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Offtake values for phosphate and potash in crop materials

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1. Abstract

At target soil indices, phosphate (P_2O_5) and potash (K_2O) fertiliser recommendations in the AHDB Nutrient Management Guide (RB209) are intended to replace crop offtake. The amount of fertiliser to apply can be adjusted using the target yield and RB209 offtake values for P_2O_5 and K_2O per tonne of yield. Thus to accurately estimate crop offtake it is imperative that P_2O_5 or K_2O offtake values for crop materials in the RB209 reference tables are representative of 'real world' data. Where the reference concentrations are lower than 'actual' data then the calculated offtake, and hence fertiliser requirement, will be lower than required to maintain soil nutrient reserves, risking a decline in soil index and, in responsive situations, a loss of yield. In contrast, where reference values are too large then the calculated offtake, and hence fertiliser requirement, will be more than required, which is both economically and environmentally undesirable.

The project reviewed recent data on P_2O_5 and K_2O offtakes for arable, grassland and forage crops (*c.*2,800 data points). Data were reviewed from field experiments carried out between 2009 and 2017 in England, Wales and Scotland where P and K offtakes had been quantified for arable, grassland and forage crops. Data was sourced from ADAS field experiments, the Yield Enhancement Network, NIAB and CF Fertilisers. Additional data from NRM laboratories, SEGES and commercial organisations were also reviewed to benchmark the experimental findings.

For grass, mean P_2O_5 (1.2 kg/t fw at 24% dry matter) and K_2O (5.2 kg/t fw at 24% dry matter) offtakes from the experimental database were lower than the current reference values in RB209 for grass silage at 25% dry matter (1.7 and 6.0 kg/t fw for P_2O_5 and K_2O, respectively). In contrast, the reviewed commercial datasets had P_2O_5 and K_2O concentrations that were higher than the values in RB209. Overall, due to the range and variability of P_2O_5 and K_2O concentrations in grass dry matter from the different data sources no changes to the offtake values in RB209 values were recommended.

For wheat and barley, P_2O_5 grain offtakes were lower than the reference values in RB209 (7.8 kg/t fw); the reviewed data suggested that there may be justification in reducing the value in RB209 to 6 kg/t fw. In contrast, there was little difference between the RB209 reference value for K_2O (5.6 kg/t fw) and the reviewed data (5.0 ± 0.1 kg/t fw) and it was not recommended that the K_2O value for cereal grain was updated. For both oilseed rape and forage maize no recommendations for changes to RB209 were made due to the limited size and variability of the available dataset.

2. Introduction

The principle of phosphate (P_2O_5) and potash (K_2O) management is to maintain the soil at the appropriate target index. For arable and grassland/forage crops this is soil P Index 2 and soil K Index 2- and is based on a rotational rather than an individual crop approach to phosphate and potash management. Phosphate and potash fertiliser recommendations given in the AHDB Nutrient Management Guide (RB209) (AHDB, 2017) are those required to meet crop requirements and replace crop offtake based on a standard yield (e.g. winter wheat: 8 t/ha, spring wheat: 6 t/ha). At target soil indices, phosphate and potash fertiliser recommendations in the AHDB Nutrient Management Guide (RB209) are intended to replace crop offtake. The amount of fertiliser to apply can be adjusted using the targeted/expected yield and RB209 offtake values for phosphate and potash per tonne of yield detailed in RB209 Table 3.2 (for grass and forage crops) and RB209 Table 4.11 (for arable crops), detailed below (Tables 1 and 2).

Table 1. Phosphate and potash in crop material (Table 3.2 from Section 3 of the AHDB Nutrient Management Guide (RB209)).

		Phosphate	Potash
		kg/t of fresh material	
Grass	Fresh grass (15-20% dry matter-dm)	1.4	4.8
	Silage (25% dm)	1.7	6.0
	Silage (30% dm)	2.1	7.2
	Hay (86% dm)	5.9	18.0
	Haylage (45% dm)	3.2	10.5
Whole crop cereals		1.8	5.4
Kale		1.2	5.0
Maize	Silage (30% dm)	1.4	4.4
Swedes	Roots only	0.7	2.4
Fodder beet	Roots only	0.7	4.0

Table 2. Phosphate and potash in crop material (Table 4.11 from Section 4 of the AHDB Nutrient Management Guide (RB209)).

		Phosphate	Potash
		kg/t of fresh material	
Cereals	Grain only (all cereals)	7.8	5.6
	Grain and straw		
	Wheat wheat/barley	8.4	10.4
	Spring wheat/barley	8.6	11.8
	Winter/spring oats	8.8	16.7
Oilseed rape	Seed only	14.0	11.0
	Seed and straw	15.1	17.5
Peas	Dried	8.8	10.0
	Vining	1.7	3.2
Field beans		110	12.0
Straw	Winter wheat, winter barley	1.2	9.5
	Spring wheat, spring barley	1.5	12.5
	Oilseed rape	2.2	13.0
	Beans	2.5	16.0
	Peas	3.9	16.0
Sugar beet	Roots only	0.8	1.7
	Roots and tops	1.9	7.5

To accurately estimate crop offtake it is imperative that phosphate or potash offtake values for crop materials in the RB209 reference tables (above) are representative of 'real world' data. Where the reference concentrations are lower than 'actual' data then the calculated offtake, and hence fertiliser requirement, will be lower than required to maintain soil nutrient reserves, risking a decline in soil index and, in responsive situations, a loss of yield. In contrast, where reference values are too large then the calculated offtake, and hence fertiliser requirement, will be more than required, which is both economically and environmentally undesirable. However, there are some concerns that RB209 standard offtake values may not accurately reflect typical nutrient contents in modern crops.

The British Survey of Fertiliser Practices (2017) reported that in 2016, overall fertiliser application rates were 9 and 12 kg/ha for phosphate and 29 and 39 kg/ha for potash, for grass and tillage crops, respectively. Phosphate and potash were applied to 38% and 39%

of grassland, respectively, at an average field application rate[1], of 23 kg/ha for phosphate and 31 kg/ha for potash, with field rates for both phosphate (28 kg/ha) and potash (46 kg/ha) being higher in grass cut for silage. In comparison, for winter cereals, phosphate and potash was applied to *c*.50% of the crop area at an average field application rate of 60 and 70 kg/ha for phosphate and potash, respectively. There has been little change in either the area of application (% of total area) or average field application rates between 2012 and 2016. However, over the past 30 years there has been a steady decline in overall phosphate and potash application rate on both tillage and grass. In particular, for grass, the reported applications rates are much lower than the RB209 recommended rates. Hence although it is important to be aware of any discrepancies between RB209 and actual phosphate and potash offtakes it is important to acknowledge that fertiliser applications do not generally reflect guidance provided in RB209.

3. Objectives:

The overall aim of the project was to review available data on phosphate (P_2O_5) and potash (K_2O) offtake values as listed in Section 3 (grass and forage crops) and Section 4 (arable crops) of the AHDB Nutrient Management Guide (RB209) (Tables 1 and 2 above).

[1] The estimates of the average field rates provide a better indication than overall application rates of actual usage levels and also of any annual variation in fertiliser practice on farms. Overall application rates takes into account both the average field rate and the proportion of the crop areas treated, giving an overview of the crop as a whole.

4. Methodology

Data were reviewed from field experiments carried out between 2009 and 2017 in England, Wales and Scotland where P and K offtakes had been quantified for arable, grassland and forage crops as well as from the Yield Enhancement Network-YEN (Table 3). In addition to the data from ADAS, field experiment datasets from NIAB (Critical P) and CF Fertilisers were also reviewed. In total, the database consisted of *c*.2,400 data points from ADAS (grass: *c*.570; winter wheat: *c*.700; winter/spring barley: *c*.400; winter oilseed rape: *c*.270 and forage maize: 45), NIAB (winter wheat/barley: *c*.400), CF Fertilisers (winter wheat: 20) (Table 3).

NRM datasets on P and K concentrations (% in dry matter) of grass (*c*.1,500 data points), arable (barley: *c*.1,650; wheat: *c*.6800; oilseed rape: *c*.3000) and forage crops (maize: *c*.580) were also reviewed. Before analysis the grass dataset was ‘cleaned’ to remove samples that could be identified as related to sports grounds (e.g. golf courses, tennis courts or football pitches), which removed *c*.300 samples from the dataset. For contextualisation, the collated grass data was also compared with published data from Thomson and Joseph (2015, 2016 and 2017) on grass silage P and K concentrations (P/K % dm); data from SEGES (Danish advisory service) for silage grass (P/K % dm by cut) and data compiled for a report to AIC (Ecopt, 2017) from a variety of sources. Unfortunately, it was not possible to include the NRM arable datasets within the review due to insufficient information regarding the growth stage at which the samples were taken, which will affect the nutrient content (green material has a higher phosphate and potash content than grain/seed).

Table 3. Datasets for review of phosphate and potash offtake

Project	*No of Sites*	*No. site seasons*	*No of data points*	*Phosphate*	*Potash*
Grass					
ADAS dataset					
DC Agri: Soil quality	2	6	117	✓	✓
DC Agri: N response	7	7	258	✓	✓
RB209 grassland	12	12	160	✓	✓
Cracking clays	1	4	36	✓	X
Other data					
NRM	~	~	1,222-1,251[a]	✓	✓
Winter wheat					
ADAS dataset					
DC Agri: Soil quality	4	7	126	✓	✓
DC Agri: N response	4	4	144	✓	✓
Cracking clays	2	5	71	✓	X
Targeted P	2	2	128	✓	X
Yield enhancement network			220	✓	X
Other data					
CF Fertilisers	1	1	20	✓	✓
NIAB (Critical P)	3	7	355	✓	X
Winter and spring barley					
ADAS dataset					
DC Agri: Soil quality	2	3	60	✓	✓
DC Agri: N response	2	2	78	✓	✓
Targeted P	3	3	188	✓	X
Other data					
NIAB (Critical P)	1	1	54	✓	X
Winter oilseed rape					
ADAS dataset					
DC Agri: Soil quality	2	2	39	✓	✓
DC Agri: N response	1	2	36	✓	✓
Targeted P	2	2	128	✓	X
Cracking clays	2	3		✓	X

[a]1,222 data points for % P in dm; 1,251 for % K in dm.

For each of the parameters (plant P and K content (% in dry matter-dm), yield (t/ha) offtake (kg/ha and kg/t fresh weight-fw) the mean, minimum, maximum, standard deviation (distribution of data around the mean), standard error of the mean (precision of the mean) and 95% confidence interval (the ‘true mean’ will lie between the lower and upper confidence interval 95% of the time) were calculated to characterise the dataset.

Each experimental dataset was assessed independently before the data were combined to calculate an average phosphate and potash offtake value for each crop type (categorised according to the crop types in the current RB209), which was compared to the current

RB209 values. Where yield data was available, predicted (using RB209 offtake values x yield) and actual offtakes (laboratory P concentration x yield) were compared to establish the difference between the two datasets. Offtake value calculations are detailed below.

Detailed associated data (or metadata) where available, such as soil texture, soil P and K index, fertiliser application rate, crop yield and crop nutrient concentration was used to assess factors that might influence phosphate and potash offtakes. Finally, data was contextualised in light of other datasets (published or unpublished) before recommendations for revisions to future RB209 guidance for phosphate and potash in crop materials for grassland, forage and arable crops were made where required.

4.1. Crop offtake (kg/ha)

Crop phosphate offtake (kg/ha) was calculated by multiplying the dry matter yield (t/ha) by the phosphorus content (mg/kg dm) and converting to phosphate:

- Grass: P_2O_5 offtake (kg/ha) = Yield (t/ha dm) x (P content, mg/kg dm/1,000) x 2.291
- Cereals: P_2O_5 offtake (kg/ha) = Yield (t/ha @ 85% dm) x 8.5 x (P content, mg/kg dm/10,000) x 2.291
- Oilseed rape: P_2O_5 offtake (kg/ha) = Yield (t/ha @ 91% dm) x 9.1 x (P content, mg/kg dm/10,000) x 2.291

For comparison, the predicted phosphate offtake was also calculated based on the values for crop (phosphate kg/t fresh weight) in RB209 (AHDB, 2017) in Table 3.2 or 4.11 as follows:

- Predicted P_2O_5 offtake (kg/ha) = yield (t/ha fw) x RB209 P_2O_5 content (kg/t fw)

Similarly, potash offtake (kg/ha) was calculated by multiplying the yield (tonnes (t) per hectare (ha) dry matter (dm) by the crop potassium content (mg/kg dm) and converting to potash:

- Grass: actual K_2O offtake (kg/ha) = Yield (t/ha dm) x (K content, mg/kg dm/1,000) x 1.205
- Cereals: actual K_2O offtake (kg/ha) = Yield (t/ha @ 85% dm) x 8.5 x (K content, mg/kg dm/10,000) x 1.205

- Oilseed rape: actual K_2O offtake (kg/ha) = Yield (t/ha @ 91% dm) x 9.1 x (K content, mg/kg dm/10,000) x 1.205

For comparison, the predicted potash offtake was also calculated based on the values for crop (potash kg/t fresh weight) in RB209 (AHDB, 2017) Table 3.2 or 4.11 as follows:

- Predicted K_2O offtake (kg/ha) = yield (t/ha fw) x RB209 crop K_2O content (kg/t fw)

Note: for grass the appropriate value from RB209 Table 3.2 was selected based on the dry matter of each sample.

4.2. Crop offtake (kg/t fw)

Offtake (kg/t fw) was calculated for each data point by dividing the actual offtake (calculated as described above by the yield (t/ha fw):

- P_2O_5 offtake (kg/t fw) = actual P_2O_5 offtake/yield (t/ha fw) or
- K_2O offtake (kg/t fw) = K_2O offtake/yield (t/ha fw)

5. Statistical analysis

Linear regression analysis was used to quantify the relationship between predicted and measured crop offtakes by fitting a linear equation to observed data. A linear regression line has an equation of the form $y = bx + c$, where x is the explanatory variable and y is the dependent variable. The slope of the line is b, and c is the intercept (the value of y when $x = 0$). The calculated value for the slope (b) estimates the rate at which y (the actual offtake) increases for a unit increase in x (the predicted offtake). The adjusted r^2 determines how close the data are to the fitted regression line; an r^2 of 100% would indicate that all of the variation in y could be explained by x.

To confirm that there was a true relationship between x and y the slope of the assumed linear relationship was compared to 1 to determine if it was different from the 1:1 line (i.e. the predicted and actual values were not the same). If the predicted and measured values were the same then the regression line would equal the 1 to 1 line. To quantify the precision of the estimate of the rate of increase, or slope the 95% confidence intervals (CI) for the slope were calculated. For example for a slope of 0.6 with a 95% CI of 0.05, the 'true' slope will fail to be included in the estimate (0.6 ± 0.05) only 5% of the time. The intercept was not constrained to zero (i.e. when RB209 predicted zero offtake the actual crop offtake was not assumed to be zero) and was allowed to vary.

To compare the fitted relationship between sub-sets of data (e.g. at different soil P levels) the regression analysis was repeated using linear regression with groups. This analysis compared whether each group had different intercepts and the same slope (i.e. parallel lines) or different intercept and slopes (i.e. each group had a different line).

A one-sample t-test was used to compare the measured offtake data (kg/t fw with the values in RB209 for crop offtake to test a null hypothesis that the population mean (the offtake data) was equal to a specified value (the RB209 value in Table 1 or 2). The calculated t value was compared to the critical t value from the t distribution table with degrees of freedom df = n - 1 and chosen confidence level. If the calculated t value was greater than critical t value, then the null hypothesis was rejected.

6. Results

6.1. Grass

The average grass yield across all experiments was 30 t/ha fresh weight (6.6 t/ha dry matter) with a dry matter content of 24 ± 0.8%.

The mean soil Olsen extractable P concentration at the grassland sites was 25 mg/l (high P Index 2) and the mean soil extractable K concentration was 132 mg/l (K Index 2-), which was similar to the average P and K soil indices reported by PAAG (2017), Table 4.

Table 4. The proportion of samples from sites at P or K Index 0-≥3 compared with PAAG data

Grass			Percentage of samples in Index:			
		Mean	***0 (0-9 mg/l)***	***1 (10-15 mg/l)***	***2 (16-25 mg/l)***	***≥3 (≥26 mg/l)***
P Index	ADAS	25 mg/l [Index 2]	7	22	34	37
	PAAG	25 mg/l [Index 2]	11	23	31	36
			0 (0-60 mg/l)	***1 (61-120 mg/l)***	***2-/2+ (121-240 mg/l)***	***≥3 (≥241 mg/l)***
K Index	ADAS	132 mg/l [Index 2-]	<1	40	48 (44/4)	11
	PAAG	163 mg/l [Index 2-]	8	35	40 (26/14)	16

The soil types at the grassland sites were representative of the three main cross compliance soil groups with 22% of sites on heavy soil, 56% on medium soil and 22% on sand and light silt soils.

6.1.1. Phosphate

Grass P (% P in dry matter)

The mean grass P concentration was 0.23 ± 0.01% dm with range of P concentrations from 0.11-0.53% dm (Table 5). At soil P Index 1, grass P concentration was lower (0.20 ± 0.01% dm) than at P Indices ≥2 (0.25-0.27% dm), Table 6. In comparison, for grass silage at 25% dry matter, the RB209 grass P concentration is higher (*c*.0.3% dm), based on 1.7 kg/t fw P_2O_5 and 25% dry matter).

Predicted v measured grass P_2O_5 offtakes (kg/ha)

Measured grass P_2O_5 offtakes (35 ±1 kg/ha) were lower than predicted by RB209 (48 ± 2 kg/ha); 95% of the actual values were below the 1:1 line (Figure 1a). The slope of the regression line comparing predicted and measured offtakes was significantly different from 1

(0.56 ± 0.03 kg/ha). For example, where RB209 predicted an offtake of 50 kg/ha then the measured offtake was *c*.35 kg/ha (0.56x + 7.38). There was no practical difference in the relationship between predicted and measured P_2O_5 offtakes when the data was grouped according to P index (Figure 1b) or cross compliance soil type (Figure 1c).

Phosphate offtake (kg/t fw)

Mean grass P_2O_5 offtake (1.21 ± 0.02 kg/t fw) was significantly lower (P<0.001) than the reference value in RB209 (1.7 kg/t fw) for grass with a similar dry matter (25%), Figure 2a. Grass P_2O_5 offtake was highest at P Index 0/1 (1.4 kg/t fw) and lowest at P Indices 2 and 3, Figure 2b.

6.1.2. Potash

Grass K (% K in dry matter)

The mean grass K concentration was 2.07 ± 0.07% dm with range of K concentrations from 0.84-4.41% dm (Table 5); soil K Index had no effect on grass K content. Table 6. The RB209 grass K concentration was similar (*c*.2% dm), based on 6 kg/t fw K_2O and 25% dry matter.

Predicted v measured grass K_2O offtakes (kg/ha)

Measured grass K_2O offtakes (161 ± 6 kg/ha) were lower than predicted by RB209 (174 ± 6 kg/ha); 70% of the actual values were below the 1:1 line (Figure 3a). The slope of the regression line comparing predicted and measured offtakes was significantly different from 1 (0.74 ± 0.06 kg/ha). For example, where RB209 predicted an offtake of 200 kg/ha then the measured offtake was *c*.180 kg/ha (0.74x + 32.2). There was no practical difference in the relationship between predicted and measured K_2O offtakes when the data was grouped according to K index (Figure 3b) or cross compliance soil type (Figure 3c).

Potash offtake (kg/t fw)

Mean grass K_2O offtake (5.18 ± 0.1 kg/t fw) was significantly lower (P<0.001) than the reference value in RB209 (6 kg/t fw) for grass with a similar dry matter (25%), Figure 4a. Grass K_2O offtake was lower on sites at K Index 1 than from the sites with K Index ≥2, Figure 4b.

Table 5. Grass: mean, minimum (min), maximum (max), lower and upper 95% confidence interval (CI), standard deviation (SD) and standard error of the mean (SEM) for phosphorus (P) and potassium (K) concentration in dry matter (P or K % dm), phosphate (P_2O_5) and potash (K_2O) offtakes (kg/ha, kg/t fw).

	Phosphorus				**Potassium**			
	% dm	*Predicted (kg/ha)*	*Actual (kg/ha)*	*kg/t fw*	*% dm*	*Predicted (kg/ha)*	*Actual (kg/ha)*	*kg/t fw*
Mean	0.23	48	35	1.21	2.07	174	161	5.2
Min	0.11	14	11	0.74	0.84	48	40	2.5
Max	0.53	96	68	2.18	4.41	328	321	9.2
Lower CI	0.23	46	33	1.19	1.99	168	154	5.1
Upper CI	0.24	50	36	1.24	2.14	180	167	5.3
95% CI	0.01	1.74	1.11	0.02	0.07	6.2	6.1	0.11
SD	0.06	19	12	0.25	0.77	63	62	1.08
SEM	0.003	0.89	0.56	0.01	0.04	3.15	3.09	0.05
Number	*442*	442	442	442	406	406	406	406

Table 6. Grass: mean, minimum (min), maximum (max), lower and upper 95% confidence interval (CI), standard deviation (SD) and standard error of the mean (SEM) for phosphorus (P) and potassium (K) concentration in dry matter (P or K % dm), phosphate (P_2O_5) and potash (K_2O) offtakes (kg/ha, kg/t fw) grouped by P or K index.

