The challenge to sustainability of broadacre grain cropping systems on clay soils in northern Australia

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Abstract

Fertilizer inputs, crop yields and grain nutrient concentrations were determined for sorghum, wheat, barley and chickpeas - the main species grown in the extensive grain cropping systems of north-eastern Australia. Apparent nutrient budgets (nutrient input in fertilizer – nutrients removed in grain) almost universally showed negative balances, indicating a decline in native soil fertility reserves. This was consistent with analysis of soil chemical fertility in paired cropped and uncropped sites across Queensland that showed a significant decrease in reserves of N, P and K in all cropping areas. Variable yields from cropping under rainfed conditions in these subtropical environments make additional investment in fertiliser inputs financially risky. It is suggested that an increased frequency of legumes (grain or pasture ley) in the farming system may reduce the requirement for N fertiliser, thus allowing growers to meet the demands for other fertiliser nutrient inputs. Such changes may be essential to ensure long term sustainability of the farming system.

Key Words

Fertility decline, nutrient budgeting, farming systems, legumes, nitrogen

Introduction

The northern grains region (Figure 1) occupies approximately 4M ha across northern NSW, southern and central Queensland. The cropping system is dominated by winter and summer cereals (wheat, sorghum and barley) with a relatively low frequency of grain legumes (predominantly chickpeas). The main cropping soils are Vertosols, Chromosols and Sodosols (Isbell 1996). Native soil fertility was high, especially on the Vertosols, but this has declined over time such that a significant proportion of the crop nitrogen (N) requirement is now supplied by fertilisers (Dalal and Probert 1997). There is also an increasing use of starter phosphorus (P) and zinc (Zn) fertiliser, while continued nutrient removal in grain is expected to increase incidence of deficiencies of other nutrients like potassium (K) and sulfur (S). Increasing reliance on costly inorganic fertilisers, combined with uncertainty in the accuracy of some of the diagnostic soil tests (especially for P and K) and erratic seasonal rainfall patterns, has increased financial risks for growers and placed significant pressures on cropping system sustainability. This paper reports the results of nutrient budgeting conducted over a period of 3 years across the major grains cropping regions, combined with soil analysis from paired cropped and uncropped sites to confirm the indicated trends in soil fertility reserves. Farming systems implications are also discussed.

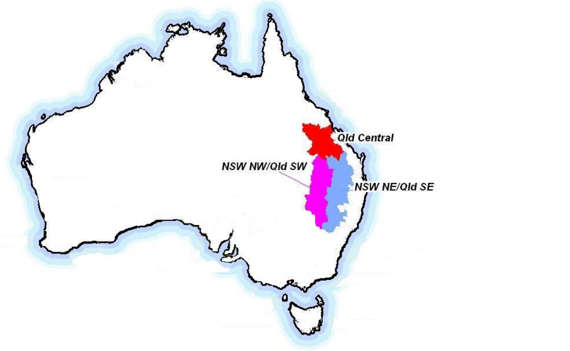

Figure 1. The northern grain cropping region of Australia, broken into the main zones of central Qld, and eastern and western areas in northern NSW. Map reproduced from GRDC (2009).

Methods

Nutrient budgeting

Grain yields were monitored from both experimental plots and commercial crops of sorghum, wheat, barley and chickpeas grown in the period from 2006-2008. Samples of grain were collected and analysed for concentrations of N, P, K, S and Zn, with total nutrient removal calculated as grain yield (expressed on a dry weight basis) multiplied by nutrient concentration. At the same time, fertiliser inputs were also recorded for each site, with additional information collected from commercial agronomists and advisors to ascertain broader nutrient application programs across typical crop cycles.

Apparent nutrient budgets were calculated from (the nutrient input from fertilizer – the nutrient removed in grain), with results presented as averages for each of the regions sampled. As there were no measurements of N_2-fixation undertaken on the chickpea crops there was no attempt to calculate the N budget for this crop. The relationship between grain yield and apparent nutrient balance for each nutrient was compared using averages of all sample points in each region. The value of additional fertiliser required to balance removal of the macronutrients N, P, K and S was calculated at fertilizer prices prevalent in mid 2008 (high) and late 2009 (moderate). Phosphorus was deemed to be supplied as monoammonium phosphate (MAP) with additional N supplied as urea, while S was supplied as sulphate of potash (SOP) and additional K supplied as muriate of potash (MOP). Where the rates of MAP or SOP needed to meet the additional removal of P or S supplied excess amounts of N or K, the value of that excess nutrient was treated as a credit.

