Potassium Removal and Use in Australia

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Abstract
Since 2002, K use in Australia has remained essentially static at around 180 kt/y with a range between 130 kt (2008/09) to 215 kt (2015/16). Over the past two decades, the use of P has declined by around 10% while N use has increased by 50%, so that Australian growers are using relatively more N and relatively less K. The industries that use the most K are the grains and cotton industries (37%) and the dairy industry (30%), with horticulture ((17%) and sugar (14%) comprising the other major segments. The grains industry produces around 40 Mt annually with the main crops being wheat, barley and canola.

Much of Australian agriculture is extensive and yields are relatively modest as most production is rainfed. Based on agricultural production figures and fertilizer use data, but excluding recycled materials and manures, Australia has a negative K balance of around nearly 400 kt per year, which is a removal to use ratio (Partial Nutrient Balance, PNB) of 3.2 across all agricultural areas. All states, except Tasmania, shown K removals more than K application, and there is significant variation from year to year in these values due to changing production in response to seasonal conditions. There are large differences among industries, with cotton showing positive balances (+9 kg K/ha/y) but most of the extensive cropping industries with negative balances (– 4 kg K/ha/y), and this pattern of removal> use has been consistent over the past 20 years. The sugar industry shows the largest apparent deficit, but the values estimated do not include recycled mill wastes.

To investigate the distribution of nutrient performance indicators among growers, a survey of 514 grain production fields over 3-5 years in south-eastern Australia was undertaken. Annual K balances were estimated from the input of fertilizer K and the removal of products. This region in particular is undergoing increased cropping intensity and the high rainfall zones in particular have high yield potentials and has promise for future expansion of the grains industry. K nutrient performance indicators were estimated for the period 2010-2014 from these survey data. Even though 15% of soil test K levels are less that the critical value, only 9% of crops received a mean K application rate of 75 kg K/ha while K removal ranged up to 250 kg K/ha/y. In only 6 fields survey there was a K-PNB<1. but 6 fields K balance was negative. Where K was applied, partial factor productivity values were in the range of 150-300 kg grain/kg K applied. Given these factors of increased production, low K application, high removals, and marginal soil K levels, growers will need to pay increasing attention to K management in particular.

Keywords: Partial nutrient balance, partial factor productivity, nutrient balance intensity, cropping systems.

INTRODUCTION TO AUSTRALIAN AGRICULTURE
Agriculture is a vital part of the Australian economy, with some 310,000 people employed directly in agriculture (2.6% of workforce) on 130,000 commercial farms over 417 Mha of agricultural land. Grazing land accounts for 87% of agricultural land use, although only 16% of land carries improved pastures. Around 50 Mha is used for cropping, and 2.5 Mha of crops and pastures are irrigated. Total factor productivity has been rising at 2.5% annually over the past 20 years and the gross value of agriculture at the farm gate in Australia has been steadily rising and in 2016 will exceed $60 billion (AUD) (ABARES 2016).

For 2016-17 the gross value of livestock and crop production is forecast to be $28.5 billion and $31.7 billion respectively. Winter crops (~40 Mt) are grown in all states, but summer crops (~5 Mt) are mainly produced in Queensland and northern New South Wales, which has a summer dominant or equi-seasonal rainfall pattern. The top three crops are wheat, barley and canola, and these are grown in the southern and western states, most often in rotation with each other and with pulse crops and pastures for sheep grazing. Over the past 20 years, the area of crops produced in the high rainfall zones (>600 mm average annual rainfall) has dramatically increased, while sheep numbers have declined. Poor livestock profitability and the development of better cultivars and agronomic support has driven this change.

Beef and sheep are grazed on annual or perennial pastures, with fertilizers and pasture improvement common in the higher rainfall zones. Half the beef cattle herd is in northern Australia, while Victoria is the principal dairy farming state. Sugar cane is produced on 3,500 cane farms along the sub-tropical and tropical regions of the north-east coastline, and is highly productive and relatively stable industry, but is very exposed to international sugar prices.