	Grass P (% dm)				**Phosphate offtake (kg/t fw)**				**Grass K (% dm)**			**Potash offtake (kg/t fw)**		
P or K Index	*0/1*	*2*	*3*	*≥4*	*0/1*	*2*	*3*	*≥4*	*0/1*	*2*	*≥3*	*0/1*	*2*	*≥3*
Mean	0.20	0.25	0.25	0.27	1.4	1.1	1.1	1.3	1.99	2.17	1.93	4.7	5.5	5.5
Min	0.11	0.16	0.14	0.19	0.9	0.7	0.7	1.0	0.84	1.10	1.24	2.5	3.3	3.9
Max	0.40	0.42	0.53	0.46	2.2	1.7	2.2	1.8	4.41	4.11	3.91	7.0	8.3	9.2
Lower CI	0.19	0.24	0.24	0.24	1.3	1.1	1.1	1.2	1.87	2.06	1.69	4.6	5.4	5.1
Upper CI	0.21	0.25	0.26	0.31	1.4	1.2	1.2	1.4	2.10	2.27	2.17	4.8	5.7	5.9
95% CI	0.01	0.01	0.01	0.04	0.05	0.03	0.04	0.1	0.12	0.11	0.24	0.1	0.1	0.4
SD	0.05	0.05	0.07	0.07	0.3	0.2	0.2	0.2	0.76	0.76	0.80	0.9	1.0	1.3
SEM	0.005	0.004	0.01	0.02	0.02	0.02	0.01	0.02	0.06	0.05	0.12	0.1	0.1	0.2
Number	128	149	146	19	128	149	146	19	168	193	45	168	193	45

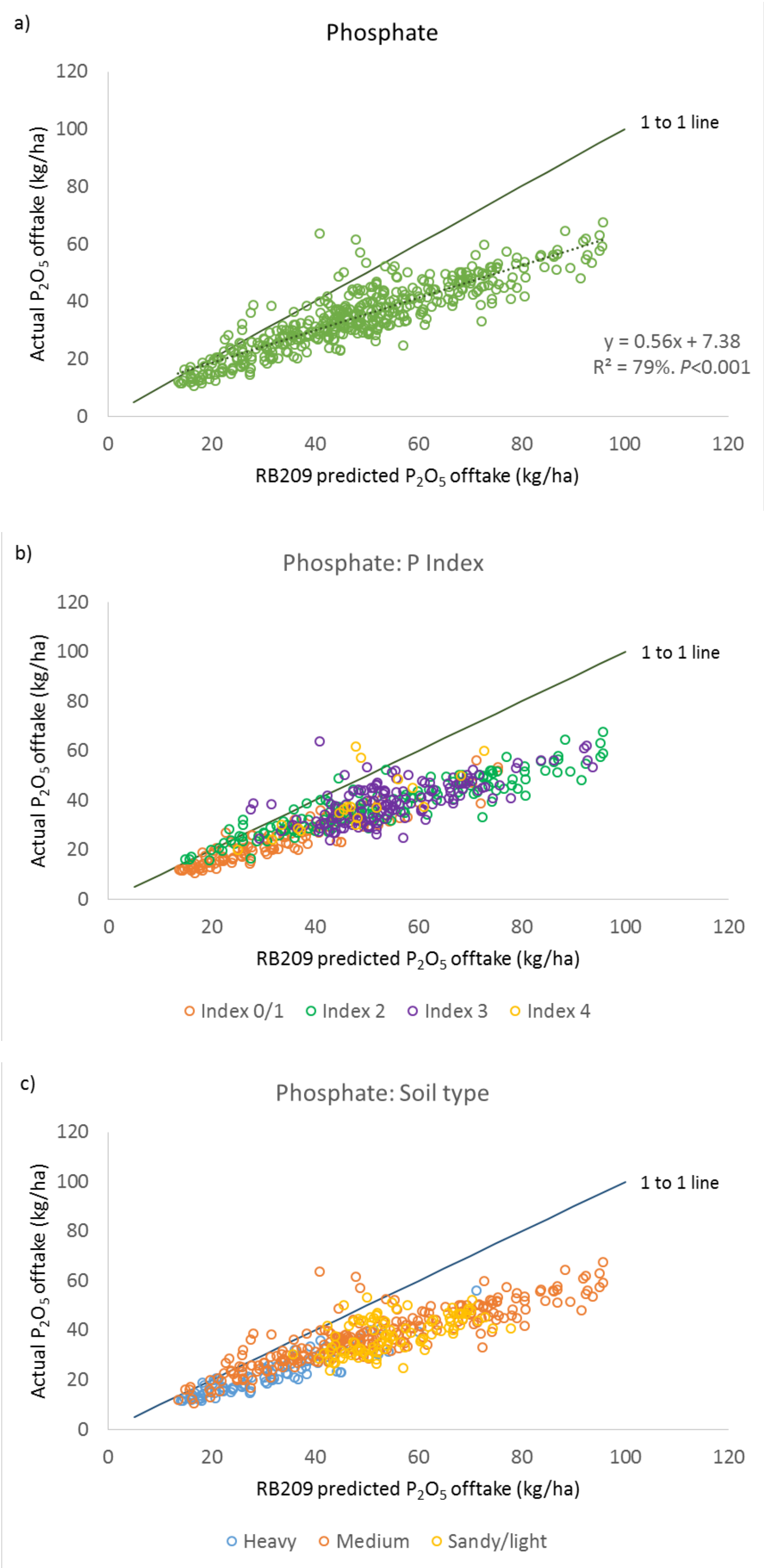


Figure 1. Grass: a) the relationship between predicted and actual offtakes (kg/ha) for phosphate (P_2O_5), b) grouped by soil P Index and c) grouped by cross compliance soil group.

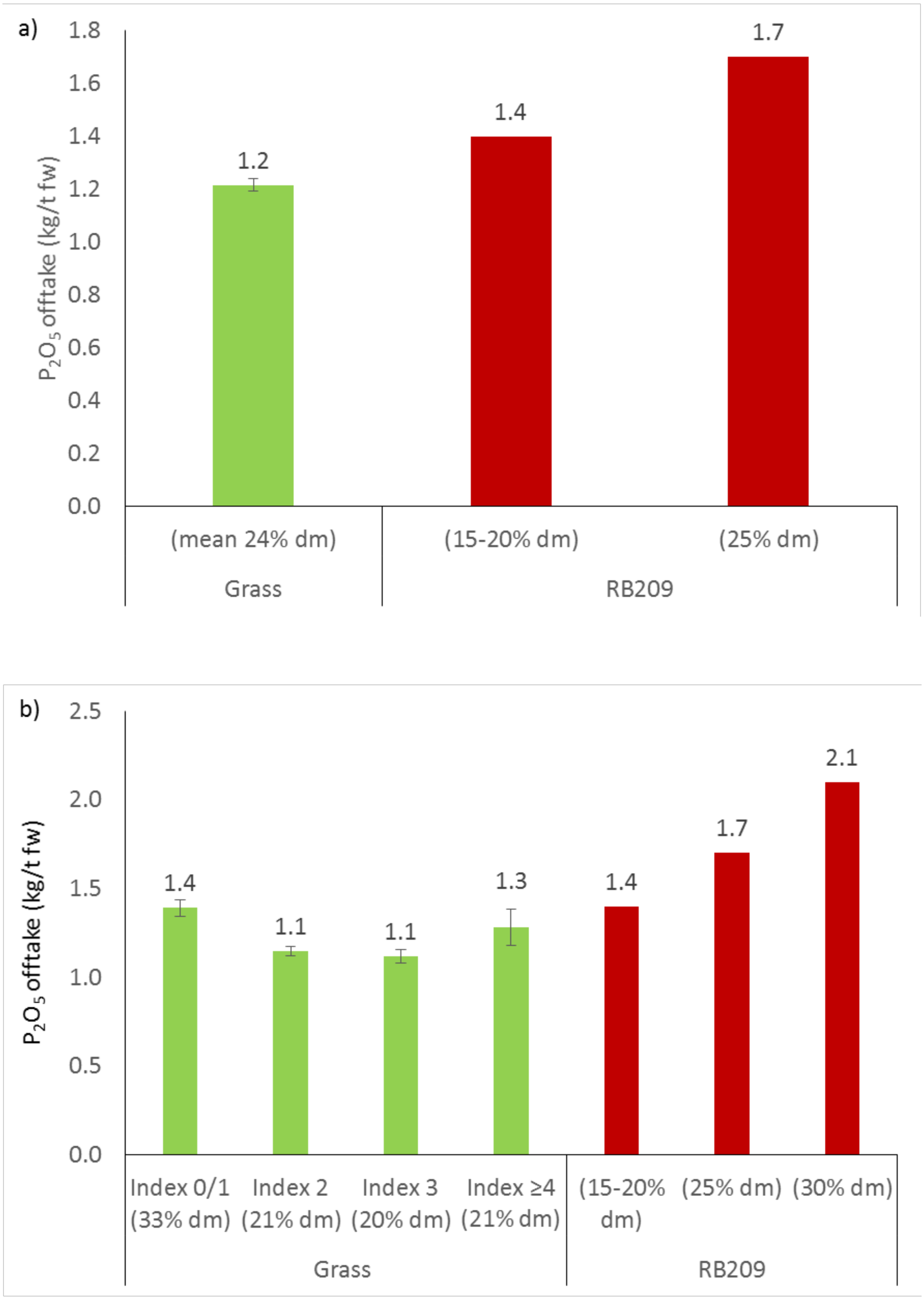
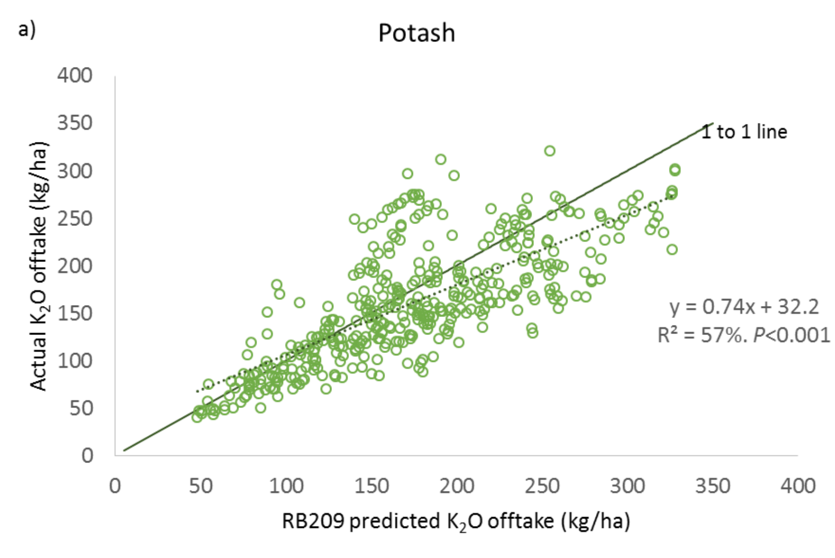
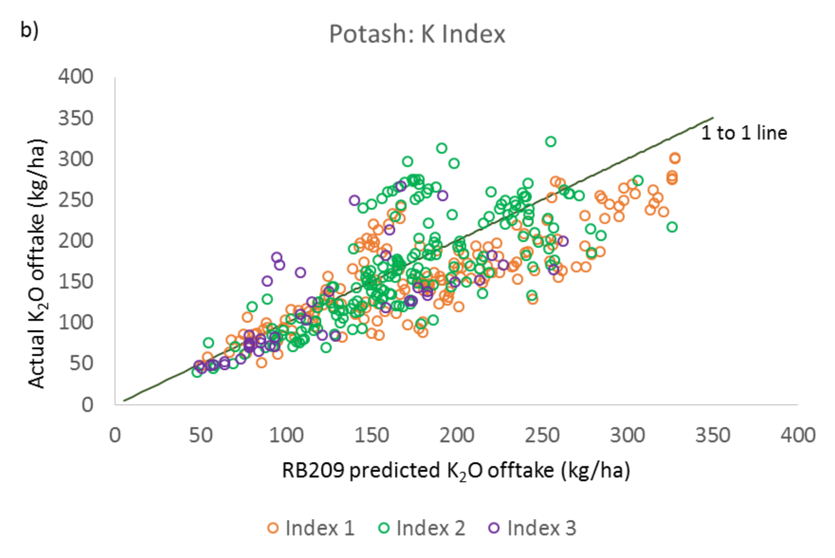


Figure 2. Grass: a) phosphate (P_2O_5) offtakes (kg/t fw) and b) phosphate offtakes (kg/t fw) by soil P Index with RB209 references values. I indicates 95% confidence intervals of the mean [2].

[2] RB209 data in Figure 2 (and subsequent Figures) are single values taken from RB209 (AHDB, 2017) and hence do not have confidence intervals.





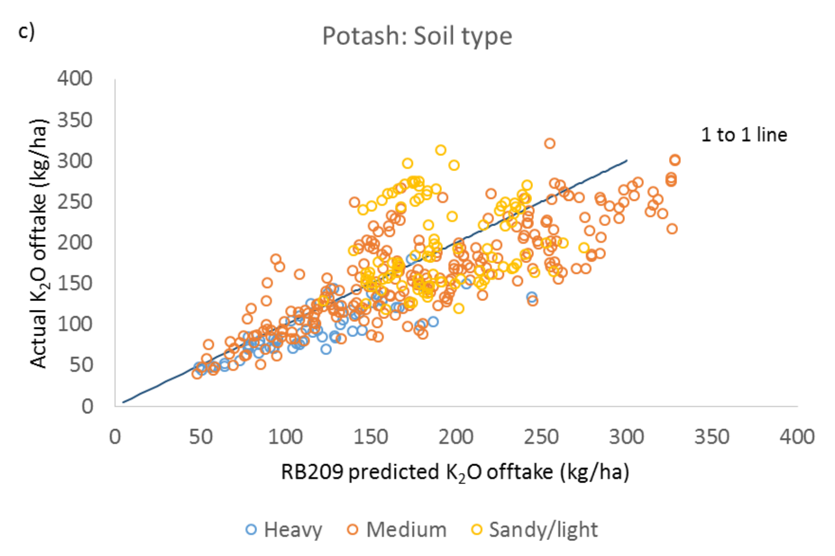
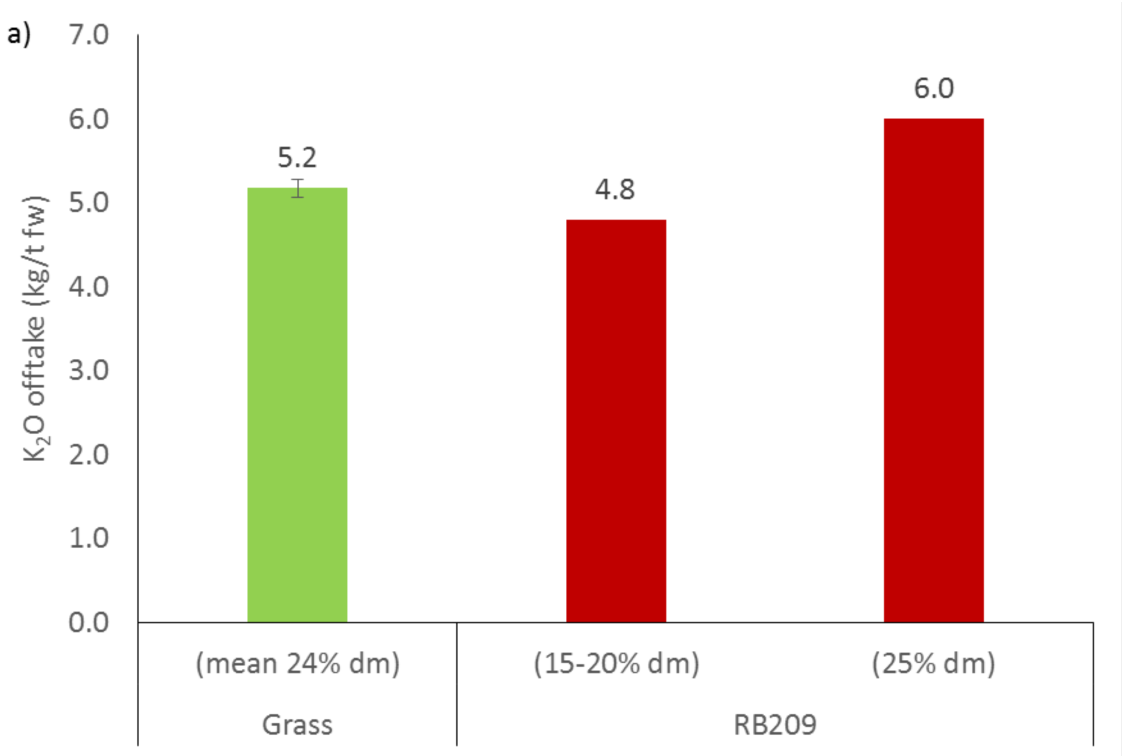


Figure 3. Grass: a) the relationship between predicted and actual offtakes (kg/ha) for potash (K_2O), b) grouped by soil K Index and c) grouped by cross compliance soil type.



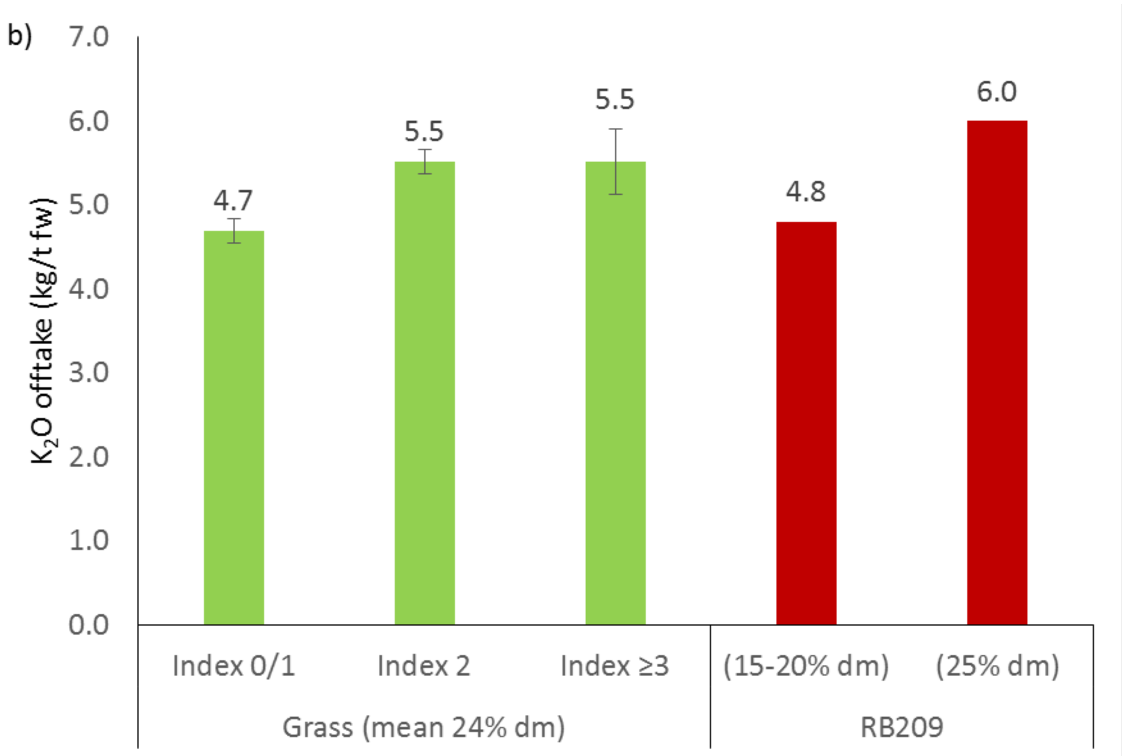


Figure 4. Grass: a) potash (K_2O) offtakes (kg/t fw) and b) potash offtakes (kg/t fw) by soil K Index with RB209 references values. I indicates 95% confidence intervals of the mean.

6.1.3. Example grass phosphate and potash offtake calculations

Phosphate and potash offtakes calculated using RB209 values for grass silage at 25% dry matter were compared with offtakes calculated using the values from the ADAS dataset (Table 3). The comparison showed that for a typical grass crop yielding 54 t/ha fw RB209 was over predicting phosphate offtake by 26 kg/ha and potash offtake by 44 kg/ha (Table 7).

Table 7. Comparison of silage grass phosphate and potash offtakes calculated using RB209 reference values (25% dry matter) and using the ADAS dataset.