Soil sampling and analyses

Soil samples from cropped and uncropped paired sites (0-10cm and 10-30cm depths) were sampled across the major grain growing areas of Queensland during 2008 and oven dried at 40C. The 0-10cm samples were analysed for total organic C and N in the bulk soil (Dumas combustion following acid pretreatment) and also C and N in the particulate organic matter (dispersed organic matter >53 um; Cambardella and Elliot 1992). Both soil layers were analysed for plant available P using 0.5M $NaHCO_3$ and 0.005M H_2SO_4:(Colwell P or Method 9B2 and acid P or Method 9G2, Rayment and Higginson 1992). Inorganic soil P was measured using 1M HCl (soil:solution 1:60, 17 h extraction period). Exchangeable K was determined using 1M NH_4Cl at pH 7 (Method 15A1, Rayment and Higginson 1992). The impact of cropping on C and N stores was assessed by comparing concentrations in the top 10cm, while reserves of P and K were assessed as the change in the concentration weighted across the two depth intervals, assuming a bulk density of 1.0 Mg/m^3 in the 0-10cm layer and 1.1 Mg/m^3 in the 10-30cm layer. Depletion ratios (cropped soil/native soil) were calculated for each parameter.

Results and discussion

Partial nutrient budgets collected from different crops grown across the various production regions indicated that with the exception of zinc (Zn – commonly applied with starter N and P fertilizer applications at planting), there were consistently negative nutrient budgets in most crops and regions. The data for both N and K (Figure 2) show contrasting relationships between average yields and net nutrient removal. In the case of N (Figure 2a), there was no clear relationship between district average yield and net N removal, although there were suggestions that net N removal in sorghum was starting to increase in the high yielding districts within the region. Interestingly, N removal data suggest that growers were consistently under-applying N fertilizer to wheat and barley (cf. sorghum) and that, with the exception of a very poor growing season where there were big N surpluses in one region for barley, 20-40 kg N/ha/crop were being withdrawn from the soil nutrient reserves. The reasons for this conservative approach to N application in winter cereals are unknown, but are consistent with the increasing perception of greater reliability of summer rainfall in recent years and a resulting shift towards summer sorghum over winter cereals (Darbis and Lawrence, 2009 unpub. data). The situation with K (Figure 2b), and to a lesser extent with P and S (data not shown), shows much stronger relationships between yield and net nutrient removal. In the case of K, where there was little if any fertiliser use in any regions, this was not unexpected and there were some interesting contrasts between crop species in what were de facto measures of grain K concentration. The average rates of K removal in chickpea (11.0 kg K/t) were at least twice that of the nearest grain crop, with average removal rates in barley (5.1 kg K/t) > wheat (4.1 kg K/t) > sorghum (3.1 kg K/t). The data for P removal were confounded by variable rates of P fertiliser use in different regions but data suggested that on average P application rates were quite conservative. Once yields exceeded 2.0t/ha (chickpeas and barley) – 2.3 t/ha (wheat and sorghum) there was net removal of soil P reserves, with the rate of removal greater in chickpeas (5.4 kg P/t) than barley and wheat (3.8 - 4.0 kg P/t) and sorghum (3.0 kg P/t).

Net removal rates of sulphur were more variable across crops and regions, and while there was net removal of 2 - 4 kg S/ha in most crops and regions, the only relationships with yield were observed in chickpea crops, where net removal of 1.6 kg S/t was recorded (R^2 = 0.85). These negative nutrient budgets clearly indicate depletion of native soil fertility reserves in the broadacre cropping system. Early evidence of the exploitative nature of northern grains cropping systems was reported by Dalal and Mayer (1986) and Dalal and Probert (1997), and although there have been significant increases in the use of fertilizers (N, and to a lesser extent P) since then, these current data suggest reserves continue to be depleted – especially for nutrients like K and S, for which consistent agronomic responses have yet to be recorded. The extent of declines in reserves of N, P and K were assessed by contrasting reserves in the 0-10cm layer [carbon (C) and N] and the 0-30cm layers (P and K) from paired cropped and uncropped sites on Vertosols from across the Queensland grain and cotton cropping areas (Figure 3).