Australia stretches from the tropics of Cape York at 12^{o}S to the temperate maritime climate of southern Tasmania at 42^{o}S, so that there is a great diversity in horticultural crops. The main industries in northern Australia are avocados, macadamia nuts, mangoes, bananas and pineapples. In the south, citrus, pome and stone fruits and nuts are produced. Major ground crops are potatoes and tomatoes, along with a wide range of other crops from asparagus to zucchini.

POTASSIUM FERTILIZER USE IN AUSTRALIA

The first used of mineral fertilizers in Australia was in the early 1900's when "English Superphosphate" was introduced. In the 1950's phosphorus expanded from crop production and became widely used on pastures used for sheep and dairy production. Potassium use was minimal as yields were generally low and the major limitation was phosphorus. Over the past 40 years in particular, the development of improved varieties, better plant protection strategies and improved soil management has resulted in higher yield potentials particularly in the grains industry, but also in the sugar and dairy industries.

All the K used in Australia is imported, and the peak quantity of muriate of potash importation was ~480 kt in 2004/2007, while the peak of sulfate of potash imports of 60 kt in 2012. Long term K used has been around 170 kt of K, but during the "Millennium Drought", total K fertilizer use declined to a low of 134 kt K in 2009 (Figure 1), but has since recovered to 211 kt K in the 2016 report from Fertilizer Australia (N Drew, pers. comm.). This amount makes up less than 1% of global K used.

The regional use patterns shown in Figure 1 largely reflect the balance of enterprises within each region, as well as the inherent K fertility of the soils. Western Australia is the largest K user, and the soils there are generally inherently low in K and most of the K is applied to annual grain crops. In Queensland, the sugar industry is the major user of K, although there are declining K levels in central and southwestern cropping systems (Bell et al. 2012). In Victoria, K use is principally on intensively managed pastures for cattle and sheep, although cropping systems are showing signs of increasing demand for supplementary K particularly in the high rainfall zones (Christy et al. 2014). The use in the other states is mainly in horticulture and pastures. The cotton industry is based mainly in New South Wales and southern Queensland, varies greatly in response to seasonal water storage levels, can be a significant K user.

Over the previous 15 years while K use has fluctuated, there has been a 50% increase in the use of N fertilizers and a 10% decline in the use of P. The attention growers pay to N management is recognised but such an imbalance in nutrient supply suggests that growers and advisors should reconsider the importance of balanced nutrition.

NATIONAL AND REGIONAL REMOVAL AND USE OF POTASSIUM

The Australian National Land and Water Audit (NLWA) (2001) reported data on a series of a series of farm-gate nutrient balances for data collected during the 1990's. While the apparent balances for nitrogen, phosphorus, sulfur, and calcium are mainly neutral (inputs ≈exports) or moderately positive (inputs ≥ exports) across much of the southern agricultural zone. However, potassium and magnesium balances are usually negative (inputs < exports) indicating that soil reserves were being progressively depleted. For all cropping regions, K balances were negative. A summary of the findings from that time is shown in Table 1.

Later estimates were reported by Edis et al. (2012) using essentially the same protocols in the NLWA, and this also showed that across Australia there were few areas that were in K excess. Figure 2 shows these regional patterns for two periods (2009-10 and 2011-12). In essence, the areas where K was in the largest deficit were in the sugar growing areas in Queensland and the lower rainfall grain growing regions of Western Australia, South Australia and Central Queensland. These data have been loaded onto an interactive map at http://www.ozdsm.com.au/ozdsm_map.php. It should be noted that the data used to generate these maps did not include any recycled materials such as mill wastes from sugar processing or manures used as inputs into crop production. In aggregate, the national removal to use ratio for K was 2.9 for the audited period, and the nutrient balance intensity was -0.6 kg K/ha, with the denominator used as the areas of land used for agricultural production. These values are consistent with the earlier NLWA assessment that K use was around one third of the amount of K supplied.

Nutrient performance indicators for K (and other nutrients) can be estimated at national scales and the date in Table 2 reports K indicators for cereals using production area and mean cereal yield, mean potassium application rate to calculate K-PNB and K-PFB. The PNB is based on a weighted cereal grain K content of 0.54% (*as is basis*). The data for cereal production is derived for two periods (2006 and 2010) from FAO crop statistics database (FAOSTAT), and fertilizer use is derived from IFA surveys (Heffer, 2013) for the same two years.

