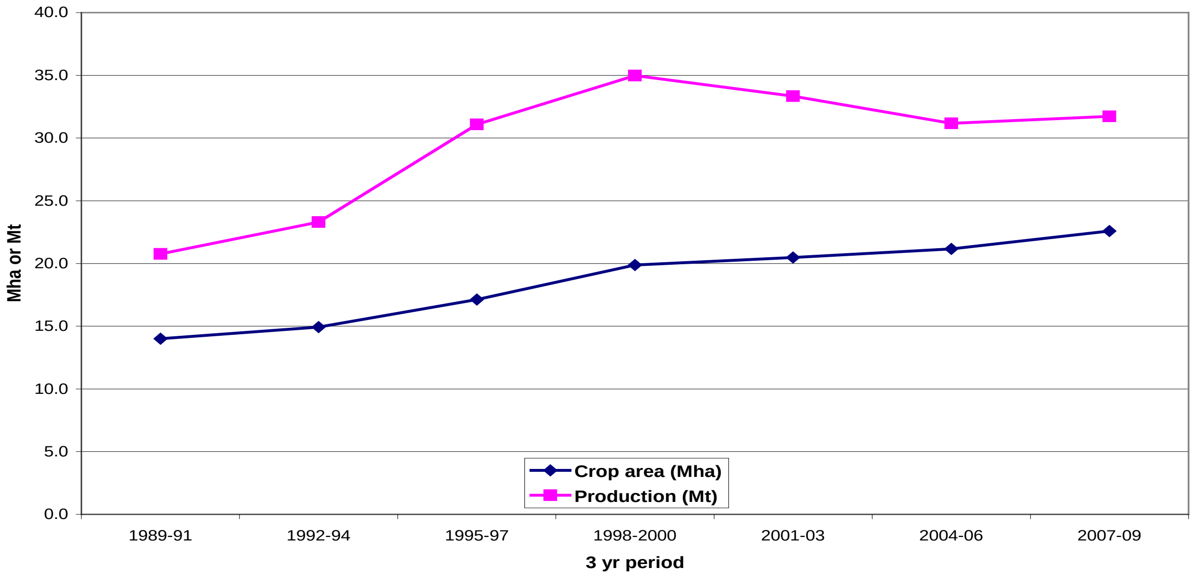

Figure 1. Changes to temperate crop area and total production in Australia since 1990.

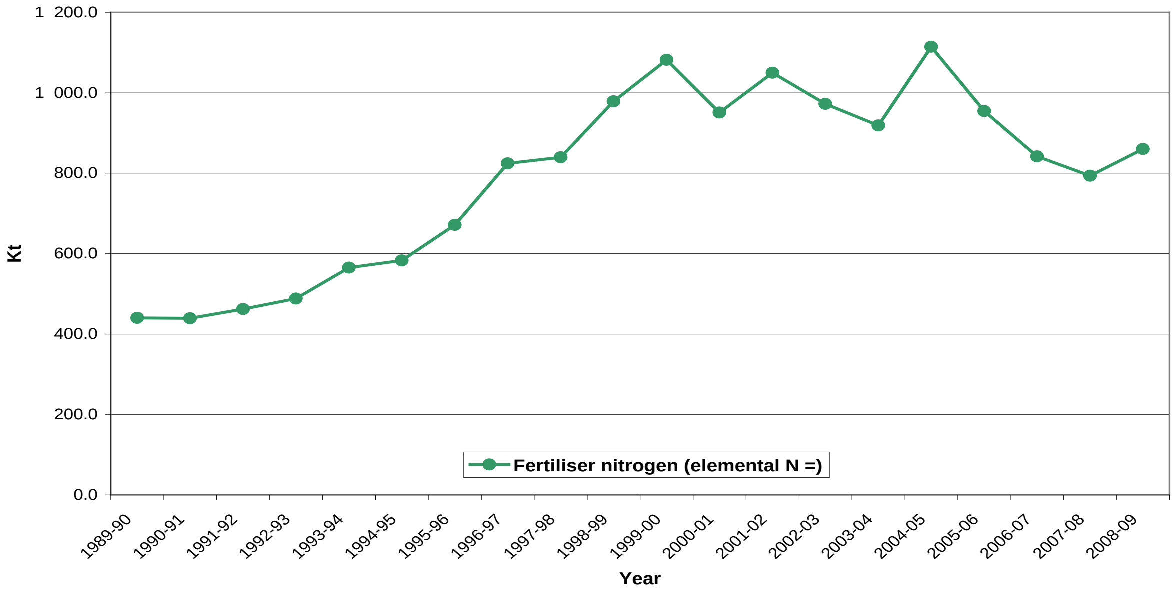

Figure 2. Changes to annual total fertiliser nitrogen use in Australia since 1990.