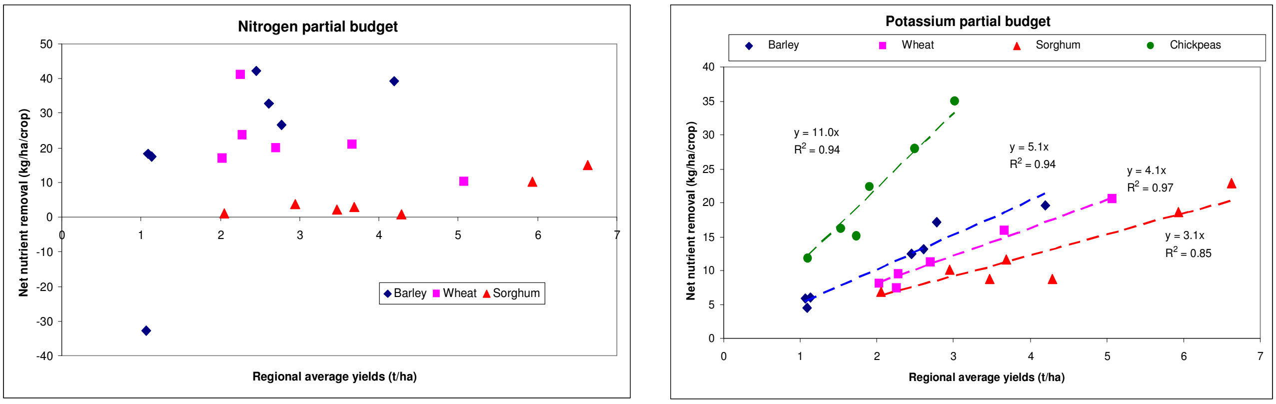

Figure 2. Relationship between district average yields and (a) N and (b) K net removal for wheat, barley, sorghum and chickpea crops grown from 2006-2008.

These results clearly confirm the impacts of fertility decline and nutrient removal, with some obvious exceptions for the P status in some soils in which initial P status was very low (ie. <15 mg/kg acid-extractable P). On average, cropped soils across all regions contained 60% (+5%) of the organic C, 48% (+6%) of total organic N, 36% (+5%) of the particulate organic N, 68% (+14%) of the inorganic P and 55% (+5%) of the exchangeable K reserves of the uncropped reference sites. This depletion is resulting in increasingly complex nutrient management decisions for growers.

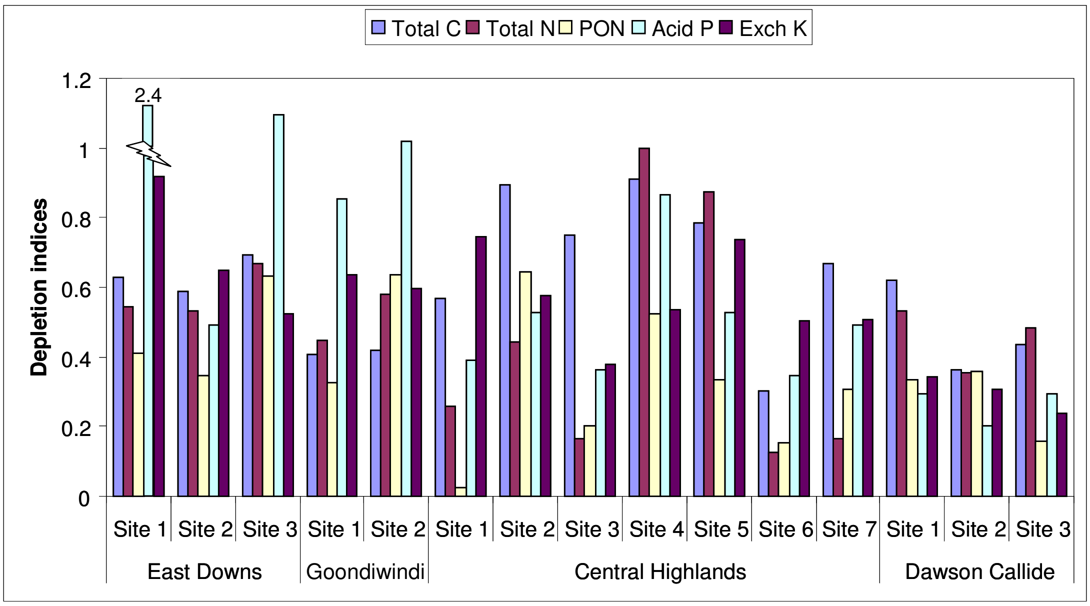

Figure 3. The ratio of organic C and N (total N and N in the particulate organic matter fraction), acid P and exchangeable K reserves in cropped Vertosols relative to that in adjacent uncropped reference sites.