Edis et al. (2012) used farm survey data that included fertilizer inputs estimated for each industry and also by region, and a national summary of these data is provided in Table 3. Both partial nutrient balance (removal to use) and nutrient balance intensity values are presented, along with the apparent application rates for each industry. The farmer reported use data is re-aggregated into total K use of about 102 kt K, compared to the industry supplied use of 160 kt K. This under-reporting by growers is a consequence of somewhat imprecise questions asked in these surveys, such as specifying the mass of K fertilizer used rather than particular K fertilizers used.

This inconsistency also flows through the industry use patterns, with the data in Table 3 suggesting that the grains industries used 27% of the K fertilizer, cotton 7%, sugar 7%, vegetable and fruits 11%, and the grazing industries 41%. This is somewhat at odds with the industry based figures which suggested that the amounts used were grains (22%), cotton (1%), sugar (20%), vegetable and fruits (24%) and grazing industries (34%) (Heffer 2013).

Despite the data inconsistencies, it is clear that there is much less K applied than is removed and the largest apparent deficits are in the sugar industry. However, these data do not consider K-rich recycled materials from sugar mills, which are reapplied to grower's fields. Similarly, the K balance figures for the dairy industry do not include K supplied to pastures that is ultimately derived from feeds purchased from outside the farm gate. Gourley et al. (2012) reported that K from cattle feed averaged 25 kg K/ha compared to a fertilizer input of 32 kg K/ha from data collected on 44 dairy farms across Australia.

Another significant deficiency in these data is that means estimated provide little or no intelligence to growers on their farm level balances. The data collected by Gourley et al. (2012) does give error terms around the inputs as well as the derived metrics concerning nutrient use efficiency. As such, these metrics can be used by farmers to assess their position relative to others in similar industries and regions.

K USE AND REMOVAL ON SOUTHERN AUSTRALIAN GRAIN FARMS

Information on nutrient removal and use at farm or field level is important to inform growers about build up or depletion of nutrients over time, and to assist them make decisions about appropriate interventions to address any imbalances. To understand the value and distribution of nutrient performance indicators at farm level, a survey of 118 grain growers used data from 474 fields covering 34,900 ha over 4 or 5 years between 2010 and 2014 in south-eastern Australia. The data came from farms in four different agro-ecological zones with different rainfall distributions and land use patterns. The zones were the High Rainfall Zone of Victoria and South Australia (HRZ), southern New South Wales (SNSW), the Victorian and South Australian Mallee, and the Victorian and South Australian Wimmera. A summary of the data collected is shown in Table 3. Nutrient balances (N, P, K and S) for each field over the audit period (3-5 years) was estimated from fertilizer use, stubble management (burned, removed, grazed) and crop yield. Grain and hay yields were recorded in the farm records, and regional wheat grain nutrient concentrations for wheat (Norton 2012) and canola (Norton 2014) were used to estimate removal in grains. Other values were derived from the values used in the NLWA (2001). The summary presented here is for the K balances alone.

The use of K on fields in this survey was largely restricted to the HRZ, where about 9% of the crops received K. Rates where K was used were about 90 kg K/ha on canola and 66 kg K/ha on cereals. Because K was only applied to 92 fields, K partial nutrient balance (PNB) and K partial factor productivity (PFP) can be calculated only for those survey fields, as the denominator - fertiliser applied - is zero. For those fields, the median PNB was 3.0 and seven of the fields surveyed showed more K use than removal over the audit period. Even where K was used, 12 fields had PNB>5 (Figure 3a). The PFP values where K was used had a median of 350 kg grain/kg K (Figure 3b).

The nutrient balance data collected is displayed in Figure 4, graphed as applied and removed K. On the 91% of fields that did not receive K, removals ranged from nil to over 250 kg K/ha. In all except seven fields the K balance was negative – that is more K was added than removed. This includes fields where K was applied at rates that were mostly sufficient to replace removals.