	RB209 offtakes	This data	Difference
Phosphate offtake	*1.7 kg/t fw*	*1.2 kg/t fw*	
Cut 1 (23 t/ha fw)	40	28	-12
Cut 2 (15 t/ha fw)	25	18	-7
Cut 3 (9 t/ha fw)	15	10	-5
Cut 4 (7 t/ha fw)	10	8	-2
			-26
Potash offtake	*6 kg/t fw*	*5.2 kg/t fw*	
Cut 1 (23 t/ha fw)	140	120	-20
Cut 2 (15 t/ha fw)	90	78	-12
Cut 3 (9 t/ha fw)	55	47	-8
Cut 4 (7 t/ha fw)	40	36	-4
			-44

6.1.4. NRM grass data

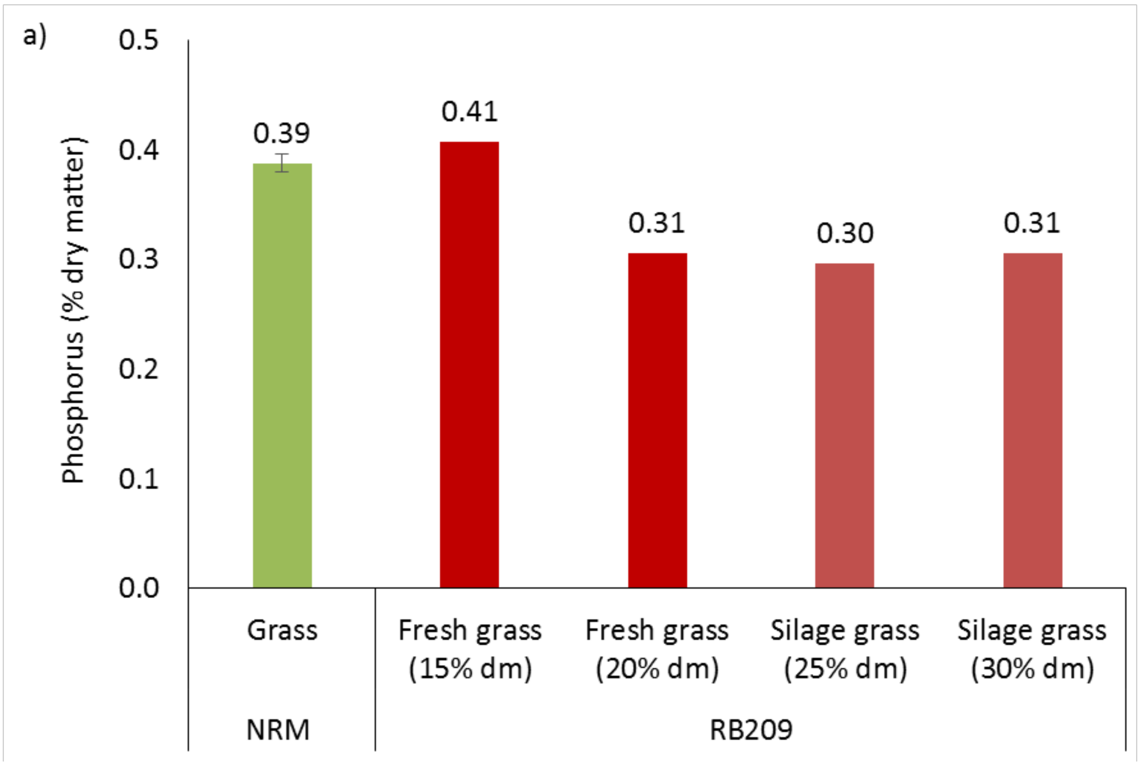
Data on grass phosphorus and potassium content from the NRM dataset is detailed in Table 8 below. The majority of this dataset did not include information on grass dry matter content so it was not possible to identify whether samples were from fresh grass or grass silage.

The mean P concentration was 0.39 ± 0.01% dm (range 0.10-0.97% dm; Table 8). In comparison, RB209 grass dry matter P concentrations range between 0.31-0.41% dm at 15 or 20% dm and 0.30-0.31 at 25 or 30% dm, Figure 5.

The mean K concentration was 2.80 ± 0.05% dm (0.28-6.21% dm; Table 8). In comparison, RB209 grass dry matter K concentration range from 1.99-2.66% dm for grass at 15 or 20% dm and is 1.99% for grass at 25 or 30% dm, Figure 5.

Table 8. Grass: NRM mean, minimum (min), maximum (max), lower and upper 95% confidence interval (CI), standard deviation (SD) and standard error of the mean (SEM) for phosphorus and potassium concentration (% dm, mg/kg dm)

	Phosphorus		**Potassium**	
	% dm	*mg/kg dm*	*% dm*	*mg/kg dm*
Mean	0.39	3,866	2.80	27,983
Min	0.10	1,025	0.28	2,759
Max	0.97	9,738	6.21	62,073
Lower CI	0.38	3,808	2.75	27,482
Upper CI	0.40	3,964	2.85	28,483
95% CI	0.01	78	0.05	501
SD	0.14	1,403	0.91	9,128
SEM	0.004	40	0.03	255
Number	*1,250*	*1,250*	*1,279*	*1,279*



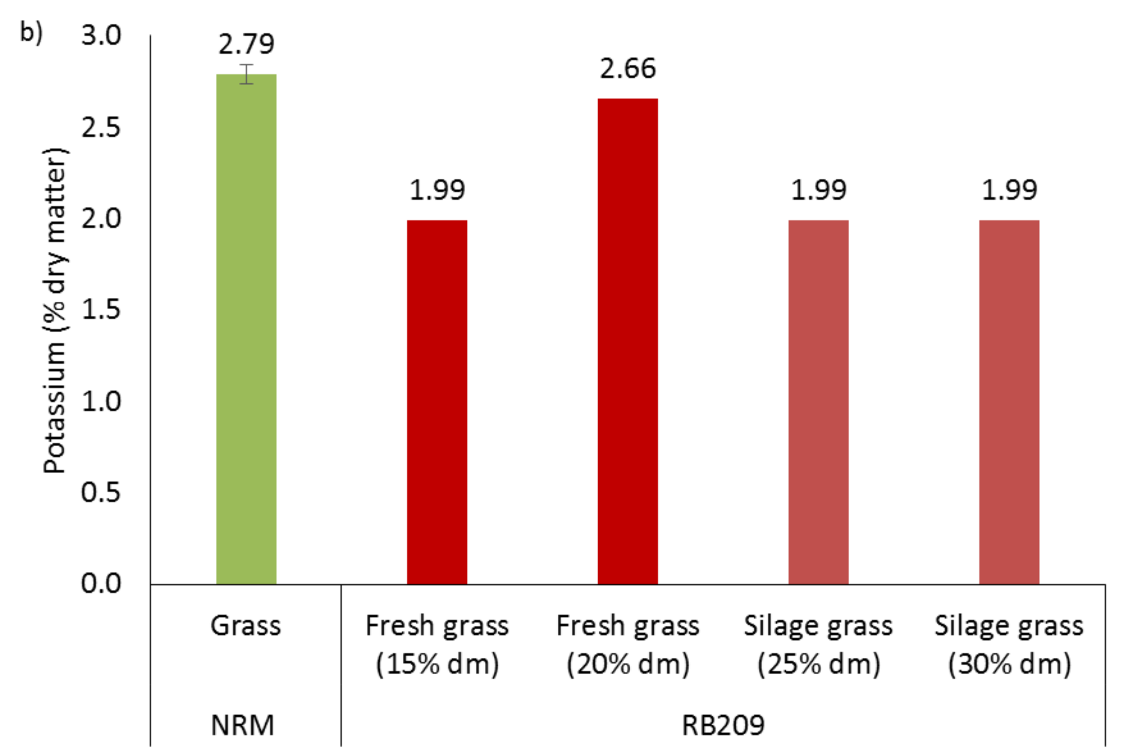


Figure 5. Grass: NRM dataset a) phosphorus (P) and b) potassium (K) concentration (% in dry matter) with RB209 reference values. I indicates 95% confidence intervals of the mean.

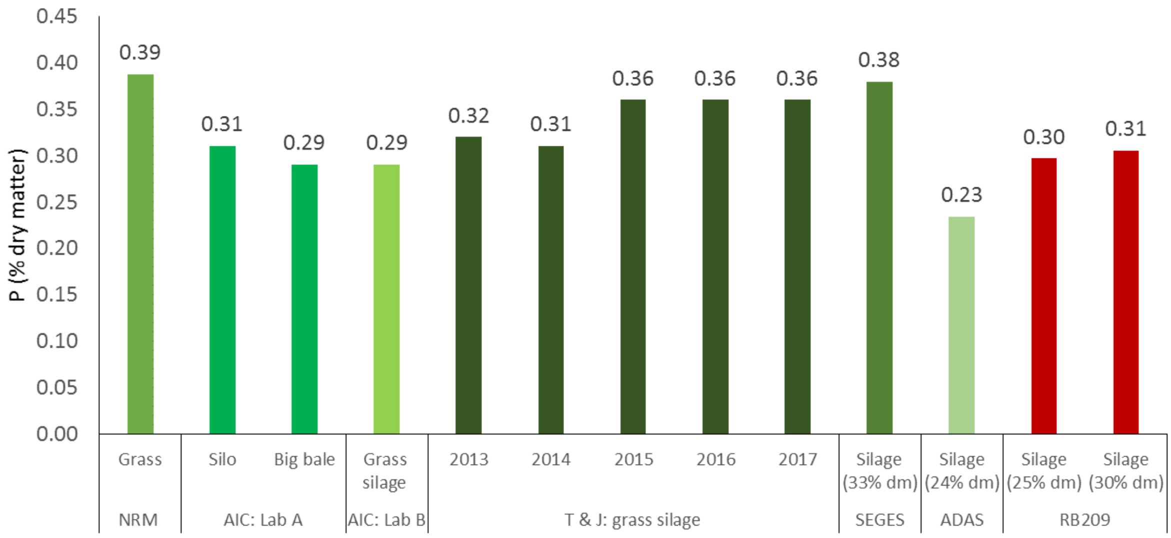
6.1.5. Other grass datasets

Data compiled for the AIC from two PAAG laboratories and Trouw Nutrition reported mean P concentrations of between 0.29 and 0.32% dm. In comparison, Thompson & Johnson (2013-2015) reported mean P concentrations ranging from 0.32 to 0.36 and SEGES (2017) from 0.35-0.42% dm. The reported values are similar to the RB209 P concentration of 0.30-0.31% dm for grass at 25-30% dm, Figure 6.The mean P concentration of fresh grass was 0.37% dm (AIC Lab A mean 2011-2016, Table 9); for comparison, the RB209 value ranges from 0.31-0.41% P in dm, depending on the grass dry matter content (15-20%) that is used to convert from the RB209 kg/t fresh weight value.

In addition, data compiled for the AIC from two PAAG laboratories and Trouw Nutrition reported mean K concentrations in grass dry matter of between 2.30 and 2.64% dm. In comparison, Thompson & Johnson (2013-2015) reported mean K concentrations ranging from 2.60 to 2.89 % dm and SEGES (2017) from 2.66-3.08% dm, Figure 6. The reported values are higher than the RB209 K concentration of 1.99% dm for grass at 25-30% dm. The mean K concentration of fresh grass was 2.85% dm (AIC Lab A mean 2011-2016, Table 9); for comparison, the RB209 values range between 1.99-2.66% K in dm, depending on the grass dry matter (15-20%) that is used to convert from the RB209 kg/t fresh weight value.

Table 9. Phosphorus and potassium concentration (% in dry matter)

Data source		**Phosphorus**	**Potassium**
Silage grass		*% dm*	*% dm*
AIC: Lab A (2011-2016)	Silo	0.31	2.54
	Big bale	0.29	2.30
AIC: Lab b (2014-2015)	Silage	0.29	2.64
AIC: Trouw Nutrition	2015	0.31	2.42
	2016	0.32	2.43
Thompson & Joseph silage grass	2013	0.32	2.89
	2014	0.31	2.89
	2015	0.36	2.60
	2016	0.36	2.68
	2017	0.36	2.80
SEGES silage grass (2017)	1st cut	0.35	2.66
	2nd cut	0.36	2.80
	3rd cut	0.36	2.79
	4th cut	0.42	3.08
	5th cut	0.41	3.08
Fresh grass			
AIC: Lab A		0.37	2.85



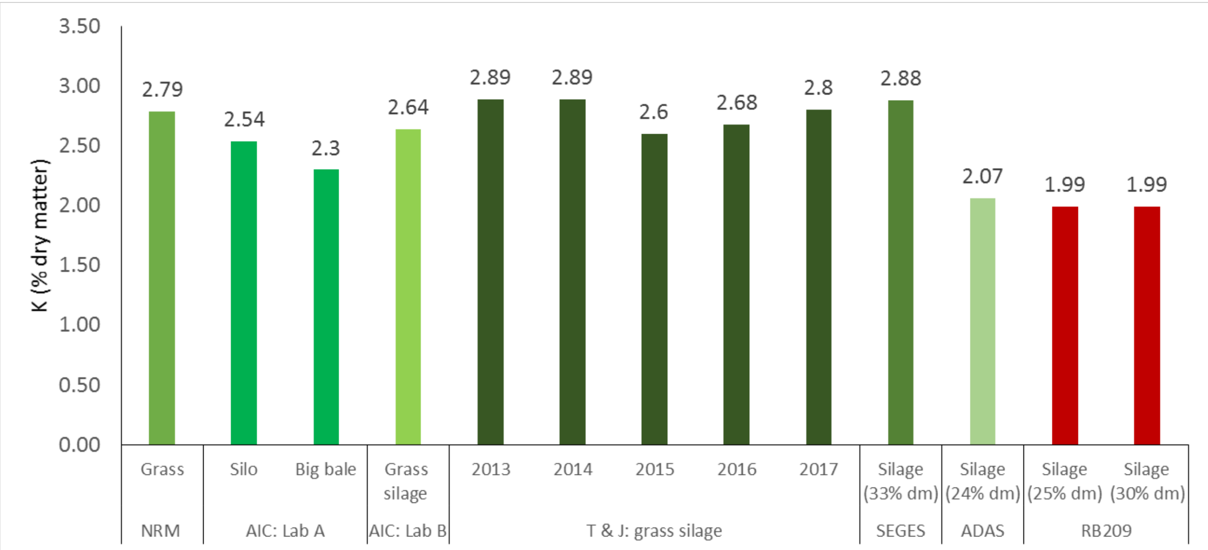


Figure 6. Comparison of a) phosphorus (P) and b) potassium (K) concentration (% in dry matter) from a range of sources with ADAS data and RB209 reference values.

6.2. Winter wheat

The mean winter wheat yield across the whole data set was 8.5 ± 0.2 t/ha @ 85% dry matter.

The mean soil P concentration of the winter wheat sites was 17 mg/l (P Index 2) and the mean soil K concentration was 209 mg/l (K Index 2+), and similar to the average soil P and K indices reported by the PAAG (2017), Table 10.

Table 10. The proportion of winter wheat samples from sites at P or K Index 0-≥3 compared with PAAG data

Winter wheat			**Percentage of samples in Index:**			
		Mean	***0 (0-9 mg/l)***	***1 (10-15 mg/l)***	***2 (16-25 mg/l)***	***≥3 (≥26 mg/l)***
P Index	ADAS	17 mg/l [Index 2]	24	25	34	16
	PAAG	31 mg/l [Index 3]	5	17	29	49
			0 (0-60 mg/l)	***1 (61-120 mg/l)***	***2-/2+ (121-240 mg/l)***	***≥3 (≥241 mg/l)***
K Index	ADAS	209 mg/l [Index 2+]	1	30	27 (11/15)	42
	PAAG	186 mg/l [Index 2-]	3	26	50 (31/19)	21

The winter wheat sites were representative of the three main cross compliance soil groups with 44% of sites on heavy soil, 38% on medium soil and 18% on sand and light silt soils.

6.2.1. Phosphate

Winter wheat P concentration (% P in dry matter)

The mean winter wheat P concentration was 0.30 ± 0.004% dm with a range of P concentrations from 0.11-0.52% dm (Table 11). At soil P Index 1, wheat P concentration was lower (0.23 ± 0.005% dm) than at P Indices ≥1 (0.27-0.32% dm) Table 12. In comparison, for winter wheat, the RB209 P concentration was higher (*c.*0.4% dm, based on 7.8 kg/t fw P_2O_5 and 85% dry matter).

Predicted v measured wheat grain P_2O_5 offtakes (kg/ha)

Measured wheat P_2O_5 offtakes (49 ± 1.2 kg/ha) were lower than predicted by RB209 (67 ± 1.3 kg/ha); with *c.*90% of the measured values below the 1:1 line (Figure 7a). The slope of the regression line comparing predicted and measured offtakes was significantly different from 1 (0.80 ± 0.04 kg/ha). For example, where RB209 predicted an offtake of 50 kg/ha P_2O_5 the measured offtake was 35 kg/ha P_2O_5 (0.82x – 4.89).

When the data was grouped according to P index the relationship between predicted and actual P_2O_5 offtakes was best modelled using parallel lines (i.e. the slope of the line was the same for each index but the intercept varied), (Figure 7b) suggesting that P uptake was lower on soils with low soil P indices. For example, where RB209 predicted an offtake of 50 kg/ha then the measured offtake was 26, 33, 39 and 39 kg/ha for P indices 0, 1, 2 and 3 respectively.

There was no significant difference in the relationship between predicted and measured P_2O_5 offtakes when the data was grouped according to cross compliance soil type (Figure 7c) indicating that soil type had no impact on crop P uptake.

Phosphate winter wheat grain offtake (kg/t fw)

Mean measured winter wheat P_2O_5 grain offtakes were 5.7 ± 0.1 kg/t fw and significantly lower (P<0.001) than the reference value in RB209 (7.8 kg/t fw), Figure 8. The measured data suggested that winter wheat P_2O_5 offtake was lower at P Index 0/1 (4.5 kg/t fw) than at P Indices ≥3 (6.0-6.1 kg/t fw), Figure 8b.

6.2.2. Potash

Winter wheat K concentration (% K in dry matter)

The mean winter wheat K concentration was 0.48 ± 0.01% dm (range 0.27-0.73% dm) (Table 11); and there was no effect of soil K index on wheat K content. Table 12. The RB209 K concentration was similar to the average measured value (i.e. 0.6% dm based on 5.6 kg/t fw K_2O and 85% dry matter).

Predicted v measured wheat grain K_2O offtakes (kg/ha)

Measured wheat K_2O offtakes (38 ± 1.3 kg/ha) were lower than predicted by RB209 (43 ± 1.8 kg/ha) with *c*.80% of the measured values below the 1:1 line (Figure 9a). The slope of the regression line comparing predicted and measured offtakes was significantly different from 1 (0.70 ± 0.02 kg/ha). For example, where RB209 predicted an offtake of 50 kg/ha K_2O then the measured offtake was 42 kg/ha K_2O (0.70x – 6.53). When the data was grouped according to soil K index, there was no practical difference in the relationship between predicted and measured K_2O offtakes, indicating that soil K index had no impact on crop K offtake (Figure 9b).

There was no significant difference in the relationship between predicted and measured K_2O offtakes when the data was grouped according to cross compliance soil type (Figure 9c) indicating that soil type had no impact on crop K uptake.

Potash winter wheat grain offtake (kg/t fw)

Mean measured winter wheat K_2O offtakes were 4.9 ± 0.1 kg/t fw and were significantly lower (P<0.001) than the reference value in RB209 (5.6 kg/t fw), Figure 10a. There was no difference in offtake from sites with different soil K indices (Figure 10b).

Table 11. Winter wheat: mean, minimum (min), maximum (max), lower and upper 95% confidence interval (CI), standard deviation (SD) and standard error of the mean (SEM) for phosphorus (P) and potassium (K) concentration in dry matter (P or K % dm), phosphate (P_2O_5) and potash (K_2O) offtakes (kg/ha, kg/t fw).

	Phosphorus				Potassium			
	% dm	*Predicted (kg/ha)*	*Actual (kg/ha)*	*kg/t fw*	*% dm*	*Predicted (kg/ha)*	*Actual (kg/ha)*	*kg/t fw*
Mean	0.30	67	49	5.7	0.48	43	38	4.9
Min	0.11	10	8	2.1	0.27	5	9	3.4
Max	0.52	122	124	10.2	0.73	88	75	7.3
Lower CI	0.29	65	47	5.6	0.47	41	37	4.8
Upper CI	0.30	68	50	5.8	0.48	45	39	5.0
95% CI	0.004	1.3	1.2	0.1	0.01	1.8	1.3	0.1
SD	0.07	20	20	1.4	0.1	20	14	0.8
SEM	0.002	0.6	0.6	0.04	0.003	0.9	0.6	0.04
Number	1,060	1,024	1,024	5.7	490	481	454	454

Table 12. Winter wheat: mean, minimum (min), maximum (max), lower and upper 95% confidence interval (CI), standard deviation (SD) and standard error of the mean (SEM) for phosphorus (P) and potassium (K) concentration in dry matter (P or K % dm), phosphate (P_2O_5) and potash (K_2O) offtakes (, kg/t fw) grouped by soil P or K Index.