Nitrogen balance scenarios

The two nitrogen balance scenarios developed both show that despite increased N fertiliser rates, estimated effective N added to crops is consistently less than that which is exported via harvested grain (Figure 3).With the most optimistic scenario (Scenario 1) there is an overall accumulated deficit of N utilised over effective N applied in the 20 years since 1989 of almost 4 million tonnes of elemental N fertiliser equivalent. With Scenario 2, the figure for the same period is estimated at above 6 million tonnes of elemental N fertiliser equivalent. In the former case, N derived from fertiliser has effectively supplied just over 2/3rds of total crop N harvested over the period and the total (soil derived) N deficit is increasing steadily at about 100 kt elemental N fertiliser equivalent p.a. In the latter scenario, less than 50% of harvested N is being supplied, and the net deficit is growing at 250 kt elemental N fertiliser equivalent p.a..

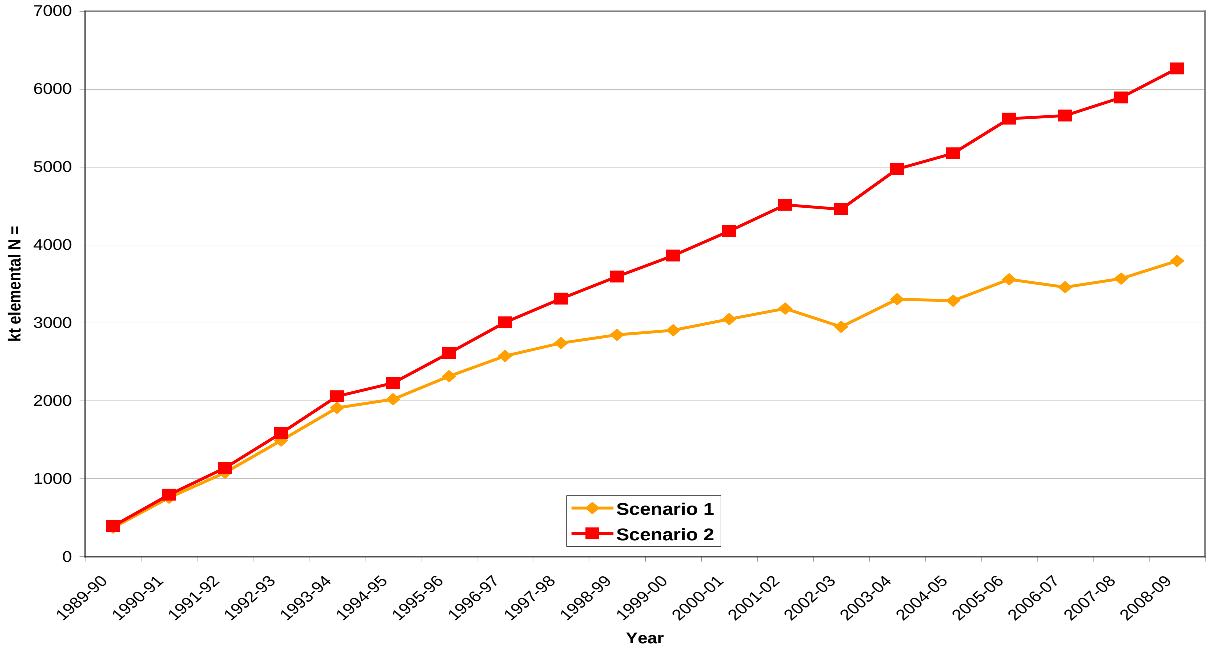

Figure 3. Accumulated N deficits expressed as elemental N fertiliser equivalents in Australian temperate crop soils as estimated by two scenarios; Scenario 1 being the best possible case of N fertiliser usage on those crops and Scenario 2 being a more realistic assessment of likely N usage levels.