K REMOVAL AND USE ON NORTHERN GRAIN FARMS

Bell and Moody (2005) reported on the K balance for grain production farms in the northern cropping region of Australia, and they reported consistently negative K budgets, which led to a significant decline in native fertility. The extent of the deficit was linked to region crop productivity and the low use of K fertiliser. K removal was highest in chickpea crops because of the higher average grain K concentrations in chickpeas being consistently higher than higher yielding crops like sorghum. Typically, K removals were between 8 and 20 kg K/ha/y over a five crop sequence.

They expressed concern about this trend as earlier research showed soils in the region have variable reserves of exchangeable and slow release K reserves. Indeed, the consistently low grain K concentrations in some areas coupled with some very low K suggested that soil K status may be approaching dangerously low levels – whether due to stratification, presence of high Na or the lack of substantial slow release K reserves.

SOIL TEST K LEVELS

The low use of K in eastern Australia in particular could be explained if there were sufficient soil reserves to supply crops and pastures so that supplementary K was not required. There is little public data on K status of soils as most of the laboratory derived soil test data are held corporately and in some cases treated as commercial-in-confidence. Christy et al. (2014) re-analysed soil test data collected in the

NLWA to assess the proportion of areas where a response to K was likely based on the soil test critical values (Brennan and Bell 2013). Figure 5 shows this distribution of southern Australia showing that large areas of Western Australia have low soil K levels, so are likely to respond to applied K. In the south-eastern grain producing areas, soil K values are generally higher in the lower rainfall areas but in the higher rainfall zones nearer the coast, there are regions where responses are likely.

It should be noted that these soil test values were derived in the mid-1990's so may not necessarily reflect the current status. A more recent analysis of soil test data was compiled from a commercial soil test database from 2010, and this found that for the HRZ of Victoria and South Australia about half the sandy and loam soil types seem to have low K, whereas on the heavier soils deficiency was not such a problem (Christy et al. 2014).

Bell and Moody (2005) also reported low, and decline soil K test levels in many of the summer cropping regions in Queensland. Soil test K values showed stratification with around 1.6-3.2 more exchangeable-K in the topsoil than the subsoil. This depletion in the subsoil has led to research projects investigating deep placement of K (and P) as a means of alleviating this deficiency.

CONCLUSIONS

Potassium fertilizer use in Australia is relatively modest on a world scale, and there is approximately 3 times more K removed in agricultural products than is supplied. While K removal is highest on sugar farms, there is a modest deficit for most farms due to low productivity. Regional differences in K use and PNB reflect the intensity of production and the inherent K fertility of the regions, although there are inconsistencies in the data available to estimate K balances and nutrient performance indicators. Western Australia uses most K on grain production, Victoria uses K mainly on intensive pastures while in Queensland K is mainly focused on the dairy industry. The data presented here indicates that grain producing fields in the higher rainfall regions of southern Australia are in significant K deficits, despite the low inherent K fertility, and IPNI in association with state and federal agencies addressing and communicating 4R nutrient management strategies to growers to overcome these deficits and improve productivity (Norton 2014, 2016).

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Figure 1. Potassium (K) use in Australia by state from 2002-2003 until 2015-16. Data from Fertilizer Australia.