	Phosphorus (% dm)				Phosphate offtake (kg/t fw)				Potassium (% dm)			Potash offtake (kg/t fw)		
P or K Index	*0*	*1*	*2*	*≥3*	*0/1*	*2*	*3*	*≥4*	*0/1*	*2*	*≥3*	*0/1*	*2*	*≥3*
Mean	0.23	0.27	0.32	0.31	4.5	5.2	6.1	6.0	0.49	0.47	0.49	5.0	5.0	5.0
Min	0.16	0.11	0.17	0.19	3.0	2.1	3.1	3.6	0.35	0.27	0.35	3.4	3.4	3.5
Max	0.35	0.43	0.45	0.45	6.7	8.3	8.6	9.1	0.61	0.73	0.70	7.3	7.2	7.0
Lower CI	0.23	0.26	0.31	0.31	4.4	5.1	6.0	5.8	0.06	0.11	0.07	0.7	1.1	0.7
Upper CI	0.23	0.28	0.32	0.32	4.6	5.4	6.3	6.2	0.01	0.01	0.01	0.1	0.1	0.1
95% CI	0.005	0.01	0.01	0.01	0.09	0.2	0.1	0.2	0.01	0.02	0.01	0.1	0.2	0.1
SD	0.04	0.07	0.05	0.05	0.69	1.3	1.1	1.2	0.48	0.45	0.48	4.8	4.8	4.9
SEM	0.002	0.004	0.003	0.004	0.05	0.1	0.1	0.1	0.50	0.49	0.50	5.1	5.3	5.1
Number	214	244	337	152	214	241	306	138	117	102	161	110	87	159

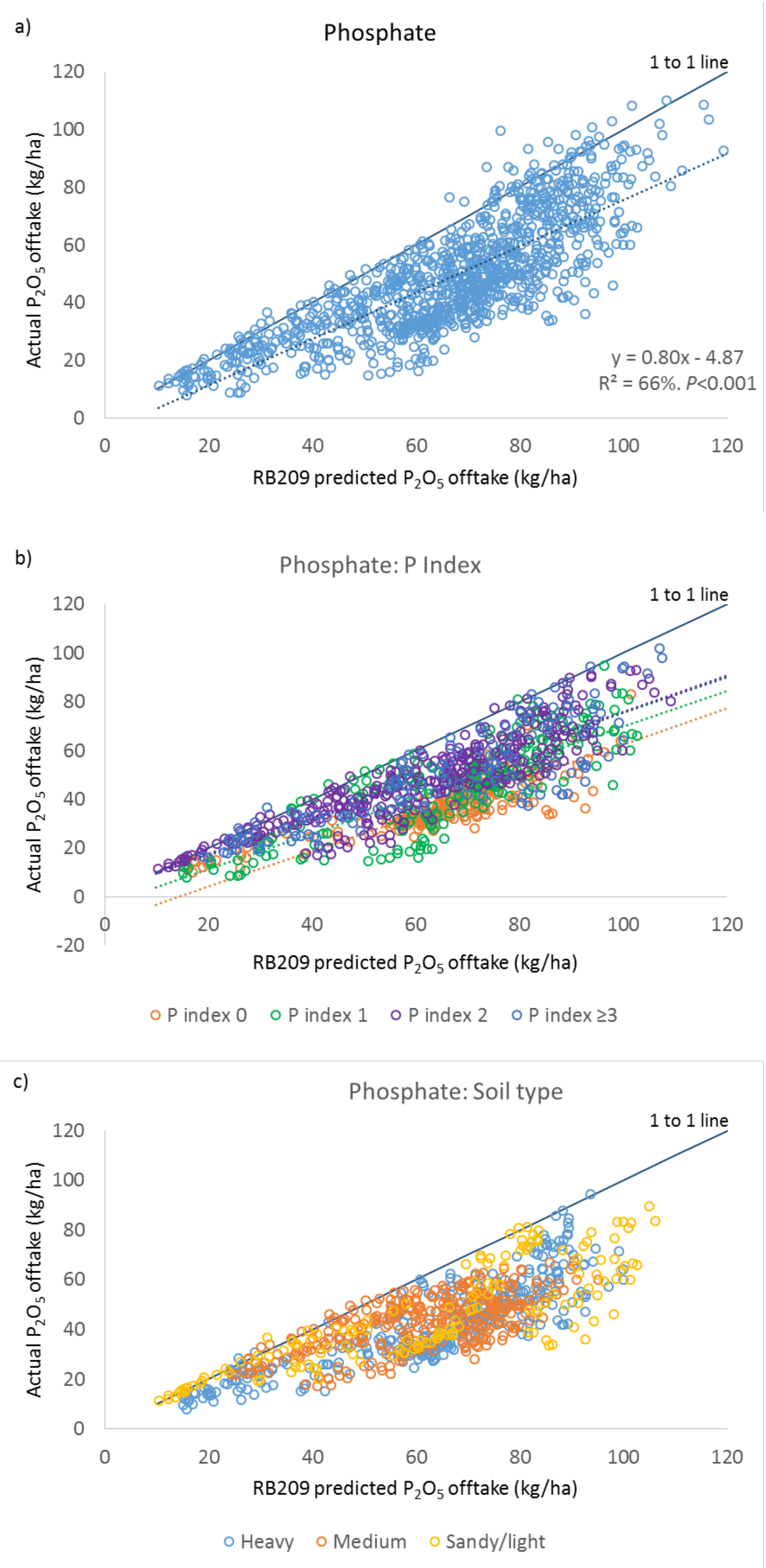
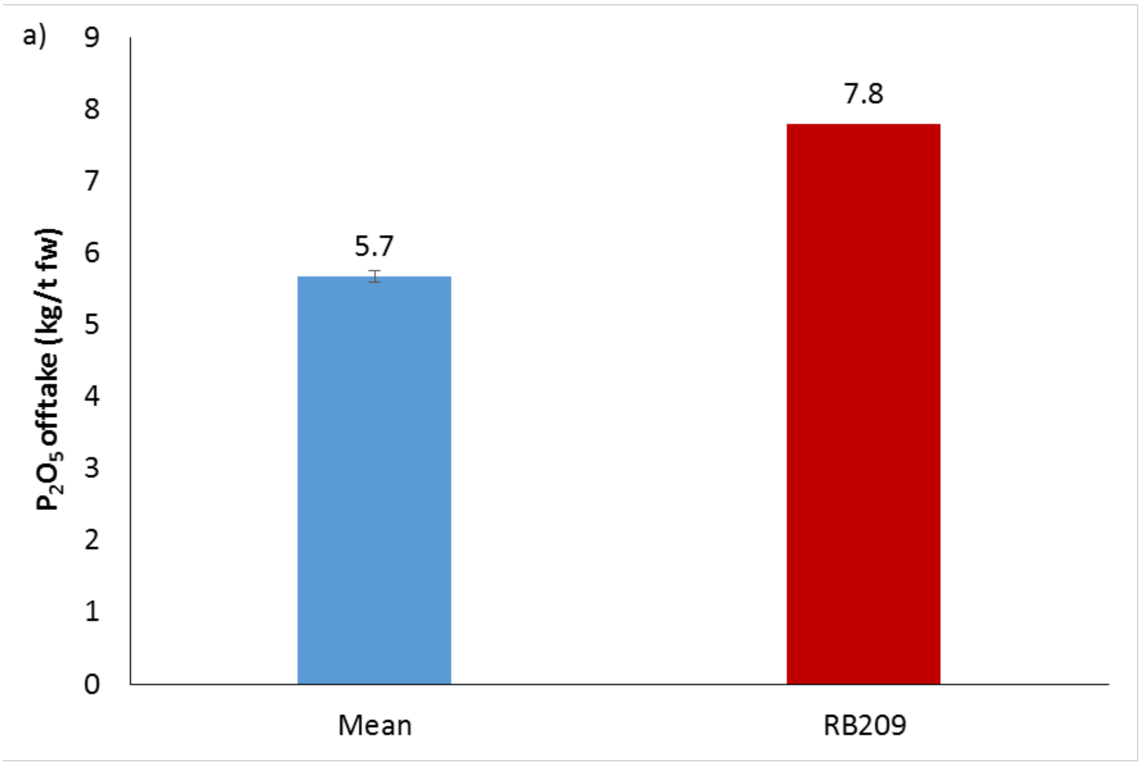


Figure 7. Winter wheat: a) the relationship between predicted and actual phosphate (P_2O_5) offtakes (kg/ha), b) grouped by soil P index and c) grouped by cross compliance soil type.



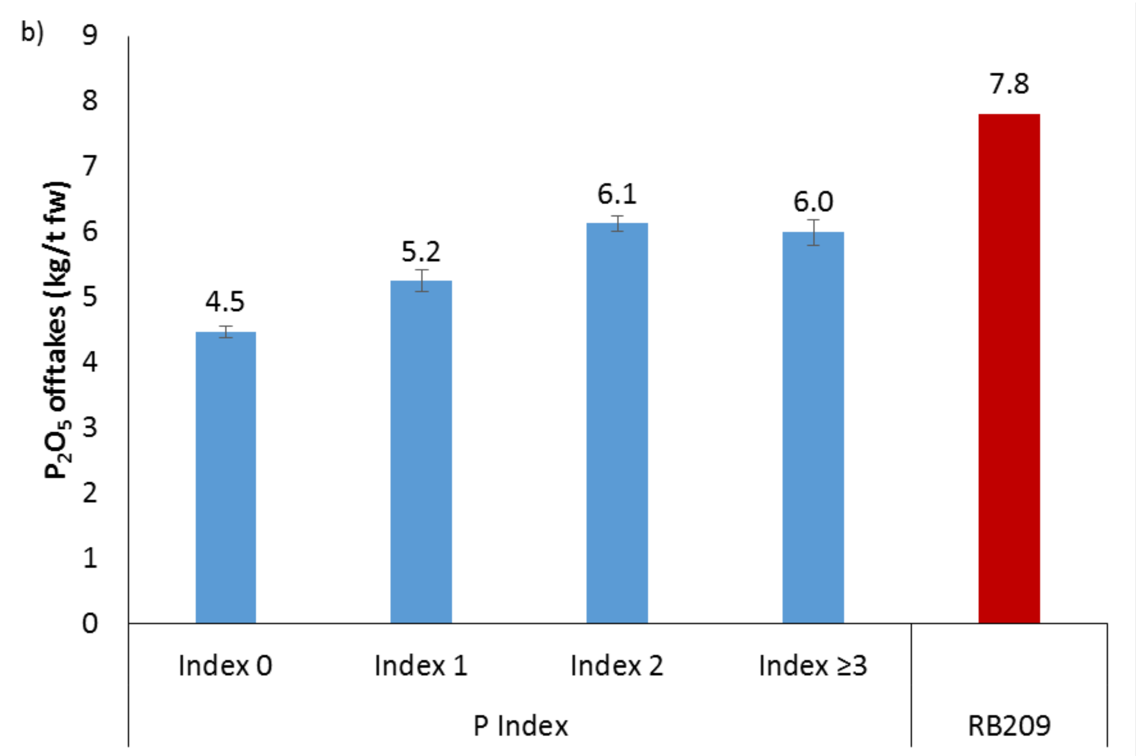


Figure 8. Winter wheat: a) phosphate (P_2O_5) offtakes (kg/t fw) and b) phosphate offtakes (kg/t fw) by soil P Index with RB209 references values. I indicates 95% confidence intervals of the mean.

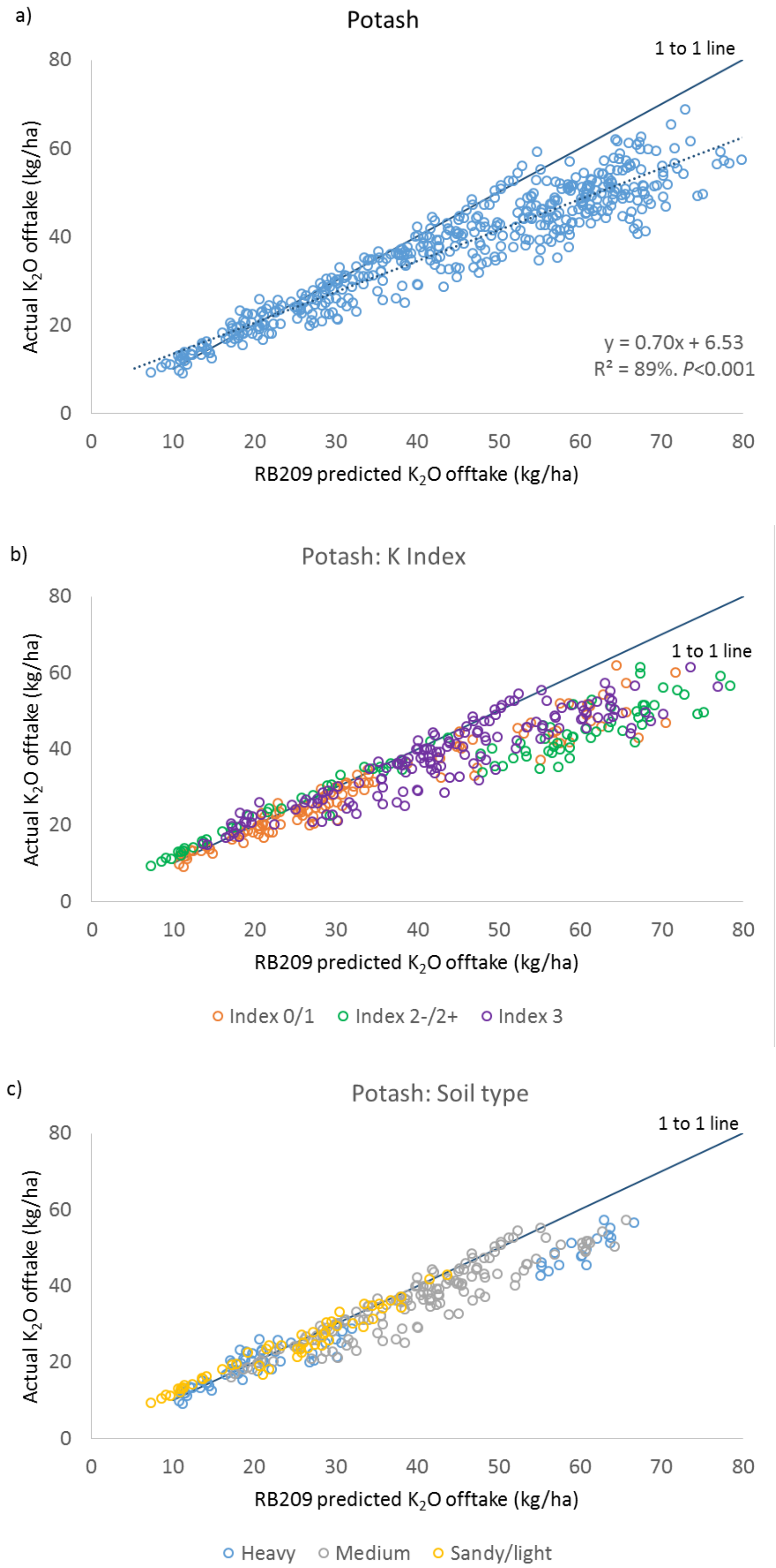


Figure 9. Winter wheat: a) the relationship between predicted and actual potash (K_2O) offtakes (kg/ha), b) grouped by soil K index and c) grouped by cross compliance soil type.

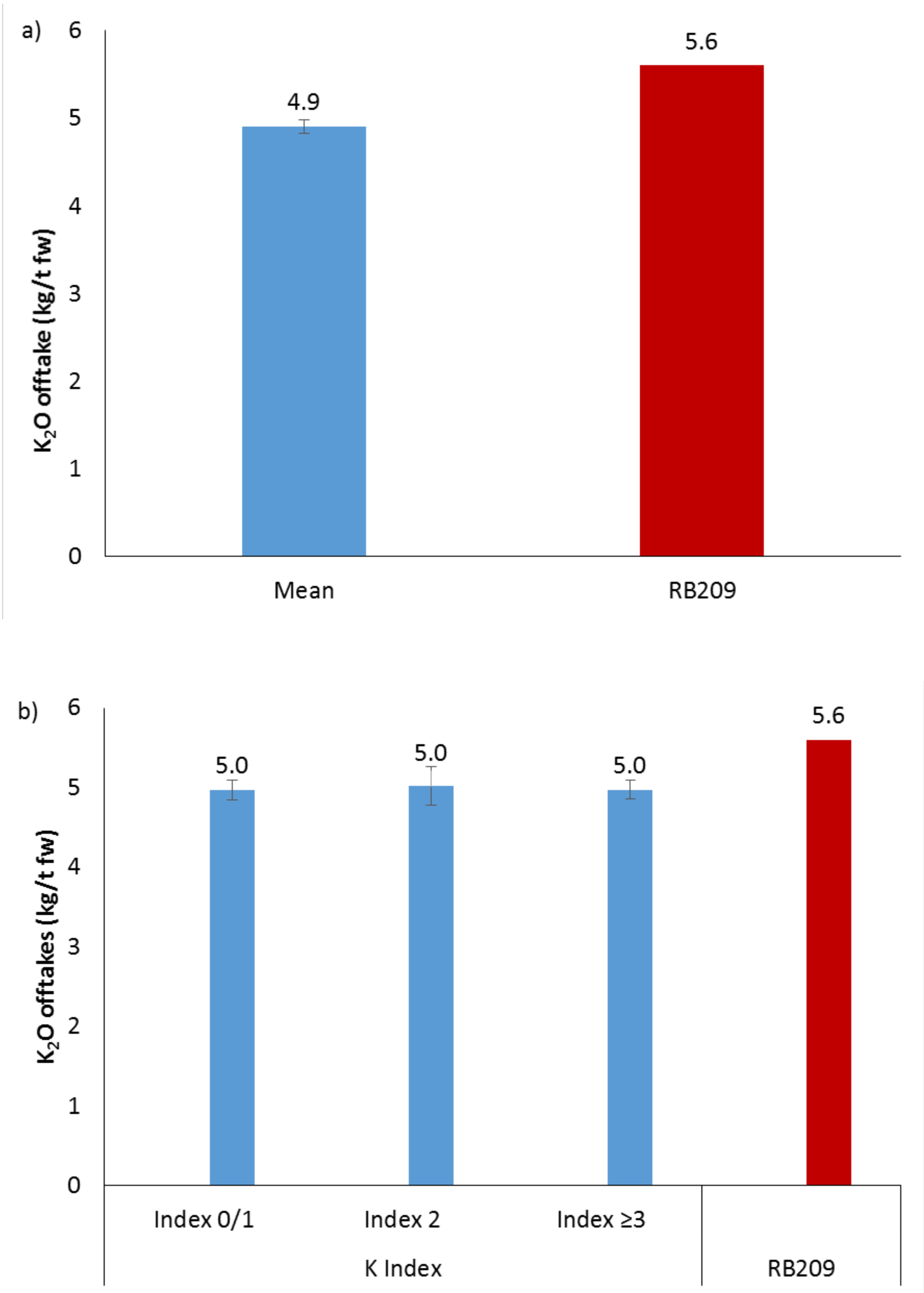


Figure 10. Winter wheat: a) potash (K_2O) offtakes (kg/t fw) and b) potash offtakes (kg/t fw) by soil K Index with RB209 references values. I indicates 95% confidence intervals of the mean.

6.3. Winter and spring barley

The average yield across the dataset was 8.9 ± 0.2 t/ha @ 85% dry matter for winter barley and 6.0 ± 0.2 t/ha @ 85% dry matter for spring barley.

The mean soil P concentration of the barley sites was 26 mg/l (P Index 3) and the mean soil K concentration was 198 mg/l (K Index 2+), which was similar to the average P and K soil indices reported by PAAG (2017), Table 13

Table 13. The proportion of winter and spring barley samples from sites at P or K Index 0-≥3 compared with PAAG data

Winter and spring barley			Percentage of samples in Index:			
		Mean	***0 (0-9 mg/l)***	***1 (10-15 mg/l)***	***2 (16-25 mg/l)***	***≥3 (≥26 mg/l)***
P Index	ADAS	26 mg/l [Index 3]	18	22	34	26
	PAAG	31 mg/l [Index 3]	5	17	29	49
			0 (0-60 mg/l)	***1 (61-120 mg/l)***	***2-/2+ (121-240 mg/l)***	***≥3 (≥241 mg/l)***
K Index	ADAS	186 mg/l [Index 2+]	0	23	57 (53/4)	20
	PAAG	186 mg/l [Index 2-]	3	26	50 (31/19)	21

The winter barley sites were representative of the three main cross compliance soil groups with 37% of sites on heavy soil, 29% on medium soil and 34% on sand and light silt soils. For spring barley most sites (*c.*70%) were on sand and light silt soils with the remainder (*c.*30%) on medium soils reflecting the soil types typically used for spring barley production.

6.3.1. Phosphate

Winter and spring barley P concentration (% P in dry matter)

The mean measured grain P concentration was 0.36 ± 0.01% dm (range: 0.27-0.49% dm) for winter barley and 0.39 ± 0.01% dm (range: 0.30-0.49% dm) for spring barley, (Table 14). The data suggested there were small differences in barley P offtake at soil P Index 1 (0.35 ± 0.01% dm) compared with soil P index 2 and above (0.39% ± 0.01 % dm) Table 15. For barley, P concentration value in RB209 was similar *c.*0.4% dm to the measured values, (based on 7.8 kg/t fw P_2O_5 and 85% dry matter).