The average fertilizer replacement costs to match the depletion of soil nutrient reserves (Figure 2) are shown for each crop and production region in Figure 4, using estimates based on the peak fertilizer prices in mid 2008 and also the current prices in late 2009. Results clearly show the significant additional costs that complete nutrient replacement would represent, especially when fertilizer prices are at levels like those experienced in 2008. Recent estimates of gross margins for summer sorghum (Anon 2008) and winter cereals and chickpea (Bach 2009) crops in Queensland show that this additional impost would significantly decrease the profitability of these cropping systems, especially under rainfed conditions.
The generally lower cost of nutrient replacement for chickpeas represents to some extent the N savings represented by growing a grain legume crop, albeit countered by higher removal rates of nutrients like P and K. The current cost of N fertilizers generally represents >65% of the fertilizer budget for both winter and

summer grain cropping, and >35-40% of the pre-harvest variable costs incurred by growers. As additional inputs of other nutrients like P, K and S are increasingly required to maintain productive cropping soils, a reduction in the expenditure on N fertilizer inputs is one way of maintaining profitability. However this will not be possible unless the current predominance of grain crops in the cropping system (80-90% in most seasons – Anon 2002) changes in favour of greater legume (grain and forage/pasture ley) frequency. Such changes will require significantly enhanced research investment in grain and forage legumes adapted to subtropical production systems, and development of farming systems to harness residual N inputs.

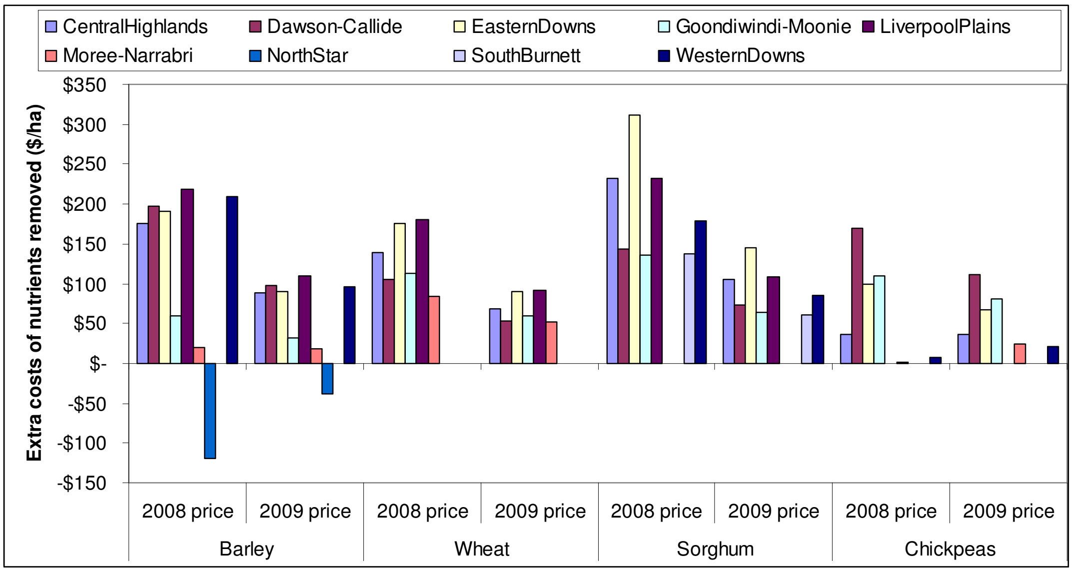

Figure 4. Average additional fertilizer costs needed in each production region to supply sufficient N, P, K and S to balance crop removal using fertilizer prices from late 2009 (moderate) and mid 2008 (recent peak). Data are shown for wheat, barley, chickpea and sorghum crops, with negative values indicating surplus nutrient addition.

Conclusion

Nutrient budgets in northern grains cropping systems remain negative, with rates of depletion for some nutrients like P and K closely linked to crop yields. The negative nutrient budgets are clearly reflected in soil reserves, with critically low levels of nutrients occurring in an increasing number of soils and regions. Additional fertilizer input costs represent a real threat to the economic viability of these cropping systems. A change to farming systems to include a higher legume frequency and resultant reduced fertilizer N requirement is a possible solution that requires investigation, but is one that will require close attention to P and K nutrition.

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