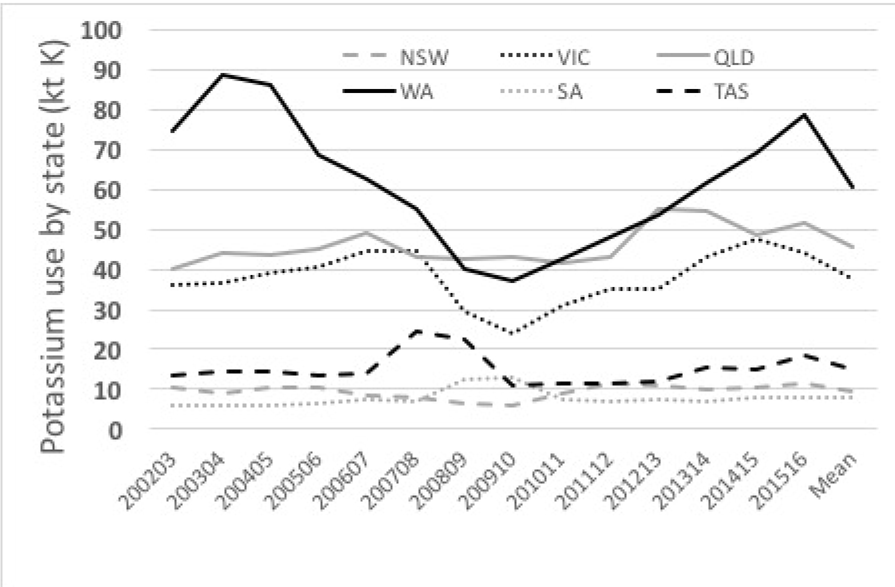
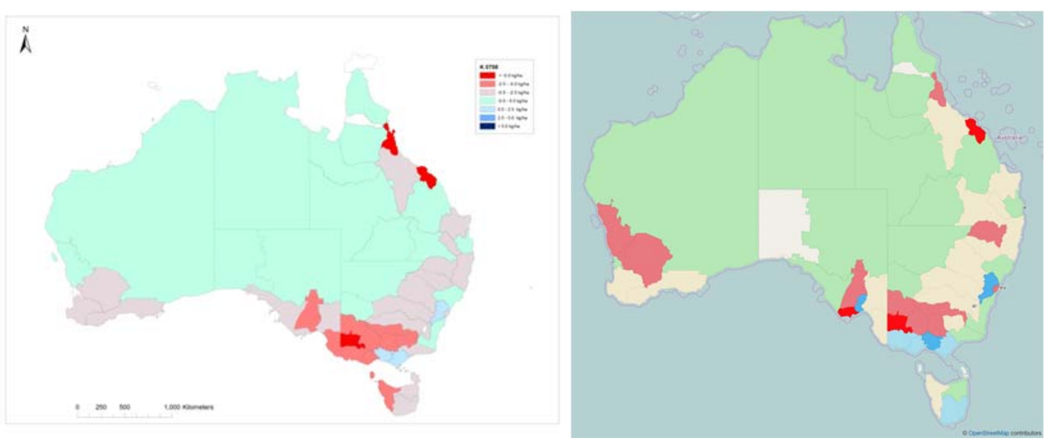
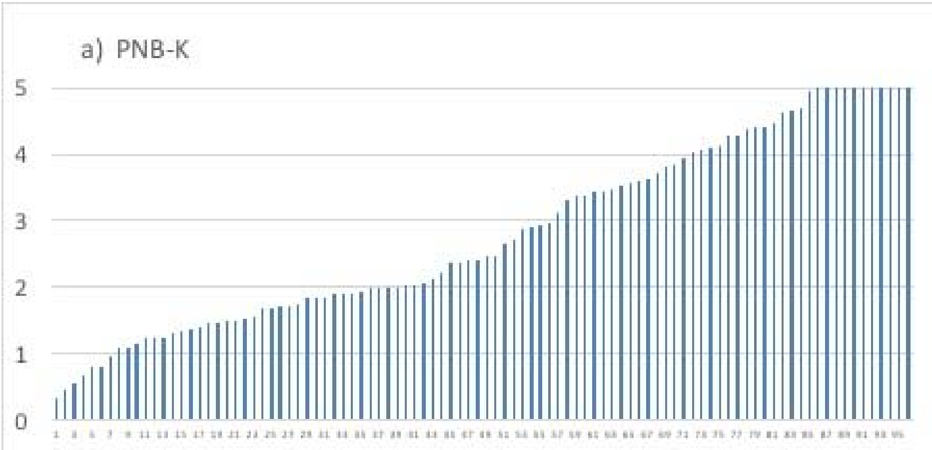


Figure 2. Nutrient balance intensity K (kg K/ha) across different natural resource management regions across Australia for a) 2007-08 and b) 2010-11. Values reported are the means for each two year period. In general, the red regions indicate where nutrient removal is more than nutrient supply, and the scales are provided on the individual graphics.