Predicted v measured barley grain P_2O_5 offtakes (kg/ha)

Measured winter and spring barley P_2O_5 offtakes (46 ± 1.3 kg/ha) were lower than predicted by RB209 (51 ± 1.4 kg/ha), (Figure 11a). The slope of the regression line comparing predicted and measured offtakes was significantly different from 1 (0.77 ± 0.05 kg/ha). For example, where RB209 predicted an offtake of 50 kg/ha the measured offtake was 45 kg/ha (0.77x + 6.63). There was no significant difference in the relationship between predicted and measure P_2O_5 offtakes when the data were grouped according to soil P index (Figure 11b). Similarly, there was no difference in the relationship between predicted and measured P_2O_5 offtakes when the data was grouped according to cross compliance soil type (Figure 11c).

Phosphate barley grain offtake (kg/t fw)

The overall mean measured barley P_2O_5 grain offtakes were 7.2 ± 0.1 kg/t fw and were similar for spring (7.4 ± 0.2 kg/t fw) and winter barley (6.9 ± 0.1 kg/t fw). Overall, barley grain offtakes were significantly lower (P<0.001) than the reference value in RB209 (7.8 kg/t fw), Figure 12a-c. The measured data suggested that barley P_2O_5 offtake was lower at P Index 0/1 (6.7 kg/t fw) than at P Indices 2 and 3 (7.5-7.6 kg/t fw), Figure 12d.

6.3.2. Potash

Winter and spring barley K concentration (% K in dry matter)

For both winter and spring barley, grain K concentration was 0.54 ± 0.01% dm (range 0.47-0.67% dm; Table 14) and slightly lower than the RB209 K offtake figure (*c.*0.6% dm), based on 5.6 kg/t fw K_2O and 85% dry matter.

Predicted v measured barley grain K_2O offtakes (kg/ha)

Measured winter and spring barley K_2O offtakes (26 ± 1.6 kg/ha) were slightly lower than those predicted by RB209 (28 ± 2.2 kg/ha), (Figure 13). The slope of the regression line comparing predicted and measured offtakes was significantly different from 1 (0.72 ± 0.05 kg/ha). For example, where RB209 predicted an offtake of 50 kg/ha then the actual offtake would be 42 kg/ha (0.72x + 6.13).

Potash barley grain offtake (kg/t fw)

The overall mean measured barley K_2O offtakes were 5.4 ± 0.2 kg/t fw with no difference between spring and winter barley. Barley offtakes were similar to the reference value in RB209 (5.6 kg/t fw) for grass, Figure 14.

Table 14. Mean, minimum (min), maximum (max), lower and upper 95% confidence interval (CI), standard deviation (SD) and standard error of the mean (SEM) for phosphorus (P) and potassium (K) concentration in dry matter (P or K % dm), phosphate (P_2O_5) and potash (K_2O) offtakes (kg/ha, kg/t fw) for a) spring barley, b) winter barley and c) spring/winter barley.

Barley	**Phosphorus**				**Potassium**			
a) Spring	*% dm*	*Predicted (kg/ha)*	*Actual (kg/ha)*	*kg/t fw*	*% dm*	*Predicted (kg/ha)*	*Actual (kg/ha)*	*kg/t fw*
Mean	0.39	43	40	7.4	0.54	26	24	5.4
Min	0.30	15	17	5.7	0.47	11	12	4.5
Max	0.49	71	60	10.1	0.67	51	41	7.2
Lower CI	0.38	41	38	7.2	0.53	23	22	5.2
Upper CI	0.39	45	43	7.6	0.56	29	26	5.7
95% CI	0.01	2.2	2.0	0.2	0.02	2.9	2.0	0.2
SD	0.05	12	11	1.1	0.06	11	7	0.8
SEM	0.004	1.1	1.0	0.1	0.01	1.4	1.0	0.1
Number	117	117	117	117	54	54	54	54
b) Winter	**Phosphorus**				**Potassium**			
	% dm	*Predicted (kg/ha)*	*Actual (kg/ha)*	*kg/t fw*	*% dm*	*Predicted (kg/ha)*	*Actual (kg/ha)*	*kg/t fw*
Mean	0.36	57	50	6.9	0.54	32	31	5.4
Min	0.27	32	32	5.2	0.49	23	24	5.0
Max	0.49	67	66	9.3	0.58	41	41	5.8
Lower CI	0.35	56	49	6.8	0.53	29	29	5.3
Upper CI	0.37	58	52	7.1	0.55	34	33	5.5
95% CI	0.01	1.1	1.2	0.1	0.01	2.2	2.0	0.1
SD	0.04	6.9	7.5	0.7	0.02	4.8	4.3	0.2
SEM	0.003	0.6	0.6	0.1	0.004	1.0	0.9	0.0
Number	143	142	142	142	21	21	21	21

	Phosphorus				Potassium			
C) All	*% dm*	*Predicted (kg/ha)*	*Actual (kg/ha)*	*kg/t fw*	*% dm*	*Predicted (kg/ha)*	*Actual (kg/ha)*	*kg/t fw*
Mean	0.37	51	46	7.2	0.54	28	26	5.4
Min	0.27	15	17	5.2	0.47	11	12	4.5
Max	0.49	71	66	10.1	0.67	51	41	7.2
Lower CI	0.37	49	45	7.0	0.53	26	24	5.3
Upper CI	0.38	52	47	7.3	0.55	30	28	5.6
95% CI	0.01	1.4	1.3	0.1	0.01	2.2	1.6	0.2
SD	0.04	12	10	1.0	0.05	10	7	0.7
SEM	0.003	0.7	0.7	0.1	0.01	1.1	0.8	0.1
Number	259	259	259	259	75	75	75	75

Table 15. Spring/winter barley: mean, minimum (min), maximum (max), lower and upper 95% confidence interval (CI), standard deviation (SD) and standard error of the mean (SEM) for phosphorus concentration in dry matter (P % dm) and phosphate (P_2O_5) offtakes (kg/t fw).

	All barley P (% dm)			Phosphate offtake (kg/t fw)		
P Index	*0/1*	*2*	*≥3*	*0/1*	*2*	*≥3*
Mean	0.35	0.39	0.39	6.70	7.65	7.52
Min	0.27	0.30	0.33	5.22	5.75	6.05
Max	0.49	0.48	0.49	9.28	9.31	10.06
Lower CI	0.34	0.38	0.38	6.59	7.43	7.27
Upper CI	0.36	0.40	0.40	6.82	7.87	7.77
95% CI	0.01	0.01	0.01	0.11	0.22	0.25
SD	0.03	0.04	0.04	0.64	0.84	1.12
SEM	0.003	0.01	0.005	0.058	0.11	0.126
Number	122	58	79	122	58	79

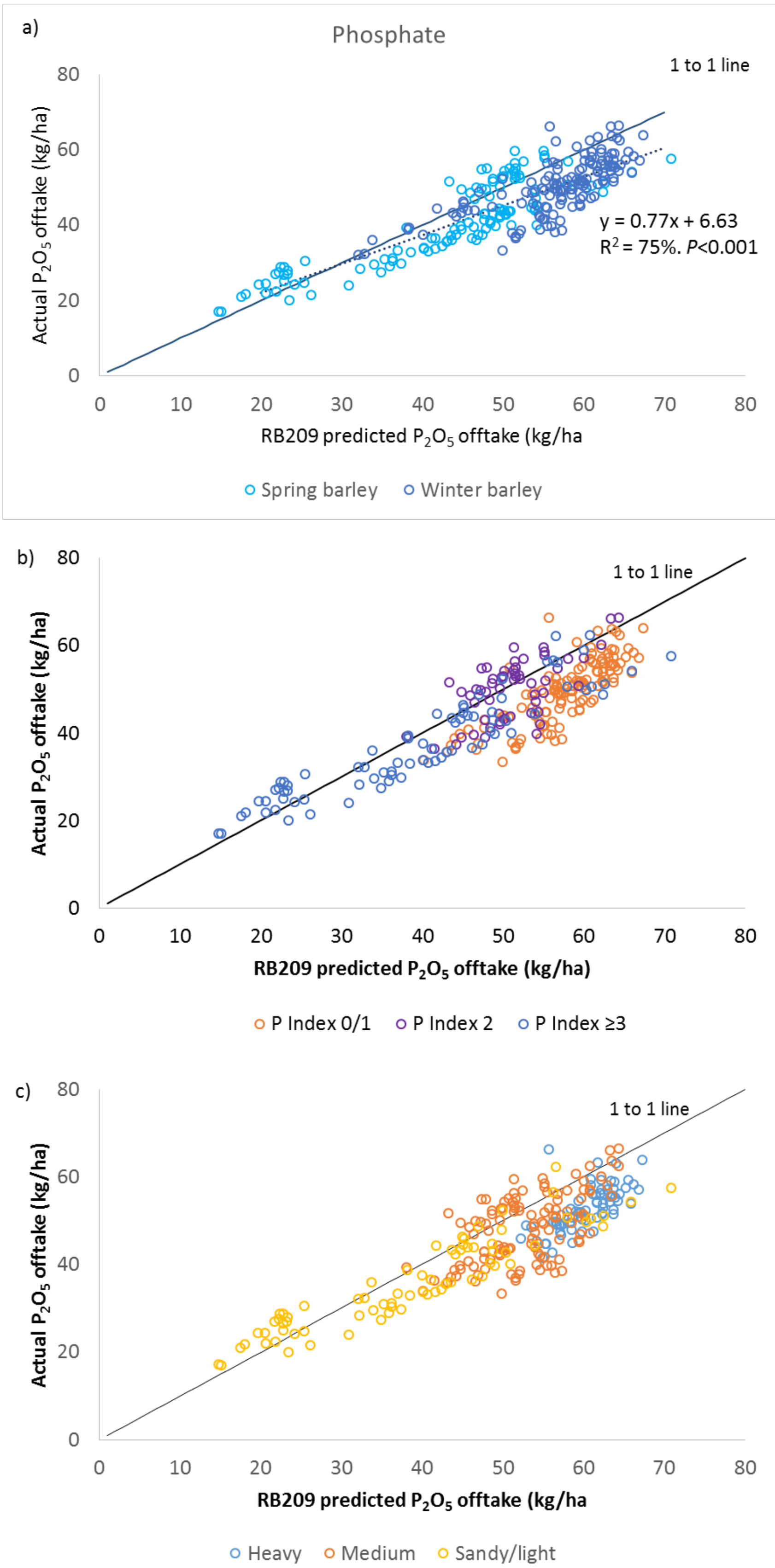


Figure 11. Winter and spring barley: a) the relationship between predicted and actual phosphate (P_2O_5) offtakes (kg/ha), b) grouped according to soil P Index and c) grouped according to cross compliance soil type.

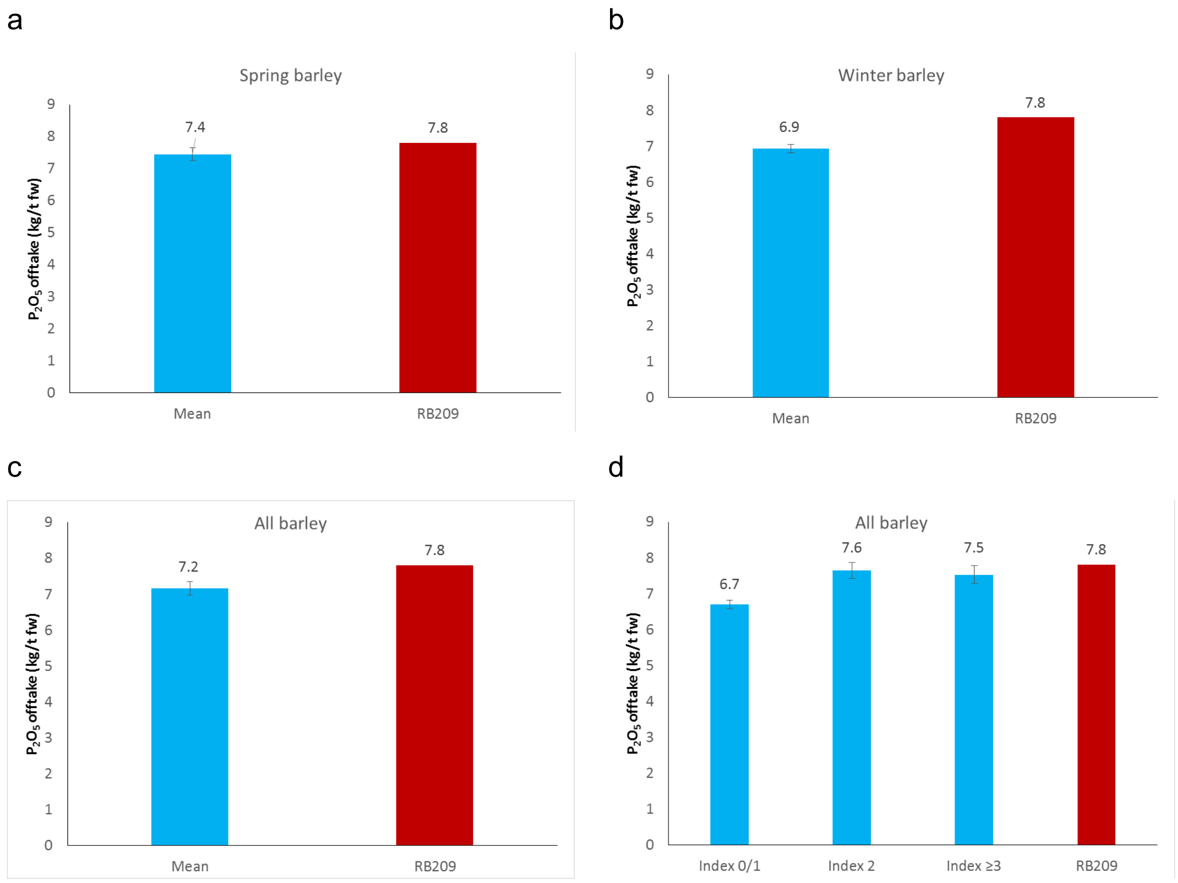


Figure 12. Phosphate (P_2O_5) offtakes (kg/t fw): a) spring barley, b) winter barley, c) spring/winter barley and d) spring/winter barley grouped by soil P Index, with RB209 references values. I indicates 95% confidence intervals of the mean.

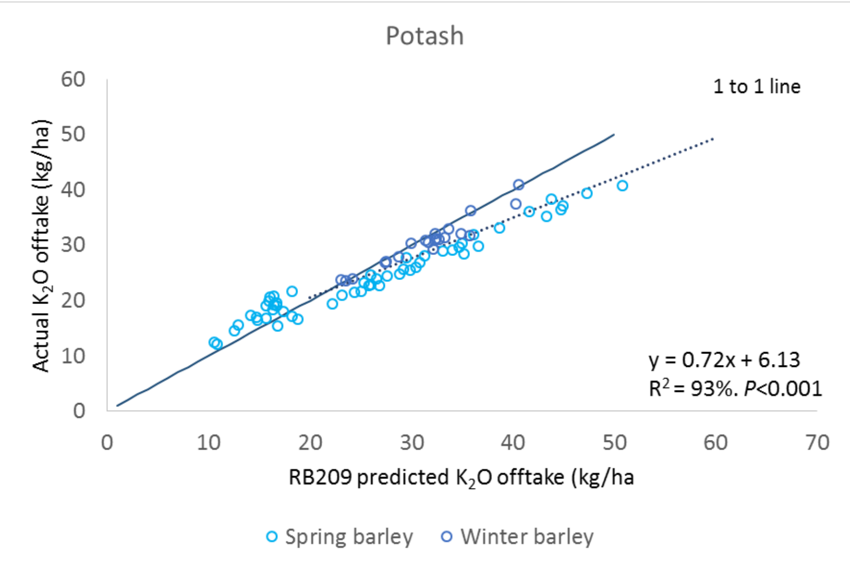


Figure 13. Winter and spring barley: a) the relationship between predicted and actual phosphate (K_2O) offtakes (kg/ha)

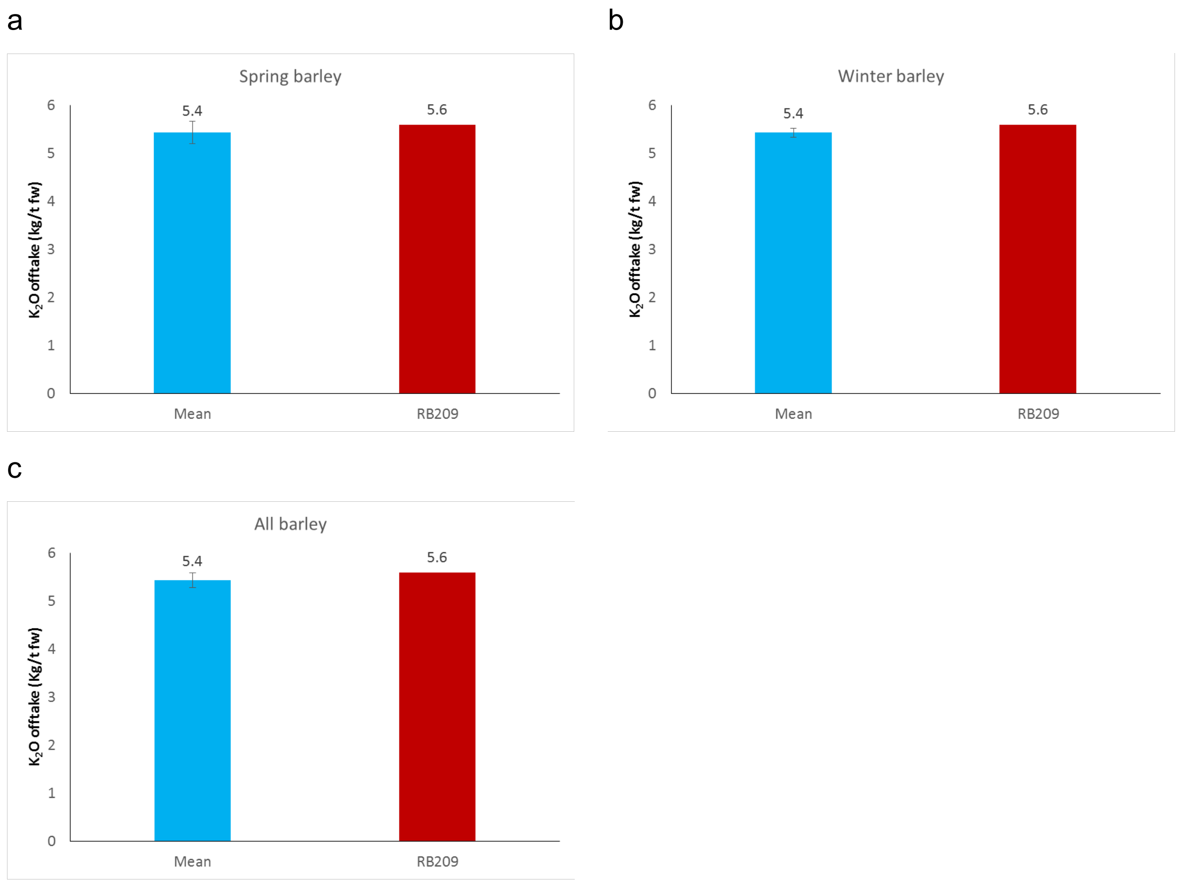


Figure 14. Potash (K_2O) offtakes (kg/t fw): a) spring barley, b) winter barley, c) spring/winter barley, with RB209 references values. I indicates 95% confidence intervals of the mean.

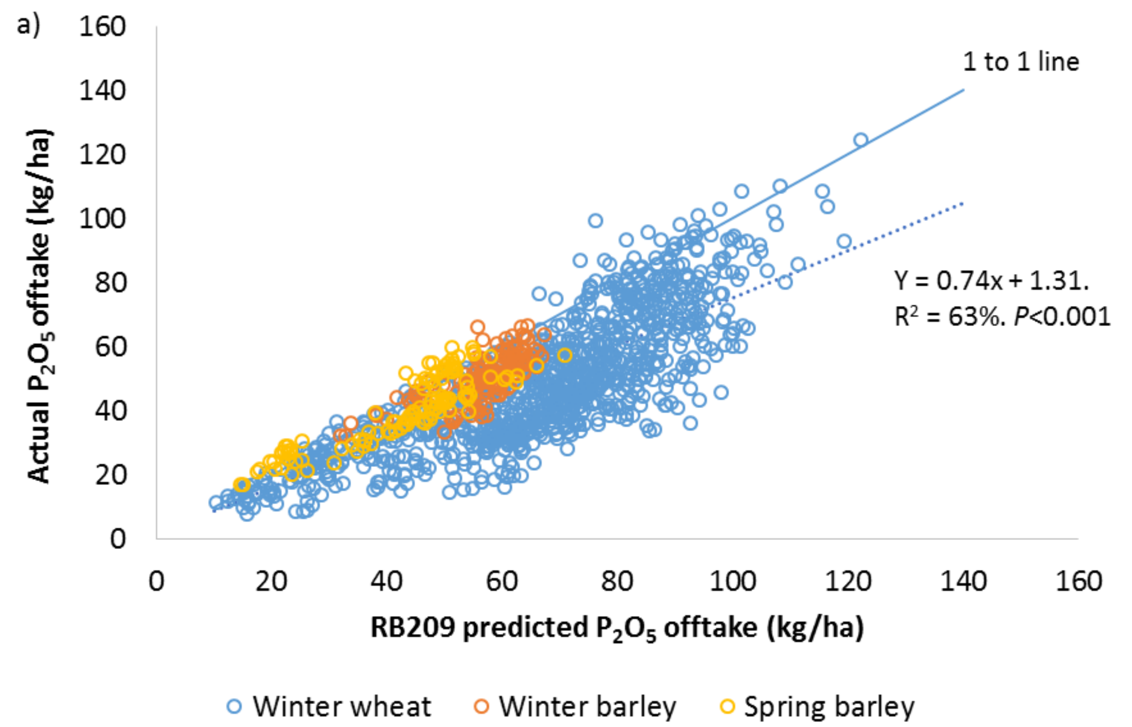
6.4. Combined cereal dataset

6.4.1. Predicted v measured grain P_2O_5 or K_2O offtakes (kg/ha)

In RB209 a single grain offtake value for all cereals is given for both phosphate (7.8 kg t/fw) and potash (5.6 kg/t fw). To determine, if there was any difference in the relationship between predicted and measured offtake for winter wheat, winter barley and spring barley the data were compared using simple linear regression (with data grouped according to crop type). For both phosphate and potash the relationship between predicted and measured offtake was the same for the three cereal types (Figure 15 and Figure 16). However, due to the smaller number of barley data-points the spread of the phosphate and potash data was much more limited, which resulted in less robust relationships than for the winter wheat dataset.