Comparison of scenarios.

As noted, Scenario 1 assumes that the entire increase in N fertiliser consumption in Australia since 1990 has been applied to broad acre crops. However, given that cheap N fertiliser has spawned rising use across many agricultural production systems, this is unlikely to be the case. Even the more conservative Scenario 2 may be overly optimistic in its N deficit estimates. For example, to calculate wheat gross margins for typical farms in SA, Rural Solutions SA quotes N fertiliser rates consistently below those required to achieve the 50% of N replacement that is estimated to have occurred under Scenario 2 (Anon 2004, *et seq*.). Hence Scenario 2, in itself possibly somewhat optimistic, is very probably much more realistic than Scenario 1.

Likely implications for crop productivity, soil health and sustainability.

The data show Australian crop production is still strongly reliant on soil N reserves. In the traditional ley farming rotations used from the 1950s (Donald 1967) to the 1980s (Crawford et al 1989) legume leys could provide more than adequate N for intervening cereal crops (Clarke and Russell 1977). However since 1990, accumulating anecdotal evidence (increased cropping, low pasture legume seed sales, most pastures having very poor legume content, etc) shows loss of legume leys from most rotation systems, with the consequent net N removed with crop product being mined from reserves built up over previous decades of ley farming. Economically according to Scenario 2, total loss of soil N reserves from 1990 to 2009 is about 4.5 million tonnes elemental N, or at 70% effectiveness of fertiliser, the equivalent of about 14 million tonnes of urea, currently worth nearly 10 billion dollars. For a typical paddock continuously cropped since 1990, this represents a loss of 2/3rds of total N reserve, a decline of C:N ratio from 30:1 to 80:1 and were it possible to do so, a restoration cost via fertiliser of $700 to $1000 /ha (data not shown). This should be financially accounted for either directly as a loss or as a write down in the value of that crop land.

Further for a soil with an 80:1 C:N ratio, there will be intense competition for N both within and between crops and soil microbial populations. The consequent reduction of microbial biomass will also reduce both nutrient mineralisation (potentially creating new nutrient deficiencies) and competition to disease organisms, thereby increasing the risk of crop yield destroying root and crown disease outbreaks.

Thus it is a reasonable conclusion on multiple grounds that soil N deficiency is a major factor in the observed wheat yield declines, and that current production systems are seriously unsustainable.

Deficiency remediation and yield improvement
One of the principal reasons for chronic farmer use of sub-replacement levels of fertiliser N is that under Australian conditions, overdosing can devastate yields through promoting excess top growth. Biological N supply (ie via mineralisation from soil organic matter) on the other hand is far less prone to such overdosing. This is because the factors that limit microbial activity and consequently N mineralisation (such as low soil moisture) are the same as those that limit plant growth. In effect then, this biological N provides a form of natural crop growth regulation that is directly tuned to growing conditions.

While legume leys are a very good means of building this biological N bank, many farmers have reservations about the cost of introducing these leys into their rotations. However, several factors currently combine to make this a very viable option to restore system sustainability and improve yield and profit. These are;

- legume N fixation slashing N fertiliser bills (fully accounted, by about $40/tonne of crop)
- a predicted yield response of up to 40% that will triple farmer profit margins (Lake, unpubl) and
- good current returns and outlook for (legume pasture grown) animal products such as prime lamb.

Thus correction of system N deficiency via legume leys is both profitable and far less risky than via fertiliser.

Conclusion
Despite large increases in fertilizer application rates since 1990, soil N reserves are still a significant source of crop N. However, in the absence of replenishment via the traditional legume leys, significant depletion of soil N has occurred since 1990. This is of sufficient magnitude that N deficiency is very likely to be a direct and major cause of the observed real decline in wheat productivity, and by extension in other crops. That decline is very likely also exacerbated by other factors indirectly related to reduced soil N, such as the reduction in beneficial soil microbial populations and activity and in natural regulation of N supply.

Because of its cost and intrinsic risk to crop yield, high rates of N fertilizer are not currently a viable means of remediation. In contrast, calculations show legume leys should result in increased farm profit even where there is zero return from the ley year, via both substantially higher yields and lower fertilizer input costs, making them a low risk means of correcting N deficiency and improving yield, profit and sustainability.

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