2007-08 b) 2010-11

Figure 3. Nutrient performance metrics for K as derived from a survey of farmers' fields. a) is the K partial nutrient balance, b) the K partial factor productivity.



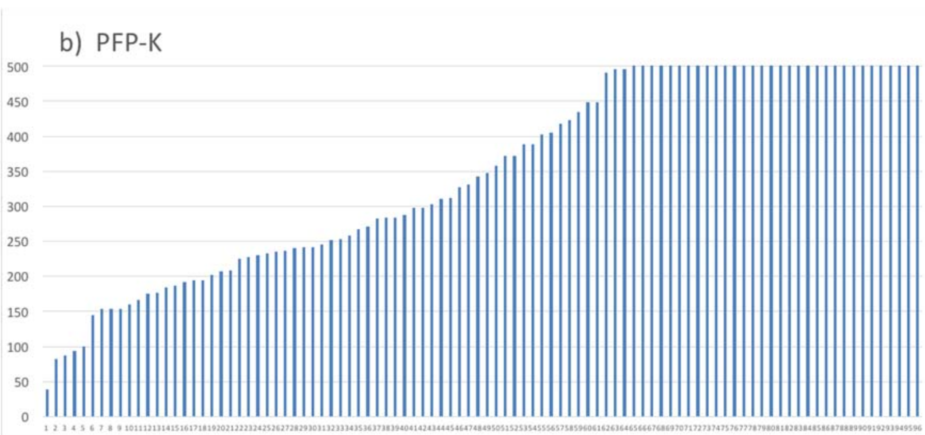


Figure 4. Potassium removal and application in surveyed fields in south-eastern Australia over the period 2010-2014. A 1:1 line is shown for reference.