6.4.2. Phosphate and potash barley grain offtake (kg/t fw)

For the combined winter wheat, winter barley and spring barley datasets, phosphate offtakes (overall mean: 6 kg/t fw ± 0.1 kg/t fw, range of means for cereal types: 5.7-7.4 kg/t fw) were lower than the RB209 value of 7.8 kg/t fw, Figure 15. In comparison, cereal potash offtakes (overall mean: 5 kg/t fw ± 0.1 kg/t fw; range of means for cereal type: 4.9-5.4 kg/t fw) were typically in line with the RB209 value (5.6 kg/t fw), Figure 16. Despite the numerical differences in offtakes between crop types it should not be assumed that this reflects differences that are simply related to crop type. Multiple factors are likely to affect crop growth (e.g. soil type, site factors (climate, rainfall, soil structure etc.), soil P or K index) and could be responsible for the observed differences in offtakes.



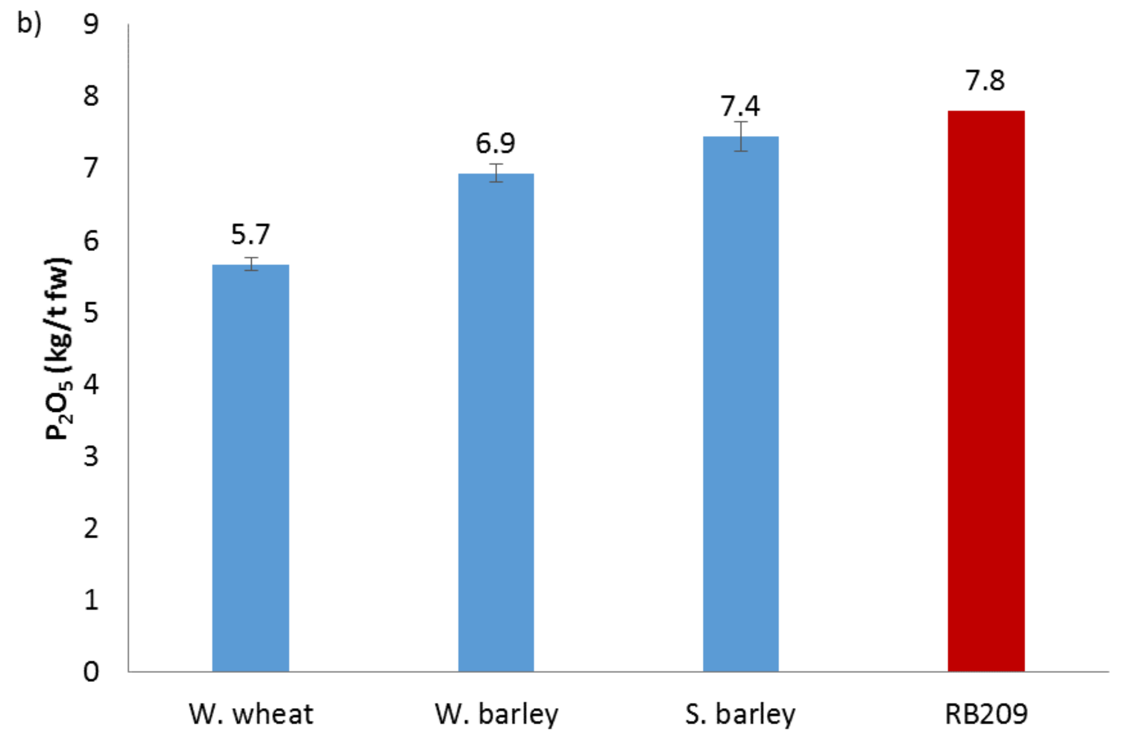


Figure 15. Cereals (winter wheat, winter and spring barley): a) the relationship between predicted and actual phosphate (P_2O_5) grain offtakes (kg/ha) grouped according to cereal crop type and b) P_2O_5) offtakes (kg/t fw) with RB209 references values. I indicates 95% confidence intervals of the mean.

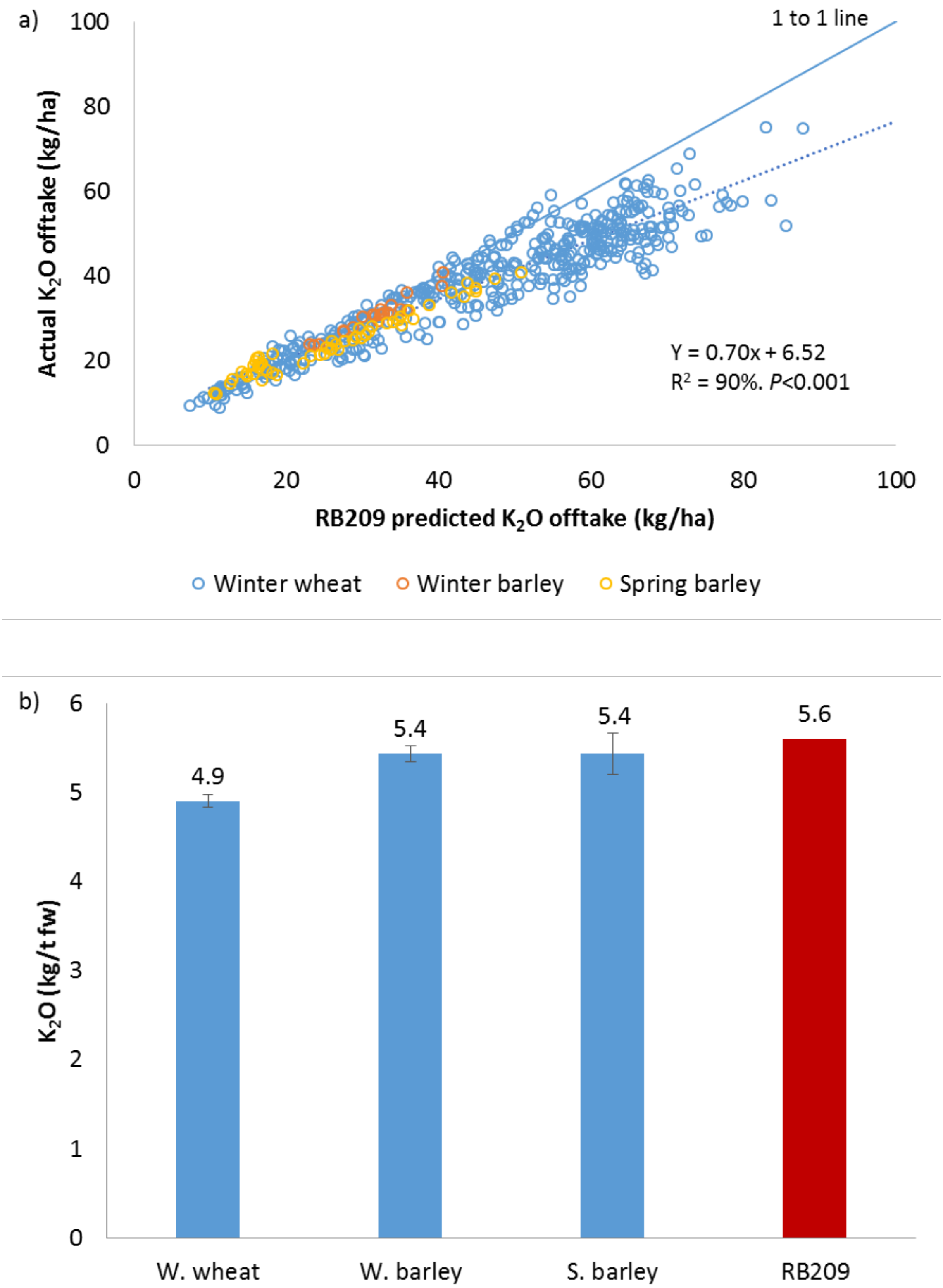


Figure 16. Cereals (winter wheat, winter and spring barley): a) the relationship between predicted and actual potash (K_2O) grain offtakes (kg/ha) grouped according to cereal crop type and b) K_2O offtakes (kg/t fw) with RB209 references values. I indicates 95% confidence intervals of the mean.

6.4.3. Example cereal phosphate and potash offtake calculations

Phosphate and potash offtakes calculated using RB209 values for winter wheat, winter barley and spring barley were compared with offtakes calculated from the dataset used in this review. The comparison showed that for a typical winter wheat crop yielding 8 t/ha RB209 predicted phosphate offtakes of 16 kg/ha and potash offtakes of 6 kg/ha (Table 16) more than the measured dataset. For barley, RB209 predicted greater offtakes for phosphate (7 and 3 kg/ha for winter and spring barley respectively), and potash (2 kg/ha for both winter and spring barley) than the measured dataset.

Table 16. Comparison of cereal phosphate and potash offtakes calculated using RB209 reference values and using the ADAS dataset.

	RB209 offtakes	This data*	Difference
Phosphate offtake	*7.8 kg/t fw*		
Winter wheat (8 t/ha)	62	46	-16
Winter barley (8 t/ha)	62	55	-7
Spring barley (6 t/ha)	47	44	-3
Potash offtake	*5.6 kg/t fw*		
Winter wheat (8 t/ha)	45	39	-6
Winter barley (8 t/ha)	45	43	-2
Spring barley (6 t/ha)	34	32	-2

*P_2O_5: winter wheat 5.7, winter barley 6.9 and spring barley 7.4 kg/t fw.

K_2O: winter wheat 4.9, winter barley and spring barley 5.4 kg/t fw

6.5. Winter oilseed rape

Average yield across the dataset was 4.0 ± 0.1 t/ha @ 91% dry matter for winter oilseed rape (range: 1.7-6.2 t/ha).

The mean soil P concentration of the oilseed rape sites was 23 mg/l (P Index 2) and the mean soil K concentration was 167 mg/l (K Index 2-), which was similar to the average soil P and K index reported by the PAAG (2017),
Table 17.

Table 17 The proportion of winter oilseed rape samples from sites at P or K Index 0-≥3 compared with PAAG data

Winter oilseed rape			Percentage of samples in Index:			
		Mean	***0 (0-9 mg/l)***	***1 (10-15 mg/l)***	***2 (16-25 mg/l)***	***≥3 (≥26 mg/l)***
P Index	ADAS	23 mg/l [Index 2]	16	26	27	31
	PAAG	31 mg/l [Index 3]	5	17	29	49
			0 (0-60 mg/l)	***1 (61-120 mg/l)***	***2-/2+ (121-240 mg/l)***	***≥3 (≥241 mg/l)***
K Index	ADAS	167 mg/l [Index 21]	0	7	84 (72/12)	9
	PAAG	186 mg/l [Index 2-]	3	26	50 (31/19)	21

The winter oilseed rape sites were representative of the three main cross compliance soil groups with 24% of sites on heavy soil, 54% on medium soil and 22% on sand and light silt soils.

6.5.1. Phosphate

Winter oilseed rape P (% P in dry matter)

The mean measured P concentration was 0.58 ± 0.01 % dm (range: 0.37-0.81 % dm) (Table 19), lower than the value in RB209 (0.67%; based on 14 kg/t fw P_2O_5 and 91% dry matter).

Predicted v measured oilseed rape P_2O_5 offtakes (kg/ha)

Measured winter oilseed rape P_2O_5 offtakes (48 ± 1.4 kg/ha) were lower than predicted by RB209 (56 ± 1.5 kg/ha), (Figure 17). The slope of the regression line comparing predicted and measured offtakes was significantly different from 1 (0.73 ± 0.07 kg/ha). For example, where RB209 predicted an offtake of 50 kg/ha then the measured offtake was 44 kg/ha (0.73x + 7.09).

When the data were grouped according to P index it was noted the relationship between predicted and measured P_2O_5 offtakes was best modelled using parallel lines (i.e. the slope of the line was the same for each index but the intercept varied), indicating that P offtakes were lower on low P index soils, Figure 17. For example, where RB209 predicted an offtake of 50 kg/ha the measured offtake was 39, 43 and 49 kg/ha for P indices 0/1, 2, and ≥3 respectively. Similarly, when the data were grouped according to soil type (heavy, medium or sandy and light) it was noted that the relationship between predicted and measure P_2O_5 offtakes was best modelled using parallel lines (i.e. the slope of the line was the same for each index but the intercept varied), indicating that OSR P offtake was greater on light/sandy soils, Figure 17. For example, where RB209 predicted an offtake of 50 kg/ha then the measured offtake was 43, 40 and 50 kg/ha for heavy, medium and sandy/light soils respectively.

Phosphate offtake (kg/t fw)

Mean measured oilseed rape P_2O_5 offtakes were 12.1 ± 0.2 kg/t fw and significantly lower ($P<0.001$) than the reference value in RB209 (14 kg/t fw), Figure 18. The data also suggested soil P status influenced P_2O_5 offtake with lower uptakes measured on soils at P index 0/1 (10.8 kg/t fw) compared with uptakes on soils at P Index 2 (12.2 kg/t fw) and P Index 3 (13.6 kg/t fw), Figure 18.

6.5.2. Potash

Winter oilseed rape K concentration (%K in dry matter)

The mean measured K concentration was 0.79 ± 0.01 % dm (range 0.69-0.93% dm; Table 19) and lower than the RB209 K concentration for winter oilseed rape (*c.*1.0% dm, based on 11 kg/t fw K_2O and 91% dry matter).

Predicted v measured oilseed rape K_2O offtakes (kg/ha)

Measured winter oilseed rape K_2O offtakes (36 ± 1.3 kg/ha) were also lower than predicted by RB209 (46 ± 1.3kg/ha), (Figure 19). The slope of the regression line comparing predicted and measured offtakes was significantly different from 1 (0.88 ± 0.12 kg/ha). For example, where RB209 predicted an offtake of 50 kg/ha then the measured offtake was 39 kg/ha (0.88x - 4.79). There was insufficient data to compare the potash data according to soil K Index or soil type.

Potash offtake (kg/t fw)

Mean measured K_2O offtakes were 8.5 ± 0.1 kg/t fw and significantly lower (*P*<0.001) than the reference value in RB209 (11 kg/t fw). Figure 19. There was insufficient data to assess the effect of soil K Index on K_2O offtakes.

6.5.3. Example winter oilseed rape phosphate and potash offtake calculations

Phosphate and potash offtake values calculated using RB209 values for winter oilseed rape were compared with the same values calculated using the offtake values from the experimental dataset. The comparison showed that for a typical winter oilseed rape crop, yielding 3.5 t/ha, RB209 predicted phosphate offtakes of 7 kg/ha and potash offtakes of 9 kg/ha (Table 18) more than the measured values in the dataset.

Table 18. Comparison of winter oilseed rape phosphate and potash offtakes calculated using RB209 reference values and using the ADAS dataset.

	RB209 offtakes	This data	Difference
Phosphate offtake	*14 kg/t fw*		
Winter oilseed rape (3.5 t/ha)	49	42	-7
Potash offtake	*11 kg/t fw*		
Winter oilseed rape (3.5 t/ha)	39	30	-9

Table 19. Winter oilseed rape: mean, minimum (min), maximum (max), lower and upper 95% confidence interval (CI), standard deviation (SD) and standard error of the mean (SEM) for phosphorus (P) and potassium (K) concentration in dry matter (P or K % dm), phosphate (P_2O_5) and potash (K_2O) offtakes (kg/ha, kg/t fw).

	Phosphorus				**Potassium**			
	% dm	*Predicted (kg/ha)*	*Actual (kg/ha)*	*kg/t fw*	*% dm*	*Predicted (kg/ha)*	*Actual (kg/ha)*	*kg/t fw*
Mean	0.58	56	48	12.1	0.79	46	36	8.5
Min	0.37	24	22	7.9	0.69	34	25	7.4
Max	0.81	87	75	16.8	0.93	57	51	9.9
Lower CI	0.57	55	47	11.8	0.78	45	34	8.4
Upper CI	0.59	58	50	12.3	0.81	47	37	8.6
95% CI	0.01	1.5	1.4	0.2	0.01	1.3	1.3	0.1
SD	0.10	12	11	1.9	0.06	5	6	0.6
SEM	0.01	0.8	0.7	0.1	0.01	0.6	0.6	0.1
Number	264	264	264	264	74	74	74	74

Table 20. Winter oilseed rape: mean, minimum (min), maximum (max), lower and upper 95% confidence interval (CI), standard deviation (SD) and standard error of the mean (SEM) for phosphorus (P) concentration in dry matter (P % dm), phosphate (P_2O_5) offtakes (kg/t fw) grouped by soil P Index.

	Winter oilseed rape P (% dm)			**Phosphate offtake (kg/t fw)**		
P Index	*0/1*	*2*	*≥3*	*0/1*	*2*	*≥3*
Mean	0.51	0.58	0.66	10.8	12.2	13.6
Min	0.37	0.44	0.50	7.9	9.2	10.3
Max	0.76	0.81	0.79	15.6	16.8	16.5
Lower CI	0.50	0.56	0.65	10.5	11.8	13.2
Upper CI	0.53	0.60	0.68	11.2	12.6	13.9
95% CI	0.01	0.02	0.02	0.4	0.4	0.3
SD	0.07	0.08	0.07	1.9	1.6	1.5
SEM	0.01	0.01	0.01	0.1	0.2	0.2
Number	110	71	83	110	71	83