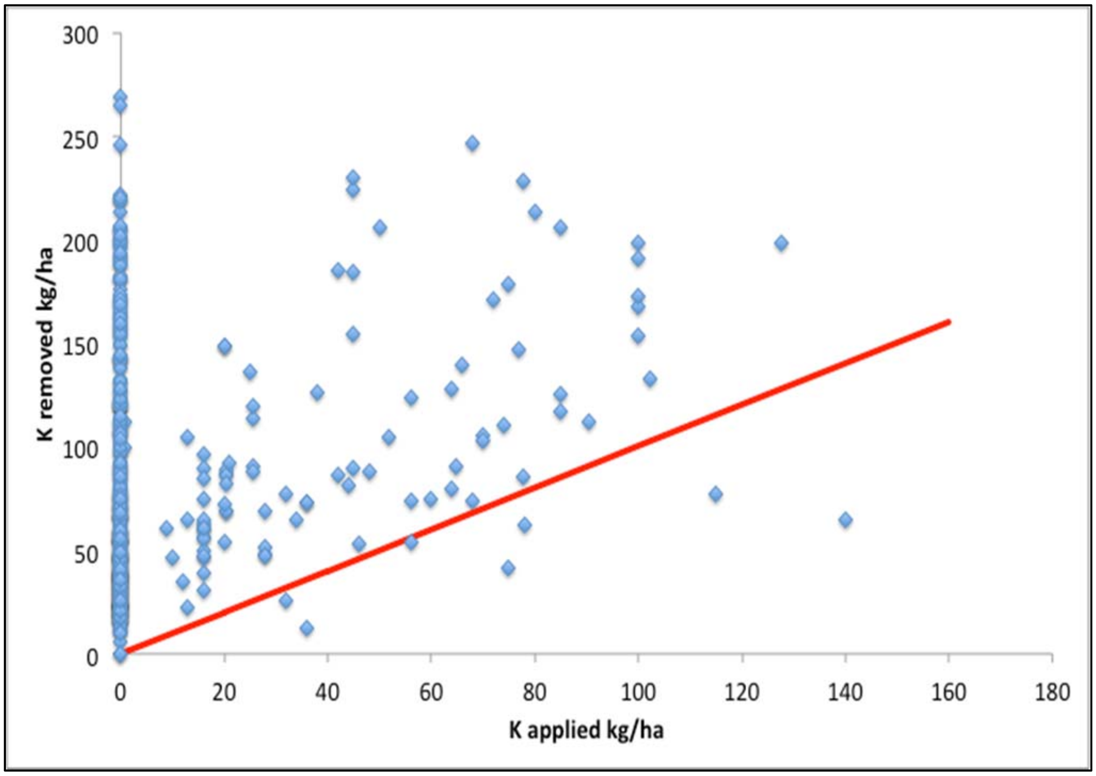


Figure 5. Percentage of soil tests indicating a response to potassium. Soil test data were derived from the NLWA (2001) and interpreted based in critical soil test values published in that report. Graphic is taken from Christy et al. (2014).

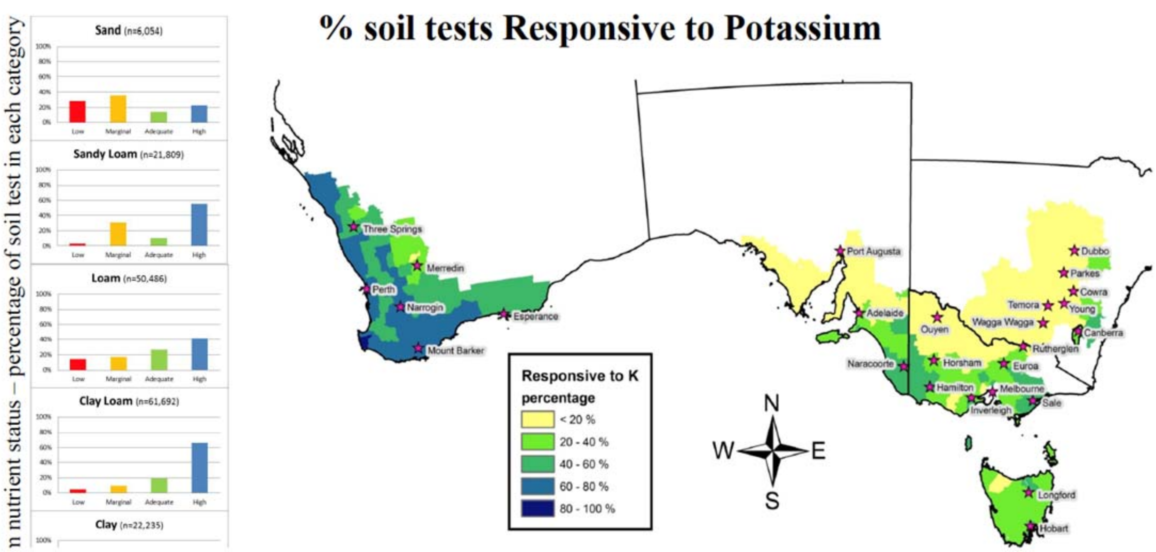


Table 1. Generalized state assessments of farm gate nutrient balance for two broad land uses within Australian agricultural zones from the Australian National Land and Water Resources Audit (2001) reporting data from 1994-1996.

Nutrient	Western Australia	South Australia	Victoria	Tasmania	New South Wales	Queensland*
Grazing						
Nitrogen	positive	positive	variable	neutral/positive	positive/neutral	negative
Phosphorus	positive/neutral	neutral/negative	neutral/positive	positive	positive/neutral	negative
Potassium	negative/positive	negative	positive/negative	neutral/positive	neutral/negative	negative
Sulfur	positive	positive/neutral	positive/neutral	positive	positive/neutral	negative
Calcium	positive	positive	positive	positive	positive	negative
Magnesium	neutral	negative	neutral/negative	neutral	neutral	negative
Cropping						
Nitrogen	positive/neutral	neutral/negative	negative	positive	neutral/positive	negative/neutral
Phosphorus	neutral/positive	neutral	negative/neutral	positive	neutral/negative	negative
Potassium	negative	negative	negative	neutral	negative	negative
Sulfur	positive/neutral	neutral/positive	neutral/positive	positive	neutral/positive	negative/neutral
Calcium	positive	neutral/positive	positive/neutral	positive	positive/neutral	negative/neutral
Magnesium	negative/neutral	negative	negative	neutral	negative/neutral	negative/neutral

* Atherton Tableland in Queensland had positive nitrogen, phosphorus, potassium and calcium balances.

Table 2. Cereal area and mean cereal yield, mean potassium application rate, and the performance indicators of Partial Nutrient Balance (kg nutrient removed/kg nutrient applied) and Partial Factor Productivity (kg yield/kg nutrient applied). The Partial Nutrient Balance is based on a weighted cereal grain K content of 0.54% (*as is basis*). The data for cereal production is derived for two periods (2006 and 2010) from FAO crop statistics database (FAOSTAT), and fertilizer use is derived from IFA surveys (Heffer, 2013) for the same two years.

	Cereal area (Mha)	**Mean cereal yield (t/ha)**	**Mean K rate (kg/ha)**	**K PFP (kg grain/kg fertilizer K)**	**K PNB (kg K_{grain}/kg fertilizer K)**
Argentina	9.24	4.37	0.4	**14619**	**78.94**
Australia	18.37	1.39	1.8	**724**	**3.91**
Brazil	18.42	3.63	36.2	**101**	**0.55**
Canada	15.95	3.26	6.8	**386**	**2.08**
China	83.14	5.48	20.3	**286**	**1.54**
Indonesia	15.13	4.62	10.4	**422**	**2.28**
Mexico	10.01	3.36	2.0	**1394**	**7.53**
Morocco	5.59	1.60	1.9	**706**	**3.81**
Russia	40.54	1.87	3.0	**565**	**3.05**
South Africa	2.99	3.65	8.0	**750**	**4.05**
Turkey	13.04	2.68	1.5	**1527**	**8.25**
USA	52.86	6.69	40.9	**178**	**0.96**
Vietnam	8.36	4.96	29.0	**182**	**0.98**
World	**679.08**	**3.43**	12.2	**278**	**1.50**

** Disaggregated data for EU-27 member countries for fertilizer use by crop is not publicly available.*

Table 3. The partial nutrient balance (PNB-K) and the nutrient balance intensity (NBI-K) for potassium taken from the ABS Agricultural Commodities, Australia (7121.0) releases averaged for 2008 and 2010. Mean rates are derived from the reported fertilizer use and the areas fertilized. The proportion of potassium of fertilizer used by each industry was derived from the survey data, which estimated a total use of 102 kt K for the audited periods.

Industry	**PNB-K kg K/kg K**	**NBI-K kg K/ha**	**Rate kg K/ha**	**% Use**
Grain & Livestock	3.1	-3.7	2	7
Other Grain Growing	5.5	-4.1	1	20
Rice Growing	6.9	-7.7	1	0
Cotton Growing	0.5	9.1	20	8
Sugar Cane Growing	7.6	-78.2	12	6
Vegetable Growing (outdoors)	1.2	-4.1	18	7
Tree Fruits & Vines	1.3	10.5	8	4
Sheep Farming Specialised	2.9	-3.6	2	4
Beef Cattle Farming (specialised)	0.9	-3.3	6	17
Sheep-Beef Cattle Farming	3.2	-3.6	2	2
Dairy Cattle Farming	1.5	-5.2	10	18

Table 4. Summary of survey data collected from south-eastern Australia, including approximate annual rainfall for each region, the number of field records surveyed and relative areas of cereals, oilseeds and legumes (pulse and pasture). Also shown are the number of fields where K was applied and the application rates on canola and cereals where applied.

Region	High Rainfall Zone	Southern New South Wales	Wimmera	Mallee
Annual Rainfall (mm)	>600	450-600	450-350	<350
Growers	45	33	17	23
Fields & Years	829	316	411	1030
Area	7,600	5,300	4,200	17,800
% Cereal	57	56	46	70
% Oilseed	34	34	14	11
% Legume	9	9	34	16
No of fields where K used	85	0	7	0
Rate on canola (kg/ha)	90	-	25	-
Rate on cereal (kg/ha)	66	-	81	-