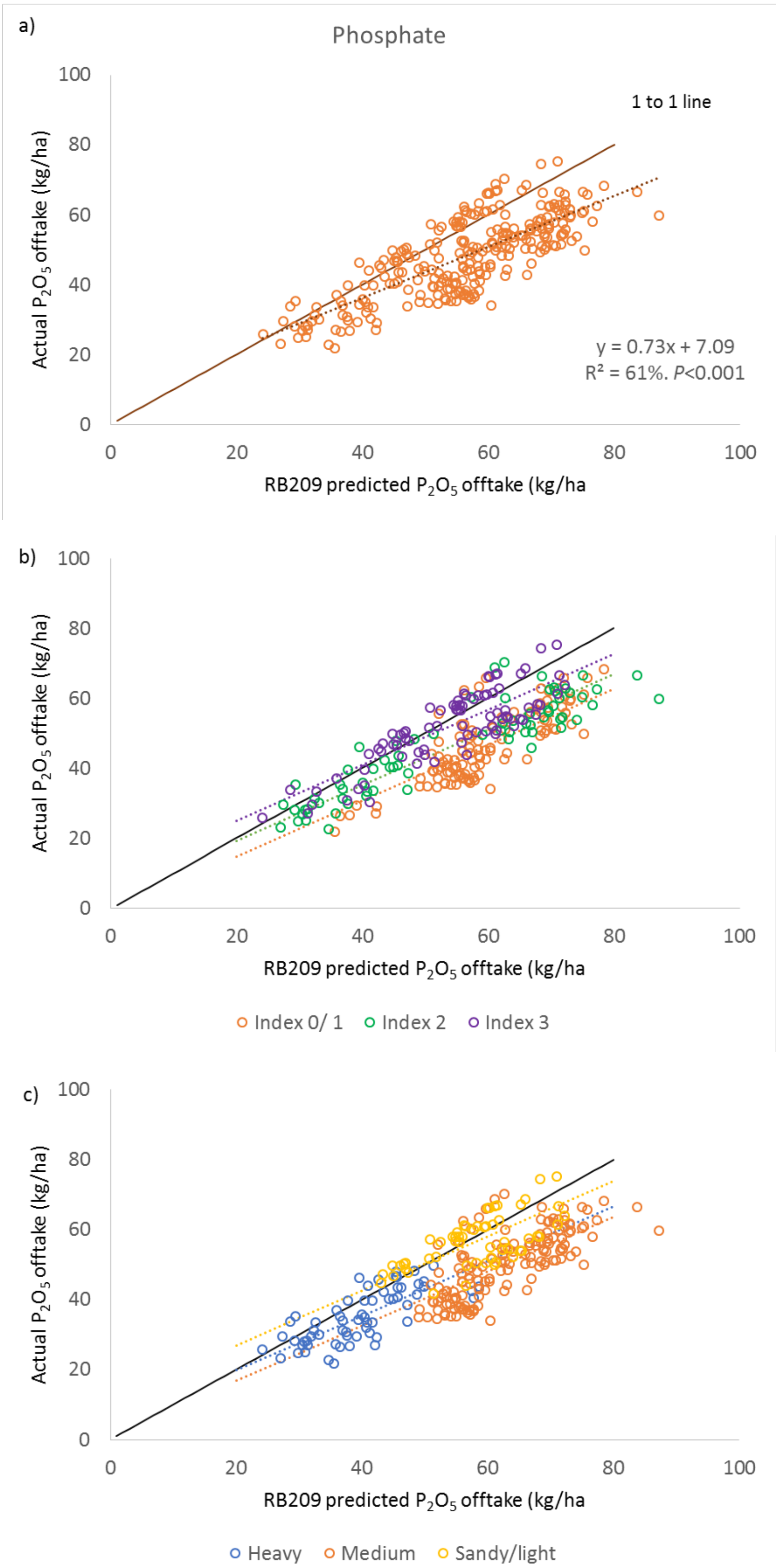
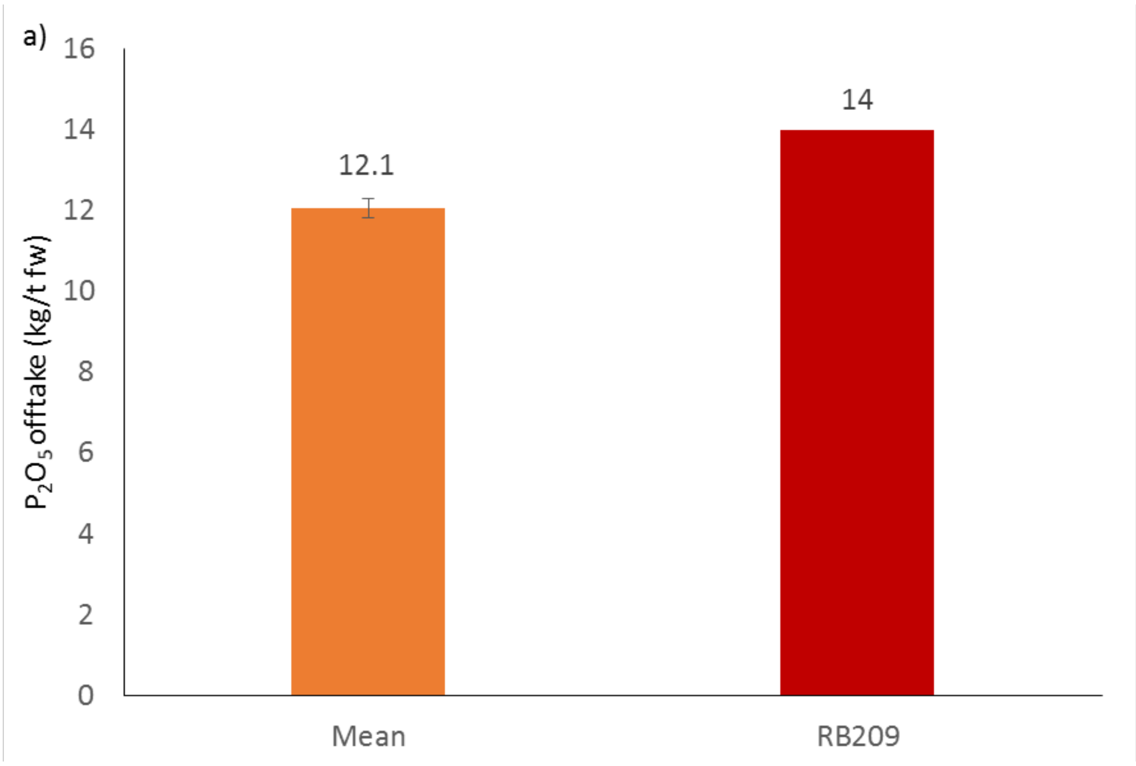


Figure 17. Winter oilseed rape: a) the relationship between predicted and actual phosphate (P_2O_5) offtakes (kg/ha), b) grouped according to soil P Index and c) according to cross compliance soil type.



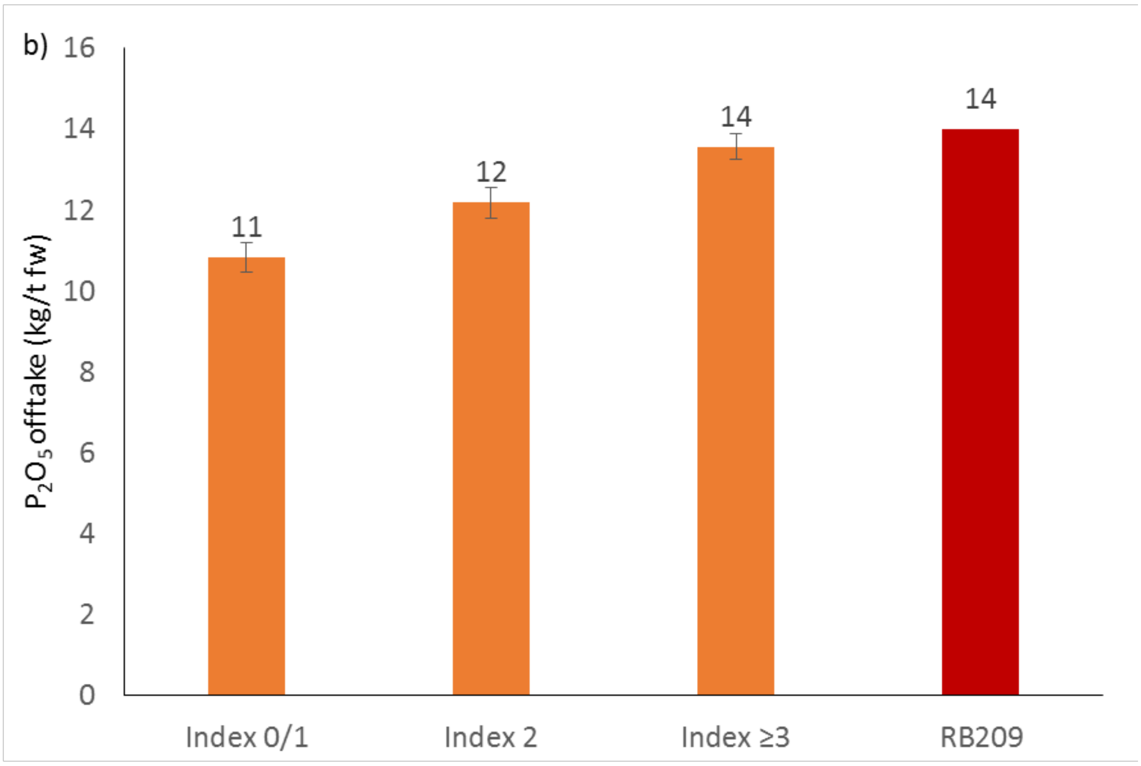
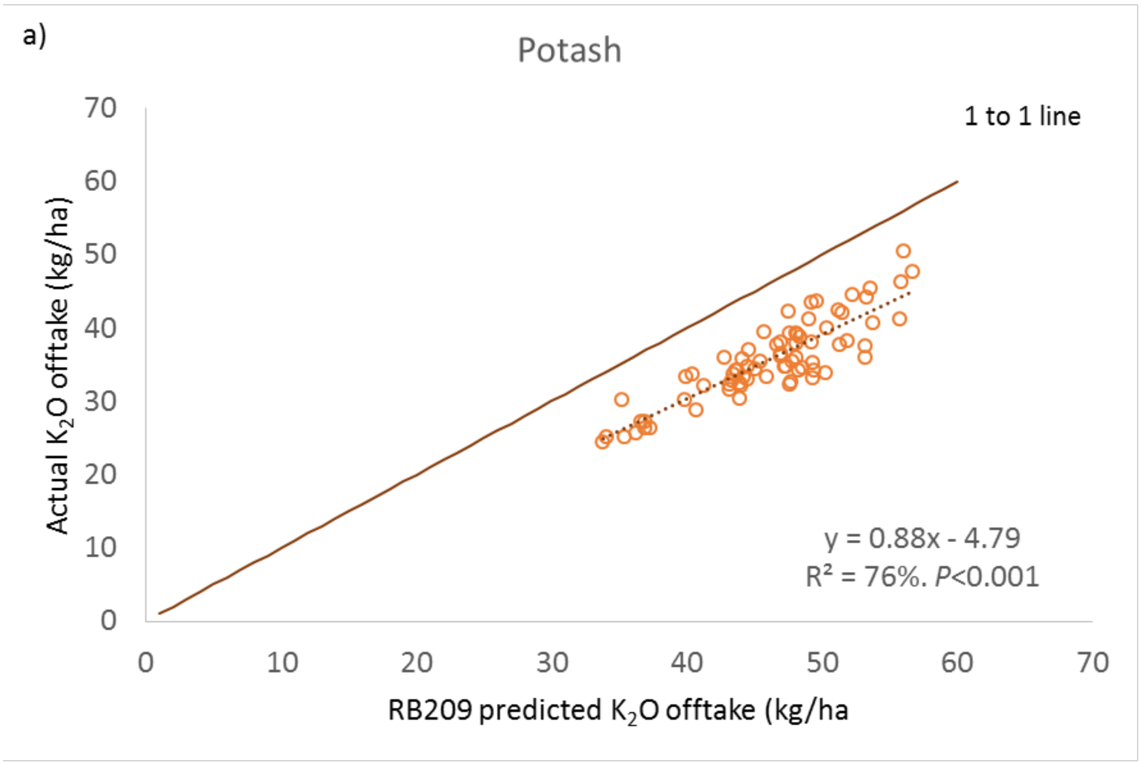


Figure 18. Winter oilseed rape: a) phosphate (P_2O_5) offtakes (kg/t fw) and b) phosphate offtakes (kg/t fw) by soil P Index with RB209 references values. I indicates 95% confidence intervals of the mean.



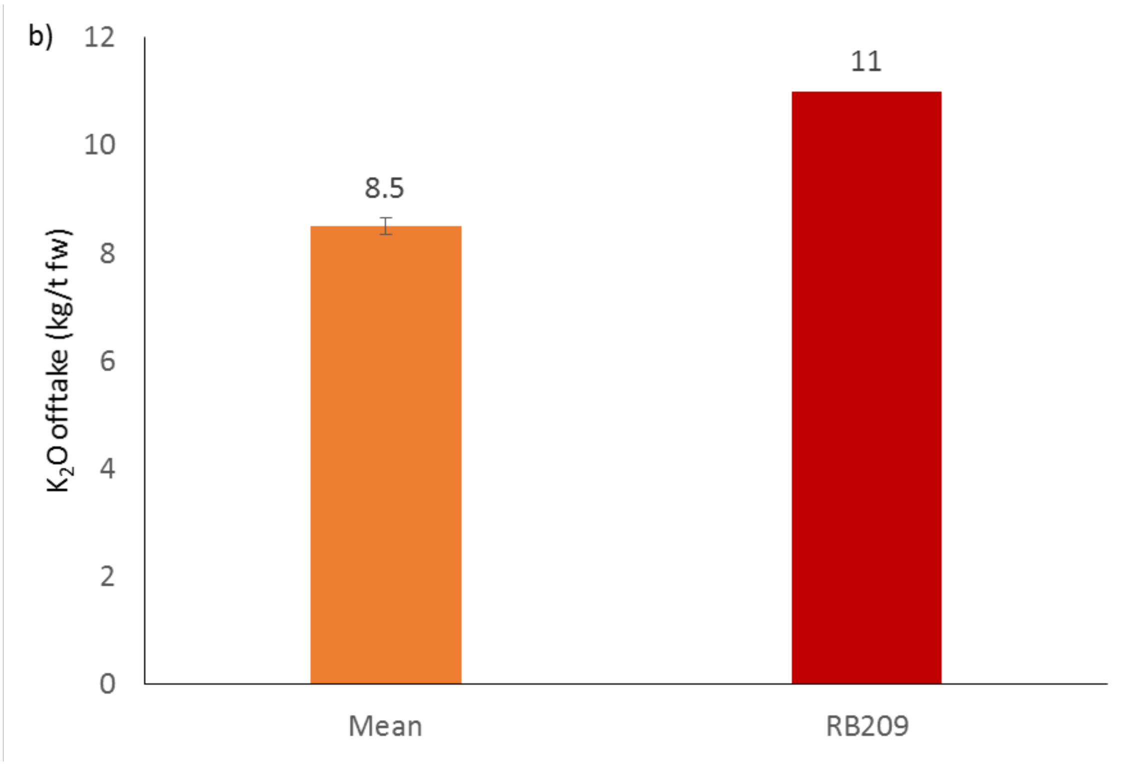


Figure 19. Winter oilseed rape: a) the relationship between predicted and actual potash (K_2O) offtakes (kg/ha) and b) potash (K_2O) offtakes (kg/t fw) with RB209 references values. I indicates 95% confidence intervals of the mean.

6.6. Forage maize

Data on phosphate and potash concentration (% in dry matter) of forage maize was available from one Defra project (45 data points) and NRM (*c.*570 data points). Crop offtake could only be calculated from the Defra dataset as there was no information on crop yield for the NRM dataset. Each dataset was assessed independently and for each of the parameters plant P/K content (% dm), yield (t/ha) and offtake (kg/ha and kg/t fw) the mean, minimum, maximum, standard deviation, standard error of the mean and 95% confidence interval was calculated to characterise the dataset.

6.6.1. Phosphate

Forage maize P concentration (% P in dry matter)

The mean forage maize P concentration of the experimental dataset was 0.19 ± 0.004% dm (range: 0.15-0.23% dm) (Table 21) compared with 0.32 ± 0.01% dm (range: 0.04-0.81% dm) for the NRM dataset (Table 22). In comparison, the forage maize P concentration, in RB209 was *c.*0.20% dm, based on 1.4 kg/t fw P_2O_5 and 30% dry matter.

Predicted v measured forage maize P_2O_5 offtakes (kg/ha)

Measured forage maize P_2O_5 offtakes (73 ± 2.0 kg/ha) were higher than predicted by RB209 (59 ± 1.2 kg/ha), (Figure 20a). The slope of the regression line comparing predicted and measured offtakes was 0.79x + 25.7 so that where RB209 predicted an offtake of 60 kg/ha then the measured offtake was 73 kg/ha (0.79x +25.7). However, the confidence interval of both the slope and intercept were wide and the percentage variance accounted for was low (R^2=20%), reflecting the small size of the dataset.

Phosphate offtake (kg/t fw)

Mean measured forage maize P_2O_5 offtakes were 1.7 ± 0.04 kg/t fw and were significantly higher (P<0.001) than the reference value in RB209 (1.4 kg/t fw), Figure 24c.

6.6.2. Potash

Forage maize K concentration (% K in dry matter)

The mean K concentration of the experimental dataset was 0.96 ± 0.01% dm (range: 0.85-1.05% dm) (Table 21) compared with 2.96 ± 0.09% dm (range: 0.56-6.74% dm) for the NRM dataset (Table 22). In comparison, forage maize, K concentration in RB209 was 1.22% dm, based on 4.4 kg/t fw K_2O and 30% dry matter.

Predicted v actual forage maize K_2O offtakes (kg/ha)

Measured forage maize K_2O offtakes (199 ± 5.5 kg/ha) were also higher than predicted by RB209 (186 ± 3.8 kg/ha), (Figure 20b). The slope of the regression line comparing predicted and measured offtakes was significantly different from 1 (1.07 ± 0.02 kg/ha). For example, where RB209 predicted an offtake of 200 kg/ha then the measured offtake was 213 kg/ha (i.e. 1.02x + 9.1).

Potash offtake (kg/t fw)

Mean K_2O offtakes were 4.7 ± 0.1 kg/t fw and were significantly higher (P<0.001) than the reference value in RB209 (4.7 kg/t fw), Figure 20d.

Table 21. Forage maize: mean, minimum (min), maximum (max), lower and upper 95% confidence interval (CI), standard deviation (SD) and standard error of the mean (SEM) for phosphorus (P) and potassium (K) concentration in dry matter (P or K % dm), phosphate (P_2O_5) and potash (K_2O) offtakes (kg/ha, kg/t fw).

Forage maize	Phosphorus				Potassium			
	% dm	*Predicted (kg/ha)*	*Actual (kg/ha)*	*kg/t fw*	*% dm*	*Predicted (kg/ha)*	*Actual (kg/ha)*	*kg/t fw*
Mean	0.19	59	73	1.7	0.96	186	199	4.7
Min	0.15	49	59	1.5	0.85	155	163	4.2
Max	0.23	67	87	2.1	1.05	211	229	5.5
Lower CI	0.18	58	71	1.7	0.95	183	194	4.6
Upper CI	0.19	60	75	1.8	0.98	190	205	4.8
95% CI	0.00	1.2	2.0	0.04	0.01	3.8	5.5	0.1
SD	0.01	4.0	6.7	0.1	0.05	12.5	18.1	0.3
SEM	0.002	0.6	1.0	0.02	0.01	1.9	2.7	0.05
Number	45	45	45	45	45	45	45	45

Table 22. NRM data for Forage maize: mean, minimum (min), maximum (max), lower and upper 95% confidence interval (CI), standard deviation (SD) and standard error of the mean (SEM) for phosphorus (P) and potassium (K) concentration in dry matter (P or K % dm.

	Phosphorus	Potassium
Mean	0.32	2.96
Min	0.04	0.5
Max	0.81	6.74
Lower CI	0.31	2.86
Upper CI	0.33	3.05
95% CI	0.01	0.09
SD	0.12	1.15
SEM	0.005	0.05
Number	576	576

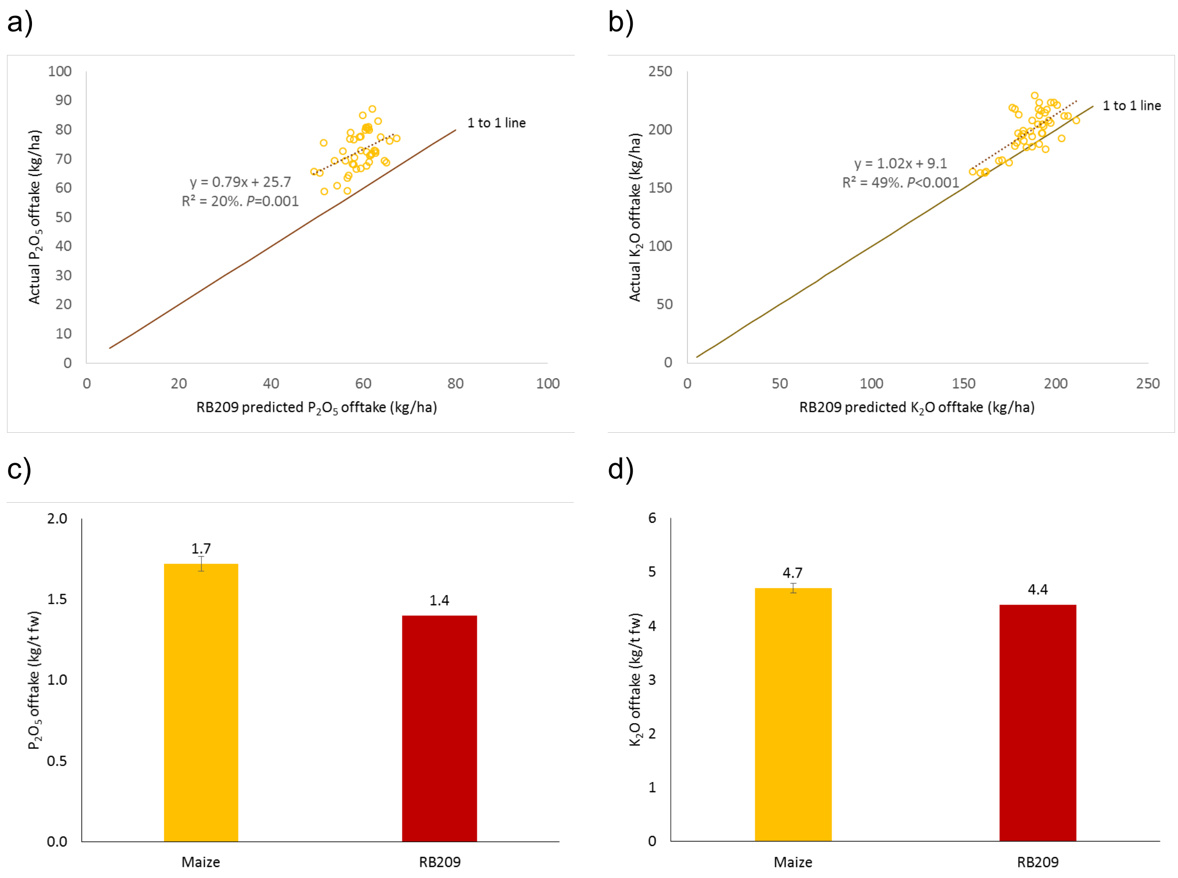


Figure 20. Forage maize: a) the relationship between predicted and actual offtakes (kg/ha) for phosphate (P_2O_5), b) the relationship between predicted and actual offtakes (kg/ha) for potash (K_2O), c) phosphate offtakes (kg/t fw) and d) potash (K_2O) offtakes (kg/t fw); c) and d) with RB209 references values. I indicates 95% confidence intervals of the mean.

7. Conclusions

7.1. Grass

- Values derived from the experimental database gave mean grass phosphate offtakes of 1.2 kg/t fw (at 24% dry matter), which was lower than the current value in RB209 (1.7 kg/t fw at 25% dry matter). For example, the P_2O_5 offtake figure for a 40 t/ha silage crop calculated using the database offtake value was 48 kg/ha compared with 68 kg/ha using the current RB209 value.
- Values derived from the experimental database gave a mean potash content in grass of 5.2 kg/t fw (at 24% dry matter), which was lower than the current value in RB209 (6.0 kg/t). For example, the K_2O offtake figure for a 40 t/ha silage crop derived using the database offtake value was 210 kg/ha compared with 240 kg/ha using the current RB209 value.
- Data from the commercial datasets reported higher grass P (range: 0.29-0.36% dm) and K concentrations (range: 2.3-2.89% dm), than the experimental dataset (P 0.23% dm; K 2.1% dm) and RB209 (P 0.3-0.4% dm; K 2% dm).
- Without background information on the commercial datasets (e.g. fertiliser application rates, management practices, soil nutrient status, crop yield etc.) it is not possible to be certain why the reported offtakes are higher than from experimental dataset. K concentration in grass is likely to be highest in early cut, leafy crops particularly those that have received potash applications from fertiliser or organic materials. Application strategies that favoured luxury K uptake could also result in atypical grass K concentrations.
- Overall, due to the range and variability of phosphate and potash concentrations in grass dry matter from the different data sources sets no changes to the grass offtake values in RB209 are recommended.

7.2. Cereals

7.2.1. Winter wheat

- Values derived from the experimental database gave a mean grain P_2O_5 offtake of 5.7 ± 0.1 kg/t fw, which was lower than the current value in RB209 (7.8 kg/t fw). For example, the P_2O_5 offtake for an 8 t/ha wheat crop derived using the database offtake value was equivalent to 46 kg/ha, compared with 62 kg/ha using the current RB209 offtake figure.

- Phosphate offtakes were higher from sites where the soil P Index was ≥2 (6-6.1 kg/t fw) compared with sites at P Index 0 (4.5 kg/t fw) or P Index 1 (5.2 kg/t fw).
- Values derived from the experimental database gave a mean grain K_2O offtake of 4.9 ± 0.1 kg/t fw, which was lower than the current value in RB209 (5.6 kg/t fw). For example, the K_2O offtake for an 8 t/ha wheat crop derived using the database value was equivalent to 38 kg/ha compared with 43 kg/ha using the current RB209 figure.
- Evidence from the experimental database suggested that there was no effect of soil type on the relationship between predicted and measured offtakes for either phosphate or potash.

7.2.2. Winter and spring barley

- Values derived from the experimental database gave an average grain P_2O_5 offtake of 7.2 ± 0.1 kg/t fw) which was similar to the current RB209 value (7.8 kg/t fw).
- As for winter wheat, phosphate offtakes were higher from barley sites where the soil P Index was ≥2 (7.5-7.7 kg/t fw) compared with sites at P Index 0/1 (6.70 kg/t fw).
- Values derived from the experimental database gave average grain K_2O offtakes of 5.4 ± 0.2 kg/t fw, which was similar to the value in RB209 (5.6 kg/t fw).

7.2.3. Cereal summary

- There was some evidence that grain P_2O_5 content was influenced by soil P index with greater offtakes at soil Index 2 and above than at soil index 0 and 1.
- RB209 reports a single value for cereal grain phosphate (7.8 kg/t fw) and potash (5.6 kg/t fw) content regardless of cereal type (e.g. wheat, barley etc.) or sowing date (winter or spring). For both phosphate and potash there was no evidence to suggest that the relationship between predicted and measured offtake was different for winter wheat, winter barley or spring barley (i.e. the data supports a single value for all cereal grain types).
- For an 8 t/ha winter wheat crop, the reference value in RB209 predicted greater phosphate (+16 kg/ha) and potash (+6 kg/ha) offtakes than the values derived from the dataset; equivalent to *c.*£9.50/ha in fertiliser P_2O_5 and *c.*£2.40/ha fertiliser K_2O.
- Given that the over prediction of cereal (grain) potash values is small (2-6 kg/ha) in practice it will have little economic or environmental significance and it is not recommended that the potash values in RB209 for cereals (grain) are updated.
- However, as there are consistent differences in measured and RB209 predicted grain P_2O_5 concentrations there may be justification in reducing the P_2O_5 offtake values for cereal grain in RB209 to 6.0 kg/t fw

7.3. Winter oilseed rape

- Mean oilseed P_2O_5 derived from the experimental database was 12.1 ± 0.2 kg/t fw, which was lower than the current reference value in RB209 (14 kg/t fw). The P_2O_5 offtake (based on a 3.5 t/ha seed yield) derived from the data base value was 42 kg/ha compared with 49 kg/ha using the current RB209 figure.
- As for the cereal crops, phosphate offtakes were higher from oilseed rape sites where the soil P Index was higher (P Index ≥3: 13.6 kg/t fw) compared with sites at P Index 0/1 (10.8 kg/t fw).
- Mean oilseed K_2O derived from the experimental dataset was 8.5 ± 0.1 kg/t fw, which was lower than the current reference value in (11 kg/t fw).
- Although the P_2O_5 and K_2O offtake values in the experimental dataset were lower than those reported in RB209 it was considered that a larger dataset would be required before any recommendations for changes to RB209 could be made.

7.4. Forage maize

- Mean P_2O_5 concentration in forage maize derived from the experimental database was 1.7 ± 0.04 kg/t fw, similar to the current figure in RB209 (1.4 kg/t)
- Similarly mean K_2O concentration in forage maize derived from the experimental database 4.7 ± 0.1 kg/t fw was close to the current figure in RB209 (4.4 kg/t fw).
- Mean % P and % K in dry matter derived from the NRM maize dataset were 0.32% and 2.96, for P and K respectively, and higher than the RB209 values (0.2% P in dm; 1.22% K in dm).
- Overall, due to the limited size of the dataset, and variability within the data, no changes to RB209 values are recommended.

8. References

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Thompson & Joseph (2017) Grass silage 2017 – early season mineral profile.

9. Appendices

9.1. Appendix 1: Grass

DC Agri

	Phosphorus				Potassium			
	% dm	*Predicted (kg/ha)*	*Actual (kg/ha)*	*kg/t fw*	*% dm*	*Predicted (kg/ha)*	*Actual (kg/ha)*	*kg/t fw*
Mean	0.23	51	36	1.2	2.00	176	160	5.1
Min	0.12	14	11	0.7	0.84	48	40	2.5
Max	0.42	96	68	1.8	4.41	328	313	8.3
Lower CI	0.23	49	34	1.1	1.93	170	154	5.0
Upper CI	0.24	52	37	1.2	2.08	183	166	5.2
95% CI	0.01	1.8	1.2	0.02	0.08	6.5	6.3	0.1
SD	0.05	18	11	0.2	0.74	64	62	1.0
SEM	0.003	0.9	0.6	0.01	0.04	3.3	3.2	0.1
Number	374	374	374	374	374	374	374	374

Cracking clays

	Phosphorus			
	% dm	*Predicted (kg/ha)*	*Actual (kg/ha)*	*kg/t fw*
Mean	0.15	27	20	1.6
Min	0.11	15	12	1.1
Max	0.20	51	32	2.2
Lower CI	0.15	24	18	1.5
Upper CI	0.16	31	22	1.7
95% CI	0.01	3.5	2.1	0.1
SD	0.02	10	6	0.3
SEM	0.00	1.7	1.0	0.05
Number	36	36	36	36

RB209 Grassland data

	Phosphorus				Potassium			
1st Cut	*% dm*	*Predicted (kg/ha)*	*Actual (kg/ha)*	*kg/t fw*	*% dm*	*Predicted (kg/ha)*	*Actual (kg/ha)*	*kg/t fw*
Mean	0.35	42	38	1.3	2.80	143	165	5.7
Min	0.23	16	17	0.8	1.49	55	51	2.8
Max	0.53	75	64	2.2	3.91	257	321	9.2
Lower CI	0.32	36	33	1.2	2.55	122	140	5.1
Upper CI	0.37	48	42	1.5	3.06	164	190	6.4
95% CI	0.02	6.1	4.3	0.1	0.25	21	25	0.7
SD	0.07	17	12	0.4	0.70	58	69	1.8
SEM	0.01	3.2	2.2	0.1	0.13	11	13	0.3
Number	32	32	32	32	32	32	32	32

	Phosphorus				Potassium			
2nd Cut	*% dm*	*Predicted (kg/ha)*	*Actual (kg/ha)*	*kg/t fw*	*% dm*	*Predicted (kg/ha)*	*Actual (kg/ha)*	*kg/t fw*
Mean	0.31	23	21	1.3	3.04	78	107	6.8
Min	0.24	5	6	1.0	1.15	17	32	2.6
Max	0.38	35	36	2.0	4.13	119	201	9.1
Lower CI	0.30	20	18	1.2	2.82	68	92	6.3
Upper CI	0.33	25	24	1.4	3.25	87	121	7.3
95% CI	0.01	2.8	2.7	0.1	0.21	10	15	0.5
SD	0.04	8	7	0.3	0.59	27	41	1.4
SEM	0.01	1.4	1.3	0.0	0.10	4.7	7.3	0.3
Number	32	32	32	32	32	32	32	32

	Phosphorus				Potassium			
3rd Cut	*% dm*	*Predicted (kg/ha)*	*Actual (kg/ha)*	*kg/t fw*	*% dm*	*Predicted (kg/ha)*	*Actual (kg/ha)*	*kg/t fw*
Mean	0.35	19	20	1.5	3.39	65	103	7.8
Min	0.19	4	4	1.1	2.40	15	30	4.5
Max	0.50	35	38	1.9	4.71	121	189	11.2
Lower CI	0.32	17	17	1.4	3.17	57	89	7.2
Upper CI	0.37	21	22	1.5	3.60	73	117	8.3
95% CI	0.03	2.3	2.3	0.1	0.22	7.8	14	0.6
SD	0.08	7.1	7.1	0.2	0.67	24	44	1.8
SEM	0.01	1.1	1.1	0.0	0.11	3.9	7.0	0.3
Number	40	40	40	40	40	40	40	40

	Potassium							
4th Cut	*% dm*	*Predicted (kg/ha)*	*Actual (kg/ha)*	*kg/t fw*	*% dm*	*Predicted (kg/ha)*	*Actual (kg/ha)*	*kg/t fw*
Mean	0.37	16	17	1.9	3.44	53	84	7.7
Min	0.19	2.1	3.0	1.1	2.39	7.2	13	5.0
Max	0.50	30	28	2.1	4.83	102	176	9.9
Lower CI	0.35	13	14	1.5	3.25	44	69	7.3
Upper CI	0.39	18	19	1.7	3.62	63	98	8.1
95% CI	0.02	2.7	2.6	0.1	0.19	9.3	14.9	0.4
SD	0.07	8.5	8.2	0.3	0.58	29	47	1.3
SEM	0.01	1.3	1.3	0.04	0.09	4.6	7.4	0.2
Number	40	40	40	40	40	40	40	40

9.2. Appendix 2: winter wheat

DC Agri

	Phosphorus				Potassium			
	% dm	*Predicted (kg/ha)*	*Actual (kg/ha)*	*kg/t fw*	*% dm*	*Predicted (kg/ha)*	*Actual (kg/ha)*	*kg/t fw*
Mean	0.30	48	35	5.8	0.52	35	31	5.2
Min	0.14	10	8	2.8	0.36	7	9	3.4
Max	0.45	97	68	9.1	0.73	70	57	7.3
Lower CI	0.29	46	33	5.7	0.51	33	30	5.1
Upper CI	0.31	51	36	6.0	0.53	37	33	5.3
95% CI	0.01	2.6	1.7	0.2	0.01	1.8	1.5	0.1
SD	0.06	21	14	1.3	0.07	15	12	0.8
SEM	0.00	1.3	0.9	0.1	0.00	0.9	0.8	0.05
Number	270	269	269	269	270	269	269	269

Cracking clays

	Phosphorus			
	% dm	*Predicted (kg/ha)*	*Actual (kg/ha)*	*kg/t fw*
Mean	0.30	55	40	5.7
Min	0.18	20	14	3.5
Max	0.41	72	62	7.8
Lower CI	0.28	52	37	5.4
Upper CI	0.31	58	43	5.9
95% CI	0.01	3	3	0.2
SD	0.05	12	12	1.0
SEM	0.01	1.5	1.4	0.1
Number	71	71	71	71

Targeted P

	Phosphorus			
	% dm	*Predicted (kg/ha)*	*Actual (kg/ha)*	*kg/t fw*
Mean	0.28	60	41	5.5
Min	0.16	28	25	3.2
Max	0.44	80	64	8.5
Lower CI	0.27	58	40	5.2
Upper CI	0.30	62	43	5.8
95% CI	0.01	2.0	1.7	0.3
SD	0.08	11	10	1.5
SEM	0.01	1.0	0.9	0.1
Number	124	124	124	124

CF Fertilisers

	Phosphorus				Potassium			
	% dm	*Predicted (kg/ha)*	*Actual (kg/ha)*	*kg/t fw*	*% dm*	*Predicted (kg/ha)*	*Actual (kg/ha)*	*kg/t fw*
Mean	0.14	52	17	2.6	1.02	37	70	10.2
Min	0.11	24	9	2.1	0.73	17	24	7.3
Max	0.16	65	24	3.1	1.27	47	100	12.7
Lower CI	0.13	46	15	2.5	0.95	33	59	9.4
Upper CI	0.14	59	19	2.7	1.10	42	81	11.0
95% CI	0.01	6.6	2.3	0.1	0.08	4.7	11.2	0.8
SD	0.01	14	5	0.3	0.16	10	24	1.6
SEM	0.00	3.1	1.1	0.1	0.04	2.3	5.4	0.4
Number	20	20	20	20	20	20	20	20

Critical P

	Phosphorus			
	% dm	*Predicted (kg/ha)*	*Actual (kg/ha)*	*kg/t fw*
Mean	0.26	77	51	5.2
Min	0.16	45	22	3.0
Max	0.41	106	95	7.9
Lower CI	0.26	75	50	5.0
Upper CI	0.27	78	53	5.3
95% CI	0.01	1.2	1.5	0.1
SD	0.05	11	15	1.0
SEM	0.003	0.6	0.8	0.1
Number	355	355	355	355

Yield Enhancement Network

	Phosphorus				Potassium			
	% dm	*Predicted (kg/ha)*	*Actual (kg/ha)*	*kg/t fw*	*% dm*	*Predicted (kg/ha)*	*Actual (kg/ha)*	*kg/t fw*
Mean	0.36	84	76	7.0	0.43	61	48	4.4
Min	0.21	41	31	4.9	0.27	29	23	3.4
Max	0.52	122	124	10.2	0.59	88	75	6.0
Lower CI	0.35	83	74	6.9	0.42	59	46	4.3
Upper CI	0.37	86	78	7.2	0.43	62	49	4.5
95% CI	0.01	1.9	2.1	0.1	0.01	1.3	1.2	0.1
SD	0.05	13	14	0.9	0.05	9	8	0.5
SEM	0.003	0.9	1.0	0.1	0.003	0.7	0.6	0.0
Number	220	185	185	185	220	185	185	185

9.3. Appendix 3: winter and spring barley

DC Agri

Winter barley	Phosphorus				Potassium			
	% dm	*Predicted (kg/ha)*	*Actual (kg/ha)*	*kg/t fw*	*% dm*	*Predicted (kg/ha)*	*Actual (kg/ha)*	*kg/t fw*
Mean	0.41	44	44	7.8	0.54	32	31	5.4
Min	0.38	32	32	7.2	0.49	23	24	5.0
Max	0.44	57	62	8.6	0.58	41	41	5.8
Lower CI	0.40	41	41	7.7	0.53	29	29	5.3
Upper CI	0.41	47	47	8.0	0.55	34	33	5.5
95% CI	0.01	3.0	3.3	0.2	0.01	2.2	2.0	0.1
SD	0.02	7	7	0.4	0.02	5	4	0.2
SEM	0.00	1.4	1.6	0.1	0.00	1.0	0.9	0.0
Number	21	21	21	21	21	21	21	21

Spring barley	Phosphorus				Potassium			
	% dm	*Predicted (kg/ha)*	*Actual (kg/ha)*	*kg/t fw*	*% dm*	*Predicted (kg/ha)*	*Actual (kg/ha)*	*kg/t fw*
Mean	0.33	40	30	6.2	0.57	29	28	5.6
Min	0.02	15	2	0.3	0.43	11	12	4.0
Max	0.49	71	58	10.1	0.90	51	55	8.5
Lower CI	0.30	37	27	5.7	0.54	27	26	5.3
Upper CI	0.36	44	33	6.8	0.59	31	30	5.8
95% CI	0.03	3.2	3.0	0.6	0.02	2.3	2.3	0.2
SD	0.12	14	13	2.5	0.10	10	10	1.1
SEM	0.01	2	2	0.3	0.01	1.2	1.2	0.1
Number	75	75	75	75	75	75	75	75

Targeted P

Winter barley	Phosphorus			
	% dm	*Predicted (kg/ha)*	*Actual (kg/ha)*	*kg/t fw*
Mean	0.36	60	53	6.8
Min	0.31	52	42	5.9
Max	0.49	67	66	9.3
Lower CI	0.35	60	52	6.7
Upper CI	0.37	61	54	7.0
95% CI	0.01	0.9	1.3	0.1
SD	0.03	3.6	5.2	0.5
SEM	0.003	0.4	0.6	0.1
Number	68	67	67	67

Spring barley	Phosphorus			
	% dm	*Predicted (kg/ha)*	*Actual (kg/ha)*	*kg/t fw*
Mean	0.30	52	38	5.8
Min	0.11	38	12	2.1
Max	0.48	68	60	9.3
Lower CI	0.28	51	36	5.4
Upper CI	0.32	53	41	6.2
95% CI	0.02	1.2	2.3	0.4
SD	0.11	6.4	13	2.1
SEM	0.01	0.6	1.2	0.2
Number	119	119	119	119

Critical P

Winter barley	**Phosphorus**			
	% dm	***Predicted (kg/ha)***	***Actual (kg/ha)***	***kg/t fw***
Mean	0.34	57	50	6.7
Min	0.27	50	33	5.2
Max	0.42	64	66	8.1
Lower CI	0.33	56	47	6.5
Upper CI	0.36	58	52	7.0
95% CI	0.01	1.0	2.3	0.2
SD	0.04	3.6	8.4	0.9
SEM	0.01	0.5	1.1	0.1
Number	54	54	54	54

9.4. Appendix 4: winter oilseed rape

DC Agri

	Phosphorus				Potassium			
	% dm	*Predicted (kg/ha)*	*Actual (kg/ha)*	*kg/t fw*	*% dm*	*Predicted (kg/ha)*	*Actual (kg/ha)*	*kg/t fw*
Mean	0.67	59	56	13.5	0.79	46	35	8.4
Min	0.54	43	0	0.0	0.69	34	0	0.0
Max	0.78	72	75	15.8	0.93	57	51	9.9
Lower CI	0.65	57	54	13.0	0.78	45	34	8.1
Upper CI	0.69	60	58	14.0	0.81	47	37	8.7
95% CI	0.02	1.6	2.2	0.5	0.01	1.3	1.6	0.3
SD	0.08	7	10	2.2	0.06	5	7	1.2
SEM	0.01	0.8	1.1	0.3	0.01	0.6	0.8	0.1
Number	73	75	74	74	74	75	75	75

Targeted P

	Phosphorus			
	% dm	*Predicted (kg/ha)*	*Actual (kg/ha)*	*kg/t fw*
Mean	0.52	63	49	11
Min	0.37	49	34	8
Max	0.72	87	68	15
Lower CI	0.50	62	48	11
Upper CI	0.53	65	51	11
95% CI	0.01	1.5	1.6	0.2
SD	0.06	8.4	9.3	1.2
SEM	0.01	0.7	0.8	0.1
Number	128	128	128	128

Cracking clays

	Phosphorus			
	% dm	*Predicted (kg/ha)*	*Actual (kg/ha)*	*kg/t fw*
Mean	0.60	40	35	12.3
Min	0.41	25	22	8.6
Max	0.81	60	50	16.6
Lower CI	0.58	38	33	11.9
Upper CI	0.62	42	37	12.8
95% CI	0.02	2.0	1.9	0.4
SD	0.09	8	8	1.8
SEM	0.01	1.0	1.0	0.2
Number	63	63	